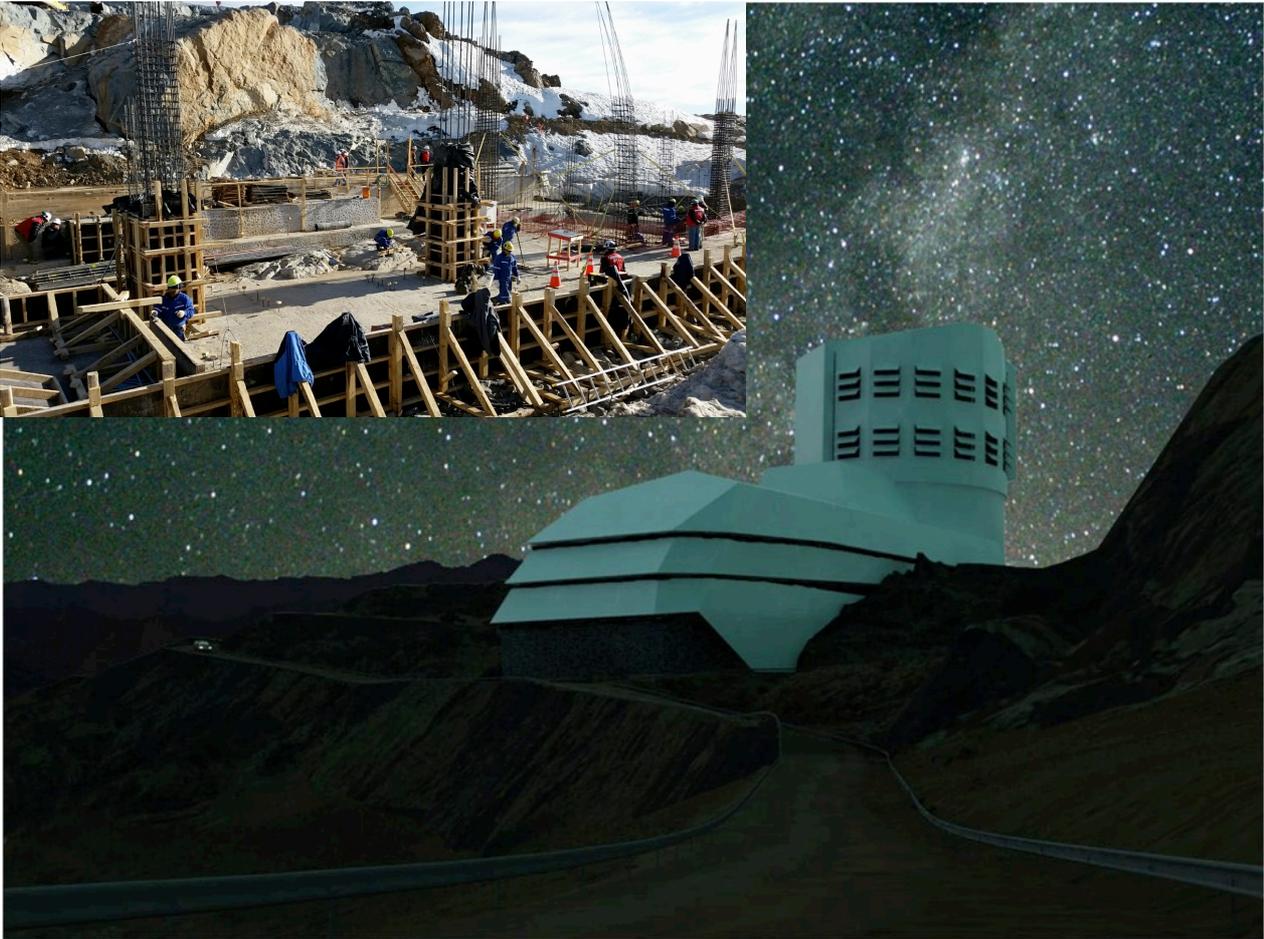




CONSEIL SCIENTIFIQUE DE
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STATUS ON CONSTRUCTION AND SCIENTIFIC PREPARATION AT IN2P3



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1. EXECUTIVE SUMMARY

Understanding the nature of dark energy is one of the most fundamental challenges facing Physics and Cosmology today. First proposed in 2004, the Large Synoptic Survey Telescope (LSST) aims to meet that challenge with a large-area, wide-field, ground-based telescope designed to image half the visible sky every four nights over ten years. Unprecedented for its combination of depth and area, the LSST survey will provide an exceptional data set to study the nature of Dark Matter and Dark Energy.

The construction of LSST has been identified by state agencies in the US (NSF and DOE) and in France (IN2P3), as a priority for the current decade, its construction started mid-2014 for a first light in late 2019. In France after a strong R&D efforts on the LSST camera started in 2007, a team from nine IN2P3 laboratories is now contributing to the LSST construction. In this document, we are reviewing the status of the IN2P3 contributions to the LSST construction and present the work to prepare the scientific return associated to this construction through contributions to the science, the calibration, the software and data processing preparation.

The IN2P3 won its status of “LSST core member” by the success of its early contribution to the camera R&D. The IN2P3 is only non-US members with in kind contributions to the construction, through a contribution at the ~10% level to the camera, and to the running cost, with a planned contribution of 50% to the core data processing. This double effort guaranty the access to the heart of LSST science to the Dark Energy IN2P3 community during the full length of the project.

IN2P3 groups with researchers and engineers from the APC, the CPPM, the CCIN2P3, the LMA, the LPC-Clermont, the LPNHE, the LPSC and LUPM laboratories have teamed up for this project.

The LSST team at IN2P3 counts today ~ 110 active people, including

- 17 FTE for 38 active scientists in LSST
- 28 FTE for 64 engineers and technical staff
- 5 PostDoc + 6 PhD

Its dominated by 31 FTE on the camera construction and has ramping contribution on :

- Algorithm, DB data processing preparation (~10 FTE)
- Preparation of the Dark Energy science (~ 9 FTE) related to calibration, CCD signature removal, photo-z , supernovae , BAO , lensing, cluster.

