The Large Synoptic Survey Telescope (LSST)

Dark Energy Science at APC

E. Aubourg, J.G. Bartlett, A. Bouquet, M. Crézé, Y. Giraud-Héraud, L. Guglielmi, J.-Ch. Hamilton

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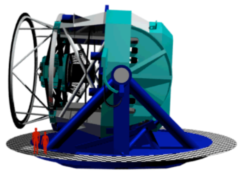


Executive Summary

Unveiling the nature of dark energy is the most compelling challenge facing Cosmology and Fundamental Physics today. We propose to put the APC at the heart of this challenge by participating in the Large Synoptic Survey Telescope (LSST) project, an unprecedented survey effort aimed at significantly advancing our understanding of this mysterious component of our Universe.

The LSST is a wide-field imaging 8-meter-class telescope dedicated to survey 20,000 square degrees of the Southern Hemisphere repeatedly over 10 years with the goal of constraining the dark energy abundance, e.g., its equation-of-state, back to reshifts approaching $z=3$. A Stage IV project according to the Dark Energy Task Force (DETF) classification, the survey will bring to bear all 4 methods identified by the task force: Supernova Type Ia Hubble diagram, cosmic shear, baryon acoustic oscillations (BAO) and galaxy cluster abundance evolution. The project is a joint NSF-DOE effort and currently in an R&D and early construction procurement phase. It passed a NSF Conceptual Design Review in September 2007 with a strong endorsement; a NSF Preliminary Design Review and a DOE Critical Decision 1 are planned before the end of 2008. Final approval by the agencies would permit construction to begin in 2011 through to first light in 2015 and science commissioning in 2016.

Over the past year, a consortium of IN2P3 laboratories lead by APC, LAL and LPNHE engaged in discussions with the LSST project and has identified a number of key areas to which our IN2P3 laboratories could actively and effectively contribute. These include contributions to science analysis using all 4 DETF methods, to camera construction (electronics, filter exchange system, detector procurement, online control software, lenses, filters), to system calibration (hardware and on-sky) and to data management. A proposal for French participation, elaborated with the LSST project, was recently presented to the direction at IN2P3. We expect an LSST R&D budget line to open for the period 2008-2011 (construction start) and classification as a *Très Grand Equipement (TGE)* at CNRS to be requested by IN2P3 and INSU. In this light, the *Conseil Scientifique* at IN2P3 will examine LSST France during its upcoming December 2007 meeting. A MOU between our IN2P3 laboratories and the LSST project detailing our technical and scientific participation during the R&D phase is being prepared for presentation at this meeting.

Participation in LSST offers an ideal opportunity for the group *Cosmologie et Gravitation* at APC to realize its strategy for important investment in dark energy research. This strategy targets methods using weak lensing (clusters and cosmic shear) and BAO. Building on our present strong expertise in the use of galaxy clusters as a cosmological probe,

we are beginning an effort on BAO methodology applied to the BOSS experiment in SDSS-3 and building know-how in cosmic shear. This will position us for high scientific return from LSST and place us at the heart of dark energy studies that are poised to reap enormous benefits from weak lensing observations over the next 15 years.

Supporting our scientific effort, we propose to take important roles in on-sky system calibration and real-time camera control systems. The scientific requirements imposed on the LSST survey – specifically, by the need for accurate photometric redshifts – demand new photometric calibration methods. Participating in current R&D activities (lead by SLAC, in charge of calibration), we are developing simulations of atmospheric extinction and of auxiliary instrumentation operations (shared lead on this Work Package with SLAC). The goal of this project-wide simulation effort is, near term, to put in place the necessary methodology and, long-term, to construct the photometric calibration pipeline. Strategically, this effort builds on the group's past experience in this area (EROS, POINT-AGAPE, Hipparcos) and puts us at the center of a key element of the LSST scientific analysis.

Our proposed involvement in real-time control brings to bear APC's extensive experience in this area (e.g., Pierre Auger Observatory). We plan to phase our involvement during the R&D period by first taking on the control of the filter exchange mechanism (starting in 2008) in collaboration with the LPNHE, who is in charge of the mechanism's mechanical design. At the same time, we will participate in designing the overall control system architecture and work progressively upstream to take charge of other subsystems.

Introduction

What is Dark Energy? Easy to pose, this simple question presents the most compelling issue facing Cosmology and Fundamental Physics today.

