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Status of the Dark Energy Survey Camera (DECam) Project

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ABSTRACT

The Dark Energy Survey Collaboration has completed construction of the Dark Energy Camera (DECam), a 3 square degree, 570 Megapixel CCD camera which will be mounted on the Blanco 4-meter telescope at CTIO. DECam will be used to perform the 5000 sq. deg. Dark Energy Survey with 30% of the telescope time over a 5 year period. During the remainder of the time, and after the survey, DECam will be available as a community instrument. All components of DECam have been shipped to Chile and post-shipping checkout finished in Jan. 2012. Installation is in progress. A summary of lessons learned and an update of the performance of DECam and the status of the DECam installation and commissioning will be presented.

Keywords: Dark Energy, CCD, camera, survey, Blanco, CTIO, imaging

1. INTRODUCTION

The primary scientific goal of the Dark Energy Survey (DES) is to measure the dark energy equation of state parameter *w* using four independent and complementary techniques: galaxy cluster counting, baryon oscillations, weak lensing, and Type Ia supernovae. The area and location of the DES overlap with the South Pole Telescope Project (SPT) (see pole.uchicago.edu/), which will provide Sunyaev-Zeldovich effect measurements for a large number of galaxy clusters. The overlap with the SPT provides an independent and complementary measurement of the galaxy cluster masses that reduce the systematic uncertainties on this quantity. The large survey volume of 5000 sq. deg. to magnitude i ~ 24 will contain ~ 300 million galaxies and will enable precise and complementary constraints on w. The five optical filter pass bands, g, r, i, z, and Y will provide photometric redshifts for all the DES targets. The DES will provide the Vista Hemispherical Survey (VHS) with Y band data, in exchange for near-infrared measurements in J, H and K that improve photometric redshift precision and accuracy for the DES area. The DES constraints and systematic uncertainties are described in the DES whitepapers that were submitted to the Dark Energy Task Force (DETF) (astro-ph/0510346, astro-ph/0510194, and astro-ph/0510195). The DES web page (http://www.darkenergysurvey.org/science/) contains additional information and a link to the DETF report (astro-ph/0609591). In the language of the DETF, the DES is a stage III project: it will improve the DETF figure-of-merit by a factor of 3-5 over current (stage II) projects and is near term and modest cost compared to the stage IV projects such as LSST.

In 2004 the Dark Energy Survey (DES) Collaboration formed and responded to the NOAO announcement of opportunity that offered a significant amount of telescope time on the CTIO Blanco 4m telescope in exchange for a new state-of-the-art prime focus instrument. The Collaboration submitted a proposal to NOAO to build the Dark Energy Camera[1,2] (DECam), and NOAO approved the proposal near the end of 2004. The collaboration has been growing since that time and now consists of approximately 120 scientists located at 4 US national laboratories, 7 US universities, NOAO/CTIO, and consortia from the United Kingdom, Spain, Brazil, Germany and Switzerland.

The Dark Energy Camera (shown in Figure 1) is a wide field 570 Megapixel CCD camera that will be mounted on the Blanco 4-meter telescope at CTIO. DECam will be used to perform the 5000 sq. deg. Dark Energy Survey with 525 nights of the telescope time over a 5 year period. During the remainder of the time, and after the survey, DECam will be available as a community instrument.

The funding for the DECam construction project was provided primarily by the Department of Energy (DOE) with significant contributions from all of the DES collaborating institutions. Funding for upgrades to the facilities at CTIO, DECam installation, commissioning and operations, and for a DES data management system were provided primarily by

the National Science Foundation (NSF). During the construction period the funding agencies held joint reviews. For the DECam project these reviews met the requirements of the DOE Critical Decision process.

The first step for the DECam project in the DOE approval process, critical decision zero (CD-0) mission need, was achieved in Nov. 2005 and the final step (CD-4 Project complete) was achieved on June 4th, 2012, on budget and on schedule. As early as Nov. 2010 the first large components of DECam were delivered to Chile. The final piece arrived in April 2012. It took more than 45 separate shipments, including 6 full sized shipping containers that went by boat and truck, to deliver all the DECam components to Chile. Shipping of the imager[3], with the CCDs installed, and the corrector, with the lenses installed, received special attention. All the equipment arrived safely.