Camera

The IN2P3 reached its status as “LSST core member” through its successful early contribution to the camera R&D. The IN2P3 contribution to the camera focuses on two key elements, the CCDs and filter exchange system, with accompanying effort given to camera control, commissioning and calibration. Our work on calibration, a topic also considered in LSST science preparation, will ramp-up over time to become the cornerstone for the scientific return expected from our hardware investment in the camera.

IN2P3 has the following contribution to the camera construction:

- A few contribution to the focal plane, including:
 - Procurement for 2 M€ of the LSST CCDs
 - Contribution to the testing of the CCD production
 - Design, qualification, production and testing of the ASPIC, ASIC for the CCD readout.



- Responsibility for the design, implementation and qualification of the FPGA micro-code controlling the LSST Raft (a raft is an autonomous sub-system of 9 CCDs, with a total of 21 making up the LSST focal plane).
- Development and support on CCD readout and readout optimization during the focal plan construction.
- Contributions to LSST filter coating studies and characterization of small optical sample provided by vendors.
- Delivery of the *filter exchange system*.
- Contribution to the core components of the camera slow control system, and full responsibility for the development of slow control software for the *filter exchange system*.
- Delivery of the CCOB, a system to characterize the LSST camera during its assembly at SLAC prior shipping to Chile.

The overall cost of the IN2P3 participation to the camera construction between 2014-2020 is evaluated at 5.15 M€. It includes 2 M€ for sensor procurement, 0.53 M€ for sensor testing and electronics delivery, 1.4 M€ for the filter exchange system delivery, 0.3 M€ for the delivery of the camera characterization system, 0.15 M€ for slow control and the associated travel cost for meetings and hardware installation is estimated at an average of 110 k€/year over this period (with a peak of 200 k€ in 2018 during the camera assembly at SLAC). The total manpower effort for the camera construction is 120 FTE.

Computing

It should be noticed that with an annual running cost slightly below 40 M\$/year, over 10 years the total running cost of LSST will be a sizable fraction of the total cost of the project (~1000 M\$). The project plans to cover 25% of its running cost through fees from its international partners. Despite of this running cost funding mechanism, non-US partners will not have access to the computing facilities in the US for science analysis, but will instead build and use their own data analysis centers. It should be stressed that efficient access to the very large LSST dataset will be a challenge for scientific exploitation, and most particularly for dark energy science.

To address these issues – supporting running costs and ensuring competitive data access and computing resources for the French groups – IN2P3, due to its early integration in the project, will have the unique capability among all foreign partners to maintain the full LSST dataset outside the US at CC-IN2P3 and to contribute to the LSST running cost through an in-kind contribution.

In the Memorandum of Agreement signed in March 2015 between IN2P3 and LSST it is stated that :

1. 50% of the annual data release processing will be performed at CC-IN2P3
2. CC-IN2P3 will host a copy of the full LSST dataset
3. the IN2P3 contribution is valued to 0.9 M\$/year corresponding to 45 data access from French PIs (+ up to 4 students and postdocs) coming on top of the data rights given to scientists belonging to IN2P3 laboratories contributing to the camera.

The hardware and software investment at CC-IN2P3 over the project lifetime is estimated at 17.5 M€, the operations cost at around 3.5 M€ and the manpower cost at around 11 M€. This effort at CCIN2P3 will not only cover the French contribution to the project running cost, but will provide the data access with the needed processing environment for the scientific production of the IN2P3 LSST dark energy community.

Associated to this future computing effort, the IN2P3 team contributes today to the LSST software development on three fronts:

- Processing and infrastructure control



- Database
- Key algorithms for wide field survey

Science

The main science objective driving the LSST survey is to increase the sensitivity of dark energy equation-of-state determinations by one order of magnitude, with the ultimate goal of revealing the nature of dark energy: is it a dynamic field or a fixed cosmological constant/vacuum energy or a failure of general relativity? To achieve this, LSST will image the sky down to 27 magnitude and pursue studies with all known dark energy probes:

- Weak gravitational lensing: growth of structure and geometry
- Galaxy cluster evolution: growth of structure and geometry
- Baryon acoustic oscillations: standard ruler
- SuperNovae : standard candle

The key issue facing these studies is the understanding and mitigation of systematic errors. In this context, photometric calibration and photometric redshift determinations are critical elements for the dark energy analysis, as is the unbiased measurement of galaxy shapes for weak-lensing observations. The LSST survey design aims from the outset to mitigate systematic errors in galaxy shape measurements by deconvolving the instrumental response and atmospheric perturbations with a strategy that observes any sky patch hundreds of times to a depth of 24 magnitude. The ambitious science goals of the project will clearly require considerable collaborative effort to meet all analysis challenges.

It should be noticed that today the activity on these probes is on real dataset, like the one collected by DES (with a participation from US, Germany UK and Spain) or HSC (with a participation from Japan and US). It's mandatory for the LSST French team to also work on real dataset to prepare the LSST science. This will insure that the team has the state of the art knowledge and practice, but also that young scientist can be fully trained. For this reason the LSST team fully support the "intermediate projects" discussed at this Scientific Council, and in particular the photometric data analysis projects as presented by N.Regnauld, which are key science projects but are also mandatory to the LSST science preparation at IN2P3.

The LSST- Dark Energy Science Collaboration (DESC) since June 2012 directly manage all aspects of the dark energy science analysis for the LSST project, including technical tasks in liaison with the LSST project office. IN2P3 scientists actively contributed to its creation and today to its activities through contribution in its working groups with dark energy science tasks involving all major probes, as well as strategic activities in calibration and photometric redshift determination.

Today 38 permanent IN2P3 scientists have a contribution to LSST, among them 24 are already DESC full members (~15% for a total 152 scientist).