Many different observations betray the presence of this mysterious energy dominating the Universe; for instance, SNIa distance measurements directly show the accelerated expansion characteristic of Dark Energy (DE); the flatness of space indicated by the cosmic microwave background (CMB) anisotropies when combined with large-scale structure measurements of the matter content and/or determinations of the Hubble constant require DE; and cross correlations between the CMB anisotropies and large-scale structure show the late-time influence of DE on the growth rate of structure. With more observations than basic parameters, we have over-constrained the *standard cosmological model* and find a consistent scenario where DE must account for about 75% of the total energy density of the Universe.

Dark Energy is a tantalizing enigma. It challenges our understanding of our universe by flaunting a cosmic constituent that eludes coherent description on the most basic theoretical level. And its presence and behavior may hold clues to that central question of Physics – the relation between gravity and the vacuum. Unveiling its nature has understandably taken center stage in Cosmology and Fundamental Physics, a fact echoed by the U.S. Dark Energy Task Force (DETF), the ESA-ESO Working Group on Fundamental Cosmology and by the U.S. National Research Council's report on NASA's Beyond Einstein Program (BEPAC committee).

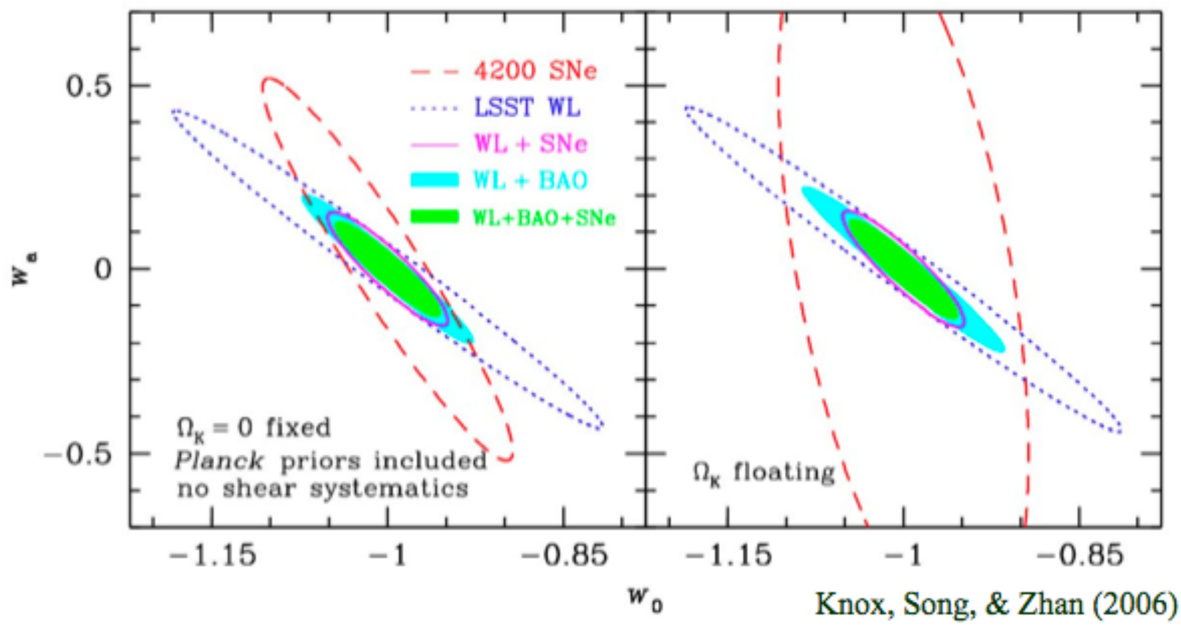


Figure 1: *Expected LSST constraints on the EoS.*

To focus DE research, one often speaks of constraining the equation-of-state (EoS) of DE. We write the relation between pressure and energy density as $p = w\rho$ and seek to constrain *w,* which is in general a function cosmic time, or scale factor *a*. A prevalent parameterization is $w(a) = w_0 + w_a(1-a)$. The goal is then to determine the two parameters w_0 and w_a. This approach is not unique, but it does have the advantage of simplicity. The expected constraints from LSST in these terms are shown in Figure 1.

The U.S. Dark Energy Task Force (DETF) applied a Figure-of-Merit (FoM) to quantify the expected performance of DE experiments and classify them into one of 4 stages. Their FoM is defined as the area of the experimental error ellipse in the w_0-w_a plane. In this scheme, the LSST is a stage IV experiment, the ultimate stage in their classification (shared by JDEM and SKA).