2. LSST : PROJECT STATUS

The LSST project has been selected by the US and French particle physics community as a dark energy experiment. Dark energy studies are the main driver of the IN2P3 scientists involved in this project. This unexpected and dominant form of energy became over the last 15 years the biggest clue in our understanding of the universe. LSST will provide detailed constraints on the nature of dark energy, through a variety of distinct and complementary techniques. Four of these techniques: measurement of baryon acoustic oscillations, surveys of clusters of galaxies, photometry of Type Ia supernovae, and measurement of cosmic shear using weak gravitational lensing, were highlighted in the report of the US Dark Energy Task Force (DETF), commissioned by both the US Astronomy and Astrophysics Advisory Committee (AAAC) and the High Energy Physics Advisory Panel (HEPAP). The DETF report concluded that no single one of these is both sufficiently powerful and well enough established to yield the necessary constraints by itself, but that *the combination of all four* (as provided by LSST) is especially compelling.

LSST will be also a critical resource for a variety of astrophysical investigations—e.g. studies of small bodies in the solar system, programs that map the outer regions of the Milky Way, and searches for faint optical transients on a wide range of time scales.

A large team of scientists and engineers from both the astronomy and particle physics communities has been assembled to pursue the LSST concept. If only US, Chile and France contribute to the construction of LSST, LSST will receive 1/3 of its running funds from many other countries making it a fully international collaboration of ~ 1000 scientists including ~50% of non-US participants.

Following the selection of LSST in August 2010 by the US National Research Council as the highest priority for a new ground-based facility, the NSF and DOE have integrate the LSST construction in their budget. The final design review of LSST as been successfully passed in December 2013, allowing the start of the construction in mid-2014. The camera construction got its final green light through its CD3 review by DOE in August 2015.

The future key dates of the LSST project are:

- First telescope light with comcam (small test camera) : 2019
- Delivery of LSST camera at summit: spring 2020
- Data management operational: end 2020
- End of scientific validation: end 2021
- Start of 10 years survey: 2023

3. LSST : CAMERA

The LSST camera will be the largest digital camera ever constructed. The 64 cm diameter focal plane will be made from a mosaic of 201 silicon sensors with 16 Megapixels (4k x 4k) each for a total of 3.2 billion $10\mu\text{m}$ pixels. The sensors are deep depletion, back-illuminated devices with a highly segmented architecture (16 channels) that enables the entire array to be read out in 2 s. The refrigeration and electrical systems will be located in the “utility trunk” at the back of the camera. The front of the camera will host the refracting optics, the filter exchange mechanism and the mechanical shutter.

This 1.65 by 3.7 meter camera, with a weight of 3 tons will be located in the middle of the secondary mirror. The LSST science-driven innovative optical design comes at a cost: there is very little room for the camera “services” such as the filter exchange system. The camera is shown in the Figure below (See fig 1).

The status of the contribution of IN2P3 to the camera construction is summarized in this section.

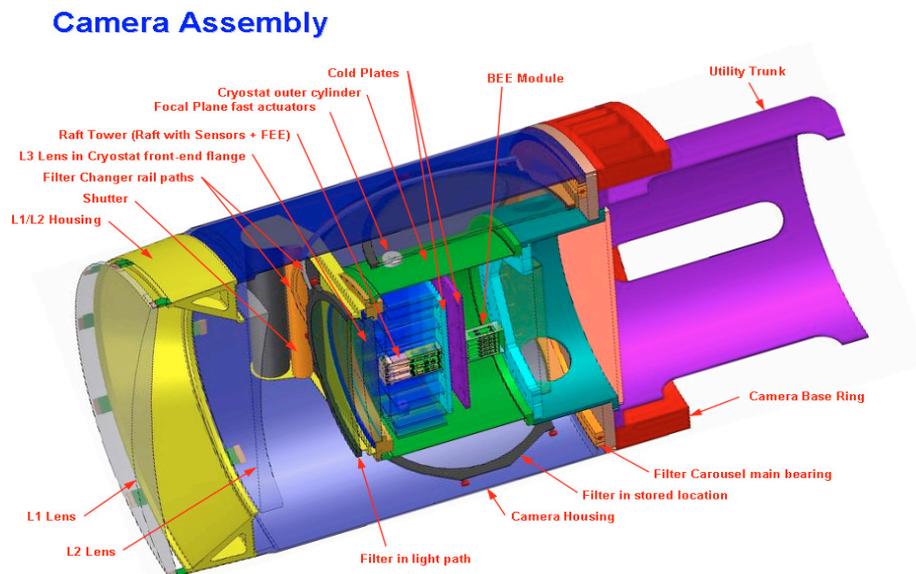


Figure 1: The LSST camera (Design Status as at CD1 review)



3.1. IN2P3 CONTRIBUTION TO THE LSST CAMERA

3.2. INTRODUCTION

In France, LSST has attracted attention in the astronomy and particle physics community and discussions have been ongoing during 2006 between several research groups and the LSST collaboration. This resulted at the end of 2006 in the sending of a Letter of interest to LSST, signed by 7 laboratory directors (4 IN2P3: APC, CPPM, LAL and LPNHE and 3 INSU: CASSIPOEE, IAP and LAM). The joint committee of the Programme National de Cosmology and the IN2P3-INSU-DAPNIA French Dark Energy group have recommended that R&D actions toward LSST be supported by French funding agencies. In 2007, efforts have started in IN2P3 groups on specific R&D actions (elements of the camera readout electronics at LAL, in Orsay, and LPNHE, in Paris, and of the filter exchange mechanism at LPNHE), and other studies such as the camera slow-control and atmospheric calibration at APC, in Paris. Previous successful collaborations between IN2P3 and SLAC (especially BABAR) helped a lot in integrating the LSST Camera team. In December 2007, the IN2P3 scientific committee fully supported a strong involvement of the IN2P3 teams in the preparation of the LSST project and in October 2012 it supported the proposed plan for the participation at LSST (construction, data processing and running). Today the IN2P3 team contributes to the construction of the camera which started in 2014. This is a joint effort from 9 IN2P3 laboratories : the APC in Paris, the CC-IN2P3 in Lyon, the CPPM in Marseille, the LAL in Orsay, the LMA in Lyon, the LPC in Clermont-Ferrand, the LPNHE in Paris, the LPSC in Grenoble and the LUPM in Montpellier.