The LSST Project

The Large Synoptic Survey Telescope (LSST) project proposes a large-area, wide-field, ground-based telescope designed to produce deep images of half the observable sky every few nights over a period of 10 years. Constraining DE is the primary target of the survey, although it will obviously be a tremendous resource for a variety of astrophysical investigations - e.g., studies of small bodies in the solar system, programs mapping the outer reaches of the Milky Way, and searches for faint optical transients over a wide range of time scales. LSST would provide detailed constraints on the nature of dark energy, through a number of distinct and complementary techniques.

Four of these techniques: measurement of baryon acoustic oscillations, surveys of clusters of galaxies, photometry of Type 1a 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 AAAC and 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. The DETF indicated that a Stage IV Large Survey Telescope (modeled on LSST) could make a major advance in our understanding of dark energy, especially if the systematic errors associated with each of these techniques can be brought under control.

The LSST is a fast 8-meter class telescope optimized for rapid surveying with a large field-of-view (FOV) from its site on Cerro Pachon in Chili. A Gigapixel camera covers the 3.5-degree FOV at any given time in one of 6 possible filter bands. The ability to take many, deep images of each part of the sky with high image quality (for lensing) drives the design. A cadence of one image every 15 seconds over 10 years will produce an unprecedented volume of high quality data calling for extensive data management. The three main elements of the project – the telescope & site, the camera and the data management, are briefly described in the following sections.

The observing strategy for the LSST maximizes observing efficiency by minimizing slew and other down time, and by making appropriate choices of filter bands given the real-time weather conditions. A prototype simulator has already been developed to evaluate this process, and it will eventually be transformed into a sophisticated observation scheduler. A prototype fast Monte Carlo optical ray trace code has also been developed to simulate real LSST images. This will be further developed to aid in the design process and for use in testing science analysis codes.

The aggressive observing schedule obligates operation during a variety of weather conditions (i.e., not just ideal photometric conditions) and minimal use of the main telescope for calibration observations. These constraints coupled with the high photometric precision (0.01mag or better over the entire survey) demanded by our science goals calls for new photometric calibration procedures (both instrumental and on-sky). The on-sky calibration is an extension of the successful SDSS *Ubër-cal* method and potentially involves real-time atmospheric monitoring with auxiliary instrumentation.

Project Structure

In the US, a large team of scientists and engineers from both the astronomy and particle physics communities has been assembled to pursue the LSST concept. As presently envisioned, LSST would be developed as a multi-agency public/private partnership, with NSF as the lead agency providing the bulk of telescope, site, and data management funding, and DOE supporting the fabrication of the LSST camera and the involvement of members of the particle physics community in the data handling and science analyses. Private and/or international funding has also been solicited to enable production of the telescope mirrors, which are long-lead, expensive items that must be started before federal funding for proposed construction is officially authorized.

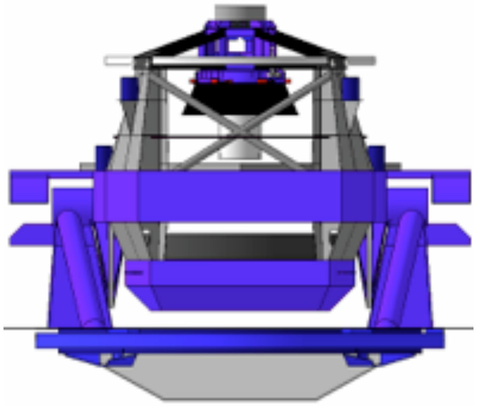
Organizationally, LSST project activities are coordinated by the Large Synoptic Survey Telescope Corporation (LSSTC), a non-profit Arizona corporation based in Tucson, Ariz. There are currently 17 institutional members of LSSTC, including universities, private philanthropic organizations, and federal laboratories. LSSTC is the designated recipient of NSF funds awarded under the Design and Development award, as well as the direct recipient of private funds and member institution dues. On the DOE side, preliminary design studies have been led by SLAC, with significant involvement at BNL and LLNL, as well as in university-based high energy physics groups. The LSST Project Director and Deputy Project Director, respectively, are Professors Anthony Tyson of the University of California, Davis and Steven Kahn of Stanford University/SLAC. The Project Manager is Dr. Donald Sweeney of LLNL and LSSTC. The Camera Lead scientist and project manager, respectively, are Pr. S. Kahn and Pr. K. Gilmore of Stanford University both at SLAC.

Telescope & Site

The key figure of merit for a survey telescope is the étendue—the product of the collecting area of the primary mirror and the field of view of the camera: $A\Omega$. The étendue is a measure of the speed at which the telescope can survey the sky down to a given depth. To maximize the field of view, it is essential to control aberrations off-axis. For LSST, this is achieved with a 3-mirror optical design. Incident light is collected by the primary, which is an annulus with an outer diameter of 8.4 m, then reflected to a 3.4-m convex secondary, onto a 5-m concave tertiary, and finally into three refractive lenses in the camera. This design maintains a 0.2 arc-second point spread function (psf) across the entire optical band over a 3.5-degree diameter field of view.

The primary and tertiary mirrors are essentially coplanar and will be fabricated from a single monolithic mirror blank using a borosilicate technology developed at the University of Arizona. The secondary will be a thin meniscus mirror fabricated in fused silica. All three mirrors are actively actuated to control wavefront distortions introduced by gravity and environmental stresses on the telescope.

The telescope structure is a compact, stiff design with a fundamental frequency of nearly 10 Hz. This is important for achieving fast slew-and-settle times, as required by the observing program. The telescope sits on a high pier within a carrousel dome that is 30 m in diameter. The dome has been especially designed to reduce “dome seeing” (local air turbulence that can distort images) and to maintain a uniform thermal environment over the course of the night.



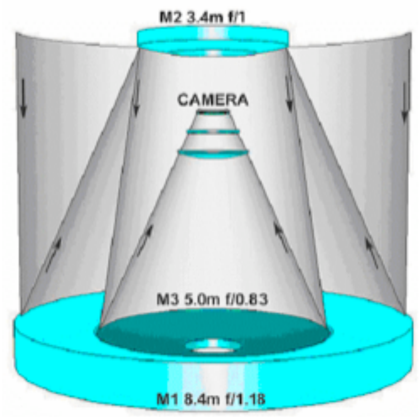


Figure 2: *Telescope mounting and optical layout.*

The telescope will be sited atop Cerro Pachón in Northern Chile, on an NSF-developed astronomical site located near the Gemini South and SOAR telescopes, not far from Cerro Tololo Inter-American Observatory.

Camera

The camera contains a 3.2 Gigapixel focal plane array, comprised of roughly 200 4K × 4K CCD sensors, with 10 μm pixels. The sensors are deep depletion, back-illuminated devices with a highly segmented architecture that enables the entire array to be read out in 2 s or less. These detectors are grouped into 3 × 3 arrays called "rafts." Each raft contains its own dedicated front-end and back-end electronics boards, which fit within the footprint of its sensors, thus serving as a 144 Megapixel camera on its own. All of the rafts, with their associated electronics, are mounted on a silicon carbide grid inside a vacuum cryostat, with an intricate thermal control system that maintains the CCDs at an operating temperature of roughly -90 degrees centigrade. The grid also contains sets of guide sensors and wavefront sensors at the edge of the field. The entire grid, with the sensors, is actuated at a rate ~ 30 Hz in a "fast guiding" mode to maintain a very narrow psf (0.7 arc-seconds median), which is limited mainly by seeing fluctuations in the overlying atmosphere.

The entrance window to the cryostat is the third of the three refractive lenses. The other two lenses are mounted in an "optics structure" at the front of the camera body. The camera body also contains a mechanical shutter, and a carrousel assembly that 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 an automated procedure accomplished during daylight hours.