3.3. ELECTRONIC & CCD

The key dates in the CCD and associated electronic development concerning IN2P3 are:

- CABAC 2 final design review March 2015
- Science Raft Final Design Review May 2015
- ASPIC Manufacturing Readiness Review October 2015
- Delivery of readout ASIC (ASPIC) : Jan 2016
- Start of REB production (Focal Plane readout board) : Spring 2016
- Start reception of pre-production CCD: fall 2015
- End CCD production / testing: summer 2018

It has contribution from LAL(ASIC), LPNHE(ASIC,Readout,CCD) and LUPM (soft)

3.3.1 CCD ACCEPTANCE TESTS, CHARACTERIZATION AND READOUT OPTIMIZATION

At LPNHE, a dedicated laboratory for the CCD characterization has been built over the last years. This structure includes two clean rooms: one ISO 7 room (~ class 10000) of 23 m² with an optical test bench (Fig. 3) and one ISO 6 room (~ class 1000) of 9 m² with two ISO 5 working area (class 100) for CCD manipulations. The metrology capability is completed today, it includes light sources (XeHg arc, Quartz Tungsten Halogen lamp, monochromator and associated filters, 4 laser sources , integrating sphere with photo-diode for flux monitoring), image generation setups (artificial star and pattern projector, fringe projector) and the usual Fe55 source for CCD response studies. The IN2P3 team will use this facility to contribute to the LSST focal plane construction effort:



- the CCD acceptance tests through optical testing should be done at CNRS/IN2P3 for a fraction of the production sensors, in particular to reduce the load on the Brookhaven National Laboratory (BNL) which is in charge of the CCD assembly.
- The single-CCD test system in Paris will be used for CCD readout optimization: electronics development, readout optimization, FPGA firmware development.
- CCD specific device characterization going beyond the basic reception test will also be performed to prepare the future LSST calibration/CCD signature removal.

3.3.2 CCD READOUT

The LAL and LPNHE had in charge the design of two front-end ASICs for the LSST focal plane electronic:

- the Analog Signal Processing ASIC (ASPIC, Fig. 4) dedicated to the analog processing of the CCD outputs. It is a 8 channel DSI, AMS 0.35 μm chip. Its development was performed between 2007 and 2015 .
- the Clocks And Bias Asic for CCD (CABAC) dedicated to provide the needed HV to the CCD. It delivers all biases and clocks and it is based on the AMS 0.35 μm HV technology. This work was performed between 2011 and 2015.

The ASPIC has been qualified for the LSST focal plane, based on the fourth generation of the chip (ASPIC IV) which fulfils all the LSST requirements, in particular for the noise ($\sim 2 e^-$) and cross-talk ($< 0.01\%$). The ASPIC production is underway (1000 chips made for the 402 chips needed) and its test&reception will be completed before the end of 2015.

The CABAC, even if the third chip generation (CABAC II) has all the required voltages and clocks, and provides extra features to contribute to the monitoring and diagnostic of the CCD, has not been selected by the project to be used for the LSST focal plane. Instead a discrete component solution (COTS) has been selected for its lower power consumption, its reliability and its shorter schedule (development and qualification of associated readout electronic using CABAC would have delayed the camera delivery).

On top of the ASICs, the team develops, optimizes, tests and supports the FPGA firmware for the focal plane. This firmware includes the configuration and control of the CCD and readout electronic for science image, guider and wavefront sensor. This work extend to the development of the diagnostic capabilities of the ASPIC and readout electronic. This firmware will be supported by LPNHE during the full lifetime of the camera, from testing, through camera integration at SLAC and commissioning at the summit, to the 10 years of LSSTCam operations.

3.4. FILTER EXCHANGE SYSTEM

The Filter Exchange System holds five large optical filters, any of which can be inserted into the camera field of view for a given exposure. A sixth optical filter will also be fabricated which can replace any of the five via a procedure accomplished during daylight hours. This system is a full deliverable of IN2P3.

The LSST filter exchange system is unique in many aspects:

- Its size, imposed by the number of filters to handle and by their individual size (70 cm in diameter with mass of 30 to 44 kg each).
- Its compactness due to the limited space available.
- Its ability to prevent filter damage, including in the event of big earthquake of mag 7.
- Its stability, repeatability and limited access for maintenance.

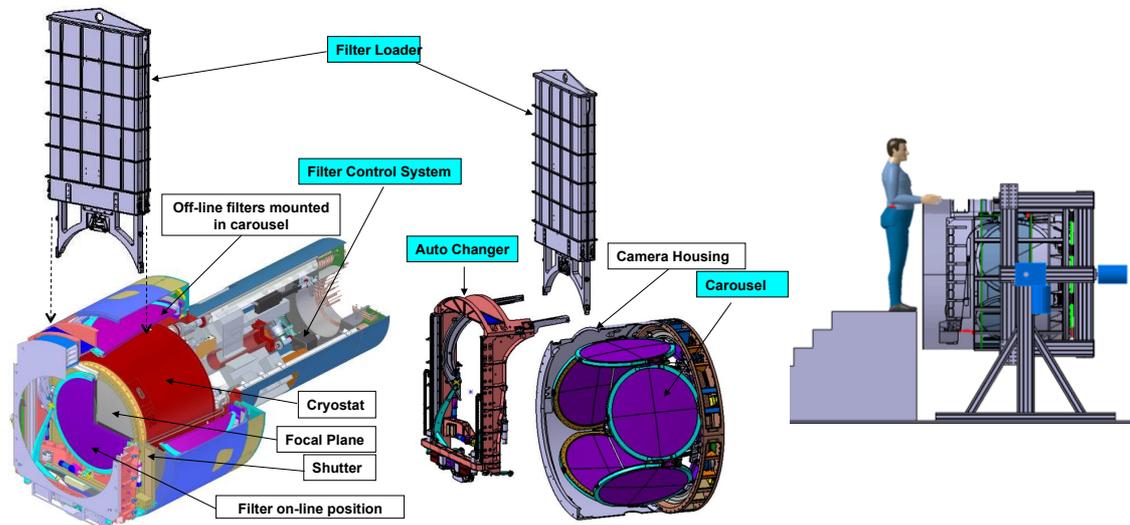


Figure 2 : *The Filter Exchange System on the camera (left), parts of the filter exchange system (center) and view of the filter exchange system on its test bench (right) that will be used to qualify and characterize it .*

The success of LSST implies a smooth running for at least 10 years. The length and the stability requirements of the LSST survey imply a qualification process for the design of this ground-based facility close to what is needed in space projects.