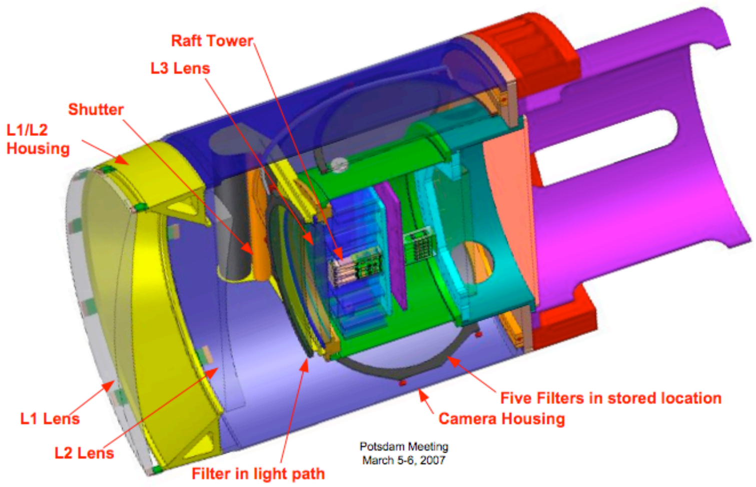


Figure 3: *Camera design.*

Data Management

LSST will produce an enormous volume of data, roughly 30 Terabytes per night, leading to a total database over the ten years of operations of several tens of Petabytes. Processing such a large database—and archiving it in useful form for access by the community—is a major challenge for the project. The data management system is configured in three "layers": an infrastructure layer consisting of the computing, storage, and networking hardware and system software; a middleware layer, which handles distributed processing, data access, user interface, and system operations services; and an applications layer, which includes the data pipelines and products, and the science data archives. There will be both a mountain summit and a base computing facility (located in La Serena, the nearest city), as well as a central archive facility and multiple data access centers in the States. The data will be transported over existing high-speed optical fiber links from South America to the U.S.

Project Status, Funding Model and Schedule

The LSST project is proposed primarily as a joint NSF and DOE venture, with international participation and some private funds. The funding model proposes NSF support for the telescope & site as well as the data management structure, while DOE would fund the majority of the camera construction. Total construction cost is estimated at ~450M$ (then-year dollars) and operations at ~45M$/year.

The project successfully passed its NSF Conceptual Design Review (CoDR) in September 2007 with a strong endorsement for continuation to Preliminary Design Review (PDR). This was a significant milestone. Project management is preparing for a combined PDR and Critical Decision-1 (CD-1, DOE) before the end of 2008. This would keep the project on schedule for first light in 2015 and science commissioning in 2016, a plan supported by NSF and DOE program officers, although not yet endorsed by at Agency Level. In this scheme, construction would begin in U.S. Fiscal Year 2011. Survey operations would continue for ten years after science commissioning.

LSST France

Lead by APC, LAL and LPNHE, a French consortium contacted the LSST project and has been discussing potential IN2P3 involvement over the past year. Additional laboratories have now also expressed interest (e.g., LPSC/Grenoble, Lyon). In close collaboration with the LSST project, the consortium has identified several areas for French participation in camera construction and system calibration (instrumental and on-sky). These options were recently presented (September 2007) to the direction at IN2P3 and discussed in the presence of LSST represented by S. Kahn. As a consequence, IN2P3 direction proposed the opening of a budget line starting in 2008 for R&D studies. In parallel, status as a *Très Grand Equipement (TGE)* by the CNRS will be requested by IN2P3 and INSU for French LSST participation, eventually starting with construction in U.S. Fiscal Year 2011. Formal presentation of the project to the Scientific Council of the IN2P3 is planned at its meeting in December 2007. For this meeting, we are preparing a MOU between our laboratories and the LSST project detailing our scientific and technical involvement during the R&D phase.

LSST at APC

Our proposal encompasses substantial implication in science analyses and technical contributions lead by members of the *Cosmologie et Gravitation* group at APC.

LSST Science at APC

We propose to center our scientific activity on three of the DE probes targeted by LSST; namely, Baryon Acoustic Oscillations (BAO), Galaxy Clusters (GC) and Cosmic Shear (CS). The latter two in fact fall under the same type of analysis - weak gravitational shear measurements. This puts into action the general strategy identified by the *Cosmologie et Gravitation* group at APC for engaging in DE studies. Building on in-house know-how, this strategy interlaces near term effort and scientific results with the building of new scientific expertise.

The group already has extensive experience in using galaxy clusters and large-scale structure as cosmological probes, and with astronomical surveys, their planning, operation and analysis (e.g., EROS, AGAPE, Hipparcos). As a next step, it is planning BAO studies by participating in the BOSS experiment of SDSS-3. At the same time, we are extending our scientific reach to Weak Lensing applied both to galaxy clusters and cosmic shear. The aim is to place the group at the heart of DE research on a variety of time scales, with near-term effort on Planck (e.g., SZ clusters) and BOSS and a ramp-up in shear analyses for LSST operations.

In particular, cosmic shear is the method of the future. It has the highest potential for DE studies and offers numerous cosmological applications, ranging from inflation physics to studies of galaxy formation and of the light-dark matter relation. The technique has been proven, but only large-scale optimized experiments will tap its enormous potential. This is the work of the next 10-15 years in experimental Cosmology that makes APC's involvement in this area a strategic imperative.

Galaxy Clusters

The abundance of galaxy clusters and its evolution is a sensitive probe of the growth rate of cosmic structure, and hence allows us to test both the workings of gravity and measure the effects of DE on the expansion. This sensitivity arises because clusters form out of extreme peaks in the matter density perturbation field. Specifically, clusters represent "several sigma peaks" on the Gaussian tail of the mass function of collapsed halos. Their abundance depends therefore exponentially on the amplitude of the density perturbations and its evolution, which in turn depends on the cosmic expansion rate.

Turning cluster counts with time into cosmological constraints requires a catalog of clusters with measured mass and redshift. To obtain the mass, one uses theoretically motivated and empirically calibrated relations that permit mass estimations from, for example, X-ray or Sunyaev-Zel'dovich (SZ) observations of the intracluster gas. Planck for example, will furnish a large catalog of massive clusters detected by their SZ effect that will yield important cosmological constraints.

Weak lensing observations offer the prospect of nearly mass-limited cluster catalogs. The lensing signal directly measures the cluster mass (projected along the line of sight) and bypasses all the uncertainties associated with modeling the gas physics in clusters. The large lensing survey of LSST will produce an unprecedented catalog of lensing-selected clusters that will enable us to place strong constraints on the behavior of gravity in untested regimes and on the DE EoS.

The group has extensive experience in this field. J.G. Bartlett has been actively using clusters as cosmological probes for more than 15 years, and has directed 3 Ph.D. theses on the subject. These have contributed, for example, to defining the Planck scientific program on galaxy clusters. This research is now being extended to weak lensing catalogs.

Baryon Acoustic Oscillations

Baryon acoustic oscillations, seen in the CMB as the famous "Doppler peaks" at decoupling, leave their imprint on the matter distribution as peaks in the density perturbation power spectrum at late times. The detection of this feature in the galaxy distribution by SDSS and 2dF handed Cosmology a new geometric tool: the location of these peaks identify standard rulers. In fact, these standard rulers are the same seen in the CMB angular power spectrum at $z \sim 1000$, but we can now observe them at a variety of (low) redshifts in large galaxy surveys.

While the first detection was made by redshift surveys, the peaks can be found in imaging surveys with accurate photometric redshifts. With its deep 6-band imaging, LSST will measure photometric redshifts for on the order of 1 billion galaxies out to redshifts beyond unity. The enormous volume of the LSST survey will push BAO cosmology to new levels of precision.

The *Cosmologie et Gravitation* group is embarking on BAO studies by participating in the BOSS survey of SDSS-III. BAO analyses rely essentially on power spectra analyses, for which the group has extensive experience. Group members have worked on power spectra extraction and analyses of CMB data (Arhceops and Planck), as well as for redshift surveys (ESO Slice Survey).

Cosmic Shear

Cosmic Shear is an exciting method whose full potential will be realized over the next 10-15 years by large surveys like that of LSST. The technique looks for weak gravitational lensing distortions of background galaxies to trace the foreground mass distribution. By using redshift information on the background (source) galaxies, one reconstructs the matter distribution as a function of cosmic epoch in a technique known as lensing tomography.

Numerous observations of have proven the use of the technique, and newer surveys, such as the CFHTLS, are providing important cosmological constraints on DE. The most spectacular example of lensing tomography is the recent COSMOS analysis.

This work, however, is only the beginning. In many ways, the field is in a state similar to that of the CMB shortly after the COBE detection: the tool's utility has been demonstrated and its potential is generating significant new effort. But the field has yet to mature and yield its fullest potential. Given the history of CMB science, we have high expectations.

Shear analysis is rich and complex, and it offers many opportunities for groups like ours at APC. The analysis relies heavily on power spectrum analyses, with which, as emphasized above, our group has good experience. This offers us a natural doorway to the subject. We will not, however, limit ourselves just to this aspect, but develop new know-how on shape measurements and lensing theory. The group's past experience with imaging and photometric measurements (EROS, AGAPE and Hipparcos) will be important. The lead-time to LSST survey operations presents us with an ideal opportunity to apply this experience and progressively engage in this crucial research area by participating in the Lensing Working Group of LSST in charge of preparing of the CS analysis.