Our development plan of the Filter Exchange system is split in three parts:

- The first part corresponded to the design phases, and was completed this month. The filter exchange system passed its final design review in April 2015, except for the carousel which will pass it at the end of October 2015.
- The second part corresponds to the construction and qualification of the key mechanisms and of a full-scale demonstrator. Over the past years a large effort of prototyping has been done:
 - clamps used to hold the filter in the carousel (at LPNHE)
 - a setup to demonstrate/test the exchange of filter between a stand "carousel like" and a stand " focal plane like " (at CCPM)
 - a prototype of the manual changer, used to load filter in the camera , was built and run (at LPSC)

The construction of the full scale demonstrator started this year. It should be operational by summer 2016. It will be used to fine tune the system and to validate the overall design, the aging rate and the maintenance plan of the filter exchange system. It should be noticed that all these test / prototype run under the final LSST slow control for the filter exchange system (FCS) developed by APC.

- The third part corresponds to the construction of the filter exchange system which should be delivered to SLAC in 2018 before the final commissioning at the summit in 2020.



To deliver the filter exchange system LSST relies on a large IN2P3 team from 5 IN2P3 laboratories, each of them in charge of a sub-system:

- APC is in charge of the slow control
- CCPM is in charge of the auto-changer, that swaps the filters between the focal plane and the carousel.
- LPC is in charge of the test bench that will be used to emulate the camera & telescope movement and to test, characterize and qualify the full scale demonstrator and the final filter exchange system.
- LPNHE is in charge of the carousel that holds up to 5 filter out of the telescope beam and present one of them to the auto-changer. Also the LPNHE will host the assembly and test of the demonstrator and of the final system
- LPSC is in charge of the manual changer used to insert filters in the camera, and of the filter storage box used to store the filters when they are not in the camera at summit.

P.Karst from CCPM does the overall coordination of the filter exchange system for IN2P3 and for the LSST camera.

3.5. FILTERS

The LSST design foresees the use of six wide-band large optical filters that can alternatively be moved in front of the CCD camera. Each of the six filters has a different band-pass covering all the wavelengths from 330 nm to 1070 nm. The way to achieve this is to coat an optimized optical thin film on a filter substrate. Each filter requires a specific design using specific appropriate materials. The main characteristics of these filters driven by the size of the camera and the calibration objective of the survey are:

- A large size (790 mm diameter with a coating area over a diameter of 760 mm) and a thickness, which varies between 14 mm and 21 mm depending on the filter considered.
- A strong out of band rejection requirement: mean transmission in 10nm interval must be less than 0.01% of Peak transmission
- A strong uniformity requirement: uniformity of the effective wavelength of the filter band pass (integrated over the incident input cone) for any 100mm aperture shall be less than 2.5% of the nominal central wavelength relative to the nominal wavelength response. Note that the filter radius of curvature (about 5.6 m) that represents a sagitta of 12.5 mm, increases the difficulty to achieve the uniformity requirement

These requirements constitute a real technological challenge. To make these 6 filters, a large deposition coater is needed and the thickness of the deposited material has to be controlled with extreme precision over the whole surface of the filters. The LMA has open two fronts on the camera optics :

- An internal front to evaluate if such optical filters, in particular the most difficult one, the u filter, could be done at LMA. This is not part of the currently agreed contribution of IN2P3 to the camera, but it is still under evaluation as the project may have an interest, if the industrial solution is of too poor quality and if LMA succeed in its on going effort on this u filter.
- A metrology front where small samples from the filters (and of the different camera lenses in general) will be characterized at LMA. An extension of this effort will be to perform the metrology of the full filter at LMA, the decision on this last point will be taken in the coming year.



3.6. SLOW CONTROL

The LSST Camera Control System (CCS) controls and coordinates the various camera subsystems. It makes sure that camera operations proceed efficiently, during science, calibration, and engineering modes. It monitors camera performance, maintaining a stable camera environment and reporting errors. It interacts with the LSST observatory, telescope, and data management, sending and receiving the data necessary for coordinated operations. It provides human interfaces both for the display of status information and for testing, diagnostic, and debug capability.

A major contribution has been made by IN2P3 for the initial concept of the design of the Control Command Software (CCS) for the LSST camera. Now the design is being specified and implemented mainly by a joined IN2P3 and US CCS team.

The CCS is under the overall coordination of Tony Johnson from SLAC and Eric Aubourg from APC. The CCS effort at IN2P3 is mainly located at APC. Our goal and responsibility in the Camera Slow Control resides in 2 parts:

- Responsibilities in the CCS core:
 - o design of the CCS architecture,
 - o delivery of software for the infrastructure and the consoles: communication busses, configuration data base, automatic tests, lock manager,
 - o delivery of support for the subsystems developers in France and in USA (there are 16 subsystems, 2 in France, 14 in USA).
- Responsible of the delivery of the Filter Control System (=the control software of the Exchanger Filters system):
 - o design of the FCS architecture,
 - o delivery of control software for Filter Exchange System test benches and for the Filter Exchange System demonstrator and final system.

The CCS successfully passed its Final Design Review in June 2015.

3.7. CCOB

The Camera Characterization Optical bench (CCOB) is an optical system that can be temporarily attached to the front of the fully assembled LSST camera while it is in either final assembly at SLAC or in the clean room at the observatory facility at El Peñon peak. The purpose of the CCOB is to provide a controlled and well calibrated source of light that can be used for verification and characterization of the fully assembled CCD camera.