APC Technical Contributions

We propose to contribute in two technical areas: on-sky photometric calibration and online control. Both build on important past experience at APC: with imaging and photometric analyses (EROS, AGAPE, Hipparcos), and with real-time control systems (e.g., Pierre Auger Observatory)

<u>Calibration</u>

Photometric calibration is crucial to LSST scientific goals. The need for highly accurate photometric redshifts places demanding requirements on the calibration over the entire 10-year survey period. Specifically, LSST must achieve 0.01mag or better calibration across the filter set and observation epoch.

The baseline LSST sky (or celestial) photometric calibration strategy builds on the SDSS experience with the *Ubër-cal* methodology. It uses a network of *sentinel stars* found within each pointing. These are main sequence stars with magnitudes spanning the dynamic range of each single-exposure image and which are easily identified from their position in the tight color-color locus of the main sequence. We expect to find ~100 such stars/CCD chip even towards the Galactic Pole. The sentinals are used to reduce photometry to a common internal standard across the FOV and observation epoch.

The SDSS has achieved a photometric accuracy close to what is needed for LSST with *Ubër-cal* applied to their repeated observations of Stripe 82. The LSST survey, however, differs in several respects from the SDSS: observations are made in one filter at time; a greater diversity of observing conditions will be encountered; and the survey must accurately link observations over a 10-year period.

Varying atmospheric conditions are the primary source of residual photometric error, in particular changes in air mass, water vapor and aerosol (particulate) abundance, and cloud cover. Direct monitoring of these conditions by additional instrumentation should diminish photometric error on individual images and help us to reduce the full survey to a tighter internal photometric standard. To this end, the LSST plans to use a bore-sighted IR camera to determine cloud opacity within each LSST FOV. In addition, we are studying the use of an auxiliary telescope (AT) to monitor atmospheric opacity as a function of wavelength by observing (simultaneously with main telescope operations) a set of bright *standard stars* with low-resolution spectroscopy and a set of photometric bands.

We will work within the LSST consortium's *Calibration Working Group* headed by D. Burke of SLAC. In this context, J. Bartlett and D. Burke lead the Work Package 4 "Auxiliary Instrumentation and Atmosphere" dedicated to simulating AT operations and atmospheric effects. The goal of these simulations during the R&D phase is to optimize the photometric reduction methodology, characterize the needed auxiliary instrumentation (AT) and quantify overall photometric performance. The long term goal is to put in place the final calibration pipeline.

Camera: online control

Top-level control of LSST operations is the charge of the Observatory Control System (OCS), which manages the principle control subsystems: the telescope control system (TCS), camera control system (CCS), data management system (DMS) and the calibration/auxiliary control system (CACS). The CCS consists of a set of software modules, nominally implemented as long-lived "server" processes running on embedded subsystem computers, controlling a number of electro-mechanical devices: motors, encoders, pressure sensors, temperature sensors, limit switches, voltage monitors and relays.

At APC we have extensive experience in online system control (e.g., Unified Boards for the Pierre Auger Observatory), and the architecture conceived for the LSST matches well this experience. We propose to apply this expertise to contribute to the development the CCS. To this end, we envisage a phased involvement beginning with the camera filter exchange mechanism in collaboration with the LPNHE. Work would begin in calendar year 2008 (start of the IN2P3 R&D period) leading to an initial prototype for the PDR/CD-1 reviews. During the R&D period, we would participate in defining the overall CCS architecture and in choices for Middleware to be used. This would facilitate larger involvement and negotiations for additional responsibilities in the CCS. By the start of construction (U.S. FY 2011), we would have clearly established our place in the CCS.

Located around the cryostat body, the filter exchange mechanism holds 5 (of the 6) filters on a ring surrounding the cryostat and bolted to its back-end flange. On command, it must rotate, unload and reload filters into the optical path in front of the shutter. The sixth filter remains outside the camera and can be automatically swapped with into the filter carousel during daylight servicing.