The goals of the CCOB are:

- System operating checking
- Data acquisition
- Image processing
- Measurement of the throughput of the optics, filters, sensors and electronics
- LSST camera scattered light assessment
- Confirmation of the spatial properties of images on the focal plane

The proposed technical solution consists in acquiring images of artificial stars produced by a collimated light beam scanning the whole spectrum wavelength through the refractive optics and filters and focusing onto the camera CCD focal plane.

The CCOB will be operated in two modes: wide beam and thin beam. The first one will be used to calibrate the response of the focal plane array with a 0.25% precision. The second one will provide zero point color determination with accuracy 0.2% in griz colors and 0.3% in u.



It will also allow comparisons of the camera response with an optical simulation and lead to an accurate check of the mechanical positioning of the different lenses.

Prototyping and characterization of the different parts of the system has been done at LPSC. The construction of the wide beam is underway at LPSC and will be delivered in 2016 to SLAC, the other beam will be delivered the following year.

The CCOB is a full IN2P3 deliverable under the coordination of M. Migliore at LPSC.

3.7.1 IN2P3 MANPOWER ON THE CAMERA : STATUS & PLAN

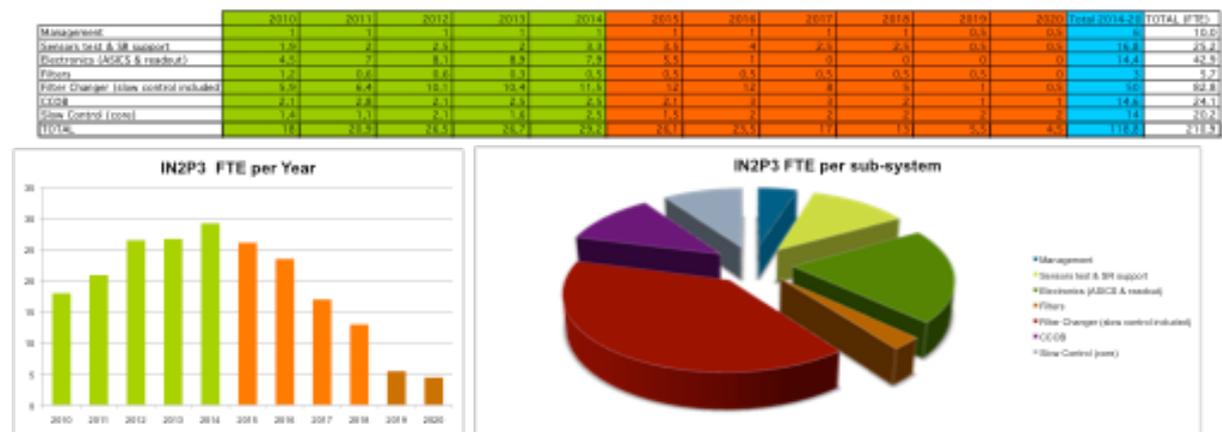


Table 1: IN2P3 Manpower involved on the LSST camera in Full Time Equivalent (FTE).

3.7.2 BUDGET FOR THE IN2P3 CONTRIBUTION TO THE CAMERA : STATUS & PLAN

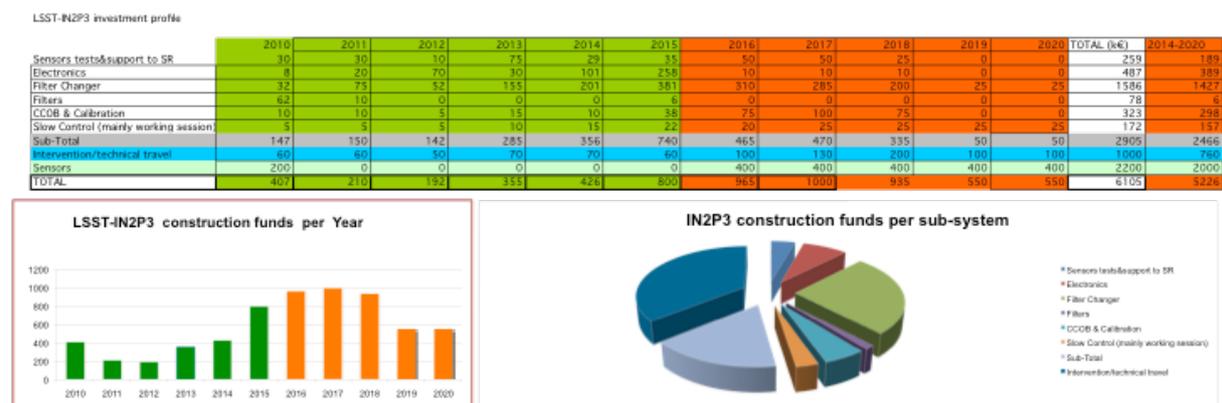


Table 2 : 2010-2012 expenses and 2013-2018 funding plan, for the IN2P3 contribution to the camera



4. CONTRIBUTION TO THE LSST DATA MANAGEMENT & LSST PROCESSING AT CCIN2P3.

4.1. LSST PROCESSING AT CC-IN2P3 : STATUS.

Even if result of the data reduction (level 2) will be made available to all participant, the current agreement of the LSSTc with IN2P3, like with all non-US participant to LSST, is that the large French scientific community involved in LSST will not rely on the computing facilities in the US for science production, but will rather build and use its own center. It should be stressed that efficient access to the huge LSST dataset will be one of the challenges for scientific exploitation of LSST, in particular for the Dark Energy science.

With the aim of ensuring competitive data access with computing resources for the French groups and having an in-kind contribution to the LSST running cost, a letter of intent was sent by the the IN2P3 director in December 2011 to LSSTc, stating the institute plan to contribute to the LSST computing effort. In this scheme, the CC-IN2P3 computing center is a major LSST partner for the Data Management sub-system, CC-IN2P3 has to provide CPU and storage resources corresponding to 50% of the LSST needs for the Data Release Processing, and to have resident at the CC-IN2P3 the full LSST data set.