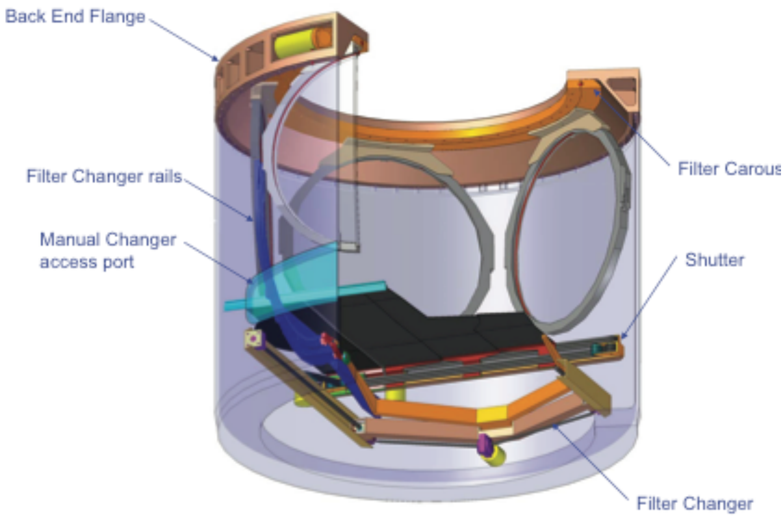


Figure 4: Diagram of the camera body highlighting the Filter Changer.

The LPNHE is taking charge of the mechanical design of the filter exchange mechanism. In collaboration with this effort, the APC will develop the associated software controlling the motors and clamps. The proposed control architecture is closely related to other systems that have been developed at APC (e.g., Pierre Auger Observatory). Work on the filter mechanism has already begun at the LPNHE. Our contribution would begin with official R&D funding by IN2P3 in early 2008 with the goal of producing an initial prototype for the PDR/CD-1 reviews (end 2008) and a fully functional prototype by 2010.

We estimate that roughly 1 FTE of technical staff is sufficient for the work on the filter changer. Additional responsibilities in the CCS will be studied during the R&D period as a function of the availability of additional staff resources.

APC Resources & Schedule

The table below summarizes the human resources implicated in the project. In addition, the APC has requested an Assistant Professor (MdC) position from Paris 7 in the area of Wide-Field Surveys to support this effort. The status of this request for possible 2008 recruitment is pending.

Name	**Position**	**Time Allocated**	**Implication**
E. Aubourg	CEA	25% (2008) 35% (2009) 50% (2010->)	Contact Physicist for the online control BAO, CS
J. Bartlett	PR 1	50%	APC Project Lead Photometric calibration (resp. WP 4 with D. Burke at SLAC) Clusters, CS
A. Bouquet	DR 2	50%	BAO, CS
M. Crézé	Prof. Emerite	30%	Photometric calibration CS
Y. Desplanches	AI	20%	Online control
C. Dufour	AI	40%	Online control
Y. Giraud-Héraud	DR 2	20%	BAO, CS

L. Guglielmi	IR 1	20% (2008) 30% (2009->)	Lead Engineer for the online control
J.-Ch. Hamilton	CR 1	40%	Photometric calibration BAO, CS

A preliminary schedule for our involvement through the R&D phase is given in the table below. A schedule for our participation in the construction and operation phases will be established during the R&D period.

Year	Photometric Calibration	Online Control	Comments
2008	Simulations – atmospheric extinction code (WP4); overall definition and preliminary evaluation of photometric calibration methodology	1. Control software for initial prototype of filter changer 2. Definition of CCS architecture & middleware	Results for PDR/CD-1 reviews, end 2008
2009	Simulations – characterization of auxiliary instrumentation and corresponding simulation software (WP4)	1. Work on full-up filter changer prototype 2. Negotiations on additional subsystems	
2010	1. Full-up simulations of calibration procedure 2. Performance evaluation 3. Definition of auxiliary instrumentation	1. Finish filter changer prototype 2. R&D on negotiated control subsystems.	Definition of baseline for 2011 construction start

Conclusion

Dark Energy science will take center stage in Cosmology research over the coming decade, and involvement in LSST would guarantee an important role for APC in the field. We propose to invest both scientific and technical effort in LSST, applying in-house expertise with cosmological probes, astronomical surveys and real-time system control.

In the context of a French consortium of IN2P3 laboratories, we are preparing our involvement in LSST R&D starting in 2008. The R&D period for LSST covers the period from 2008-2010, with construction planned to start in 2011, first light in 2015 and science commissioning in 2016. Our R&D effort will be centered on simulations of photometric calibration methodology, and on the development of real-time control software for the filter changer and of the general architecture for the camera control system.

This investment will integrate us into the LSST consortium and permit us to evolve with the field, developing in particular capabilities with Cosmic Shear, a powerful cosmological probe whose full potential will only be exploited by large surveys such as LSST. Our proposal puts into action the strategy adopted by the *Cosmologie et Gravitation* group for engaging in DE research. Considering the direction that our field will take in the coming years, involvement in LSST would consolidate an important part of our scientific activity.