The corresponding agreement between the LSST Project Office , LSSTc , NCSA (in charge of the processing for LSST) and IN2P3 has been signed in March 2015. Notice that its our status of full and trusted member of the LSSTc which opened the opportunity to have the full LSST dataset at the CCIN2P3, and to have a contribution to the LSST running cost, covered as an in kind contribution, both being unique among all foreign partners .

Since the signature of this agreement we ramped up to integrate the CCIN2P3 in the LSST processing:

- The collaboration between CC-IN2P3 and NCSA is now in place after the visit of a NCSA delegation at CC-IN2P3 last spring.
- A coordination committee between LSST, NCSA and CC-IN2P3 is now in place.
- CC-IN2P3 has setup a dedicated internal organization to proceed with LSST.
- CC-IN2P3 started an innovative study on computing infrastructure for LSST.
- The platform to distribute the LSST binaries is operated by CC-IN2P3
- Discussion with RENATER on the CC-IN2P3-NCSA network connection is underway.
- CCIN2P3 engineer (F. Hernandez) has been invited to present a key talk at the annual general meeting of LSST : CC-IN2P3 is now fully part of the LSST landscape data processing.

4.2. LSST DATABASE

The level of complexity and volume reached by LSST dataset belongs to the Big Data scale, where new challenges await the data management and their analysis: the unprecedented volume of LSST dataset and databases is one of the bottleneck for computer enabled discovery. The scaling is the major issue to be addressed: how to efficiently store, process,

¹ The NSF asked to the project that starting in 2020 at least 25% (~9 M\$/year) of the LSST running cost should be provided by non-US agencies. To answer to the NSF demands the LSSTc performed a call to foreign partners during the fall 2011 and received more than 65 letters of intent corresponding to contributions for the future running cost of more than 10 M\$ per year on the basis of 20 k\$ per scientist per year. It should be noticed than these contributions give only access to the LSST database, the access to the full LSST dataset through an access to the LSST US computing facility will have to be individually negotiated and will correspond to an extra cost.



catalog, index, distribute, visualize and analyze 100 Petabytes of data, with catalog tables reaching 4 Pbytes and trillion of rows? The answer will clearly involve a broad community.

The work in the LSST data base at IN2P3 started in 2012 through a grant (PetaSky) from the CNRS interdisciplinary mission call on Big Data, (MASTODONS), bringing together 14 researchers and 6 computer engineers from 6 laboratories: 4 laboratories from IN2P3 (APC, CC-IN2P3, LAL and LPC) bring their expertise in astronomical data analysis and the link with LSST and EUCLID projects, and 2 laboratories from INS2I (LIMOS – Clermont-Ferrand, LIRIS – Lyon) bring their expertise in large data volumes modeling, management and analysis, and in image processing and visualization. The PI of the project was Farouk Toumani (LIMOS), and Emmanuel Gangler (LPC) is the Co-PI for IN2P3.

We can underline here two key activities in 2015 :

- Following his Petasky work, F. Jammes from LPC, spent 6 months at SLAC a year ago and as a key LSST expert is now fully integrated in the core development of the LSST database. The NSF, that has to fully support this core effort, provides 1/3 of F. Jammes salary to the CNRS.
- Dell provided to the CC-IN2P3 a platform of 50 nodes with 400 processors and a storage of 0.5 Po to deploy and test the LSST database. The corresponding scale test done at CC-IN2P3 for LSST is still ongoing but the measured performances are already exceeding the design.

This work will continue in the coming year, and here again the IN2P3 has a unique contribution among the international partner to this key subject.

4.3. VERIFICATION DATASETS

In order to test its software suite, LSST has recently embarked upon a project to reprocess DES, HSC and CFHTLS datasets with the LSST software. Thanks to the deep knowledge of the Megacam instrument by the IN2P3 scientists involved in SNLS, the French LSST computing group is now fully responsible of the CFHTLS reprocessing at CC-IN2P3. These datasets and the associated software expertise will be crucial to develop and test the science pipelines in the framework of DESC.

4.4. CONTRIBUTION TO THE LSST DATA REDUCTION SOFTWARE

The LSST collaboration is currently developing its image analysis and data handling software. Regarding image analysis, a framework has been setup, together with some candidate algorithms for standard parts of the image processing. This open-source software has not been used for any scientific publication so far, but is being actively developed both within the LSST consortium and for the image analysis of the ongoing HSC survey. At variance with existing software, the design aims at providing users with a complete development framework as opposed to “canned” tasks.

During preliminary tests of the software on the CFHTLS dataset done at IN2P3, it became clear that the suite misses a simultaneous astrometry solver (known as “Scamp” in the “Astromatic” suite). We have coded the tool, first in the SNLS framework and then ported it into the LSST framework during Summer 2015. It is the first contribution to the LSST software not conducted by the original LSST software developers. It is still too early to draw any conclusion about this development scheme, still given the stock of existing software associated to the CHFTLS-SNLS work, the shown interest by the LSST Data Management for it and the growing interest of the IN2P3 team on science field requesting new and challenging algorithm (ex : Weak lensing), we will likely continue to contribute algorithms to the LSST software framework.

On the front of practicing/testing the LSST framework, we should underline a PhD thesis at CCPM on image subtraction software to extract SN Ia light curve in LSST.



5. SCIENTIFIC PREPARATION: INVOLVEMENT WITHIN THE DESC COLLABORATION

Almost every field in astronomy will be impacted by the huge dataset collected with LSST, since it will produce a deep survey with images taken at many epochs for each field, well suited for both deep sky science and sky variability science. We refer the reader to the LSST science book², that describes in details all the scientific objectives of LSST.

In the sector of our science driver, the Dark Energy, the goal of LSST is to reduce by 1 order of magnitude the current errors on the Dark Energy equation of state. For this LSST will perform a ½ sky survey at the 27 mag depth, and it will have access to all the different Dark Energy probes with their different sensitivity to the Dark Energy :

- Weak Lensing : growth of structure
- Galaxy Clustering : growth of structure
- Baryon Acoustic Oscillations : standard ruler
- SuperNovae : standard candle

The key issue of the corresponding analysis will be the Systematic Errors. For this reason the calibration and photometric red-shift understanding are major requirements for the Dark Energy analysis. Also for the most promising probe, the Weak Lensing, the LSST survey design has done a key choice to address the systematic error associated to the control of the galaxy shape measurement: LSST plan to deconvolve the instrumental and atmospheric distortions by observing the same patch of sky ~1000 of time, each time with a sensitivity of ~ 24 Mag. Clearly the Dark Energy analysis will request a strong collaborative effort to address all its technical challenges.

Until 2012 the organization of the science in LSST was focused on 11 autonomous "LSST Science Collaborations" covering the different science topics of LSST, including at least 4 collaborations concerning Dark Energy probes. In 2012, the DOE urged LSST to set up a collaboration "à la" High Energy Physics. As a consequence, the Dark Energy Science Collaboration (DESC) has been created in June 2012. This collaboration explicitly manages all the aspects of the project, including the technical tasks. It is open to all US scientists, DOE or NSF funded, international LSST partner and on the French side to all scientists from the IN2P3 laboratory involved in the camera construction + 45 "tickets" that will be open to French scientists from other IN2P3 laboratories or other French institution (CEA or INSU) under a formal agreement between them and IN2P3 direction that has still to be implemented.

IN2P3 scientists between 2012 and 2014 helped to build the DESC and today IN2P3 members are part of the DESC management:

- 2 DESC board members (P.Antilogus, D.Boutigny among 15 elected members)
- 1 working group co-coordination (P.Astier, DESC Sensor Anomaly Working Group)
- 1 member of the DESC Advisory board (D.Boutigny among 5 scientists)
- 1 member of the Membership committee (E.Aubourg)

~50 staff IN2P3 scientists have identified LSST as their future and 38 have already non-0 contribution. Also 24 IN2P3 scientists (including 1 Pdoc & 2 PhD) are already among the 152 DESC full members (~15% from IN2P3).

These scientists are involved in the working group associated to the 4 dark energy probes accessible to LSST. A few publications related to these works have been produced (see [11,12] below). It should be noticed that today the activity on these probes is on real dataset, like the one collected by DES (with a participation from US, Germany UK and Spain) or HSC

² <http://www.lsst.org/lsst/scibook>



(with a participation from Japan and US). It's mandatory for the LSST French team to also work on real dataset to prepare the LSST science. This will insure that the team has the state of the art knowledge and practice, but also that young scientist can be fully trained. For this reason the LSST team fully support the "intermediate projects" discussed at this Scientific Council, and in particular the photometric data analysis projects as presented by N.Regnault, which are key science projects but are also mandatory to the LSST science preparation at IN2P3.

Also the IN2P3 LSST Science team is quite active in preparing the scientific return through calibration effort. A short presentation of these activities is done in the rest of this section.

Photometric redshift

The estimation of galaxy redshifts from broad band photometry, named here photo-Z, which is essential for all the cosmological probes, has become a widely used tool in observational cosmology. These redshift (and galaxy property) estimates are derived from characteristic changes in the observed colors of galaxies due to the redshifting of features in galaxy spectral energy distributions through a series of broad band filters. Photometric redshifts from the u, g, r, i, z, and y LSST-passbands will be applied and calibrated over the redshift range $0 < z < 4$ for galaxies with magnitudes up to $r \sim -27.5$.

A French team from APC, LAL, LPSC and LUPM is working on this field. In particular we have developed a set of software tools which can be used to create realistic mock galaxy catalogs, as well as photo-Z reconstruction codes based on template fitting method and a neural network. The photo-Z reconstruction from both these methods has been tested on real CFHTLS data and also on simulated LSST-like catalogs, and a paper has already been published on this subject [3]. Our pipeline has already been used to study the impact of the filter passband shapes and uncertainties on the photo-Z performance. We are now improving each step of the simulation:

- Improve the photo-z algorithms (template fitting and neural network), test them on extensive catalogs, and compare their performances with existing codes.
- Improve the modeling of reddening and absorption due to intergalactic matter.
- Improve the realism of the galaxy type generation with better Spectroscopic databases. (arXiv:1309.5384, to appear in Journal of Cosmology and Astroparticle Physics).
- Study the effects of blending and stellar contamination.
- Refine the criteria used to select the "golden sample", i.e. a category of galaxies with well determined photo-z's and negligible catastrophic determinations. Such an unbiased category should therefore constitute an optimal tracer for the BAO measurements.
- Improve the simulated 3D galaxy catalog by taking into account non-linear effects (clustering)

Sensor studies: the Sensor Anomalies Working Group (SAWG)

Within DESC, a Sensor Anomaly Working Group (SAWG) has been setup, to which the LPNHE contributes both scientific work and a convener. Understanding the physics at play in CCD sensors is the driver of our activity on LSST sensors (see corresponding Camera section in this document), as we believe that understanding sensor physics is mandatory for precision measurements (typically photometry, astrometry, or shape), and we regard the involvement of the IN2P3 team in these matters as strategic. This activity now involves about 6 people (including 1 PostDoc and 1 PhD), and has produced so far three refereed papers [1,4,9] and triggered invitations to conferences. The main success to date of this activity for the IN2P3 team has been the discovery of the Brighter-Fatter effect (=due to electrostatic effect in the CCD, bright stars are "fatter" than expected compared to faint ones) and the implementation of a correction based on flat field exposure. This work has triggered a strong



attention in the photometric community and Brighter-Fatter effect is now identified as a key issue in Dark Energy science extraction.

Astrometry & Photometric Calibration

A team from CCPM, LPNHE and LUPM, has started an evaluation work on using Gaia Satellite results as an Astrometric & Photometric frame for LSST data reduction. It should be noticed that in parallel to our effort, the LSST project has positively re-evaluated its position in respect of the interest of Gaia for LSST data processing.

Our current objective is to have a non-ambiguous evaluation of what Gaia data could bring to the calibration of an existing and well known survey like CFHTLS wide. First contact with Gaia team has been taken, and an evaluation of what could be done and when with Gaia data has started.

6. LIST OF PUBLICATION BY IN2P3 LSST MEMBERS 2013-2015

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Euclid & LSST

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