The DECam construction project was defined to cover the design, construction, delivery and post shipping reassembly and testing of all DECam components at CTIO, prior to installation on the telescope; this decoupled the CTIO schedule for installation from the completion of the DECam construction project. The observatory is in charge of the installation of DECam on the telescope, which is currently in progress and expected to be complete in August 2012. Funding from DOE for DES Collaboration support during installation, commissioning and operations has been provided outside the DECam project funding channel. This paper will describe the technical status of the DECam, and provide an overview the project funding, cost, schedule and staffing and a summary of lessons learned.

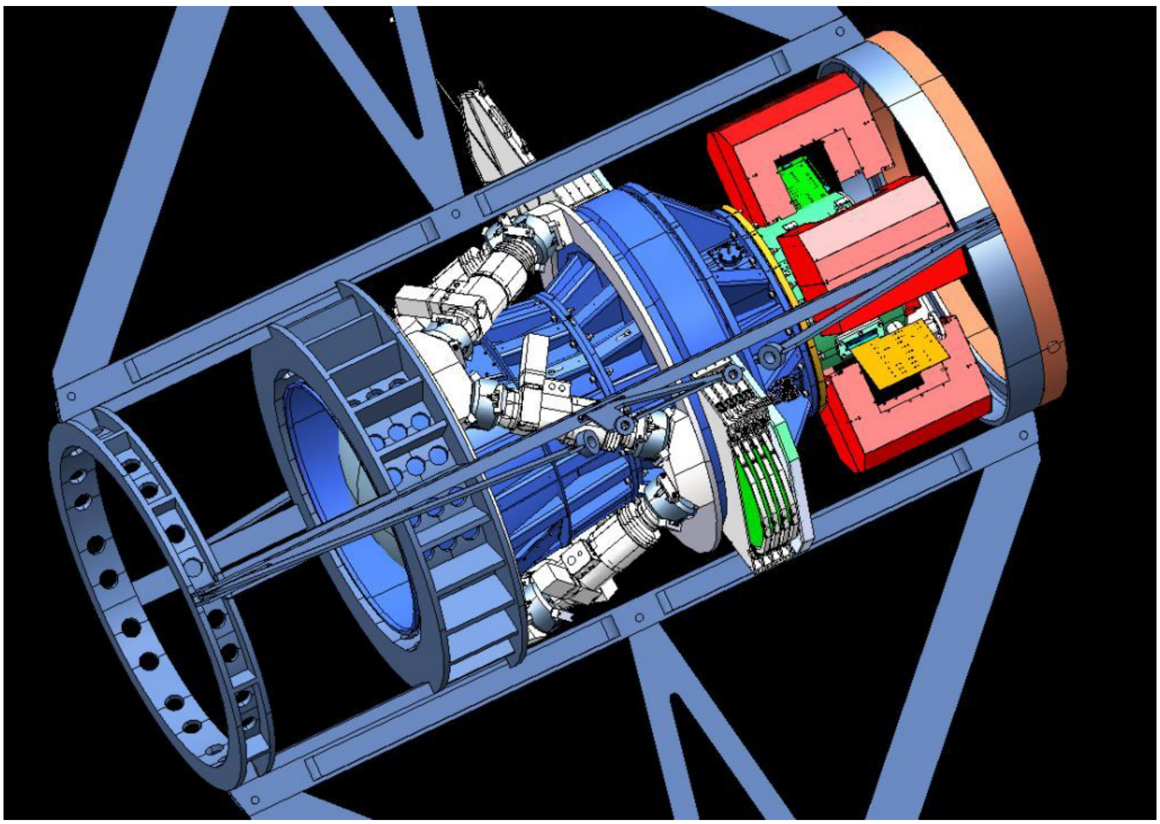

Figure 1. The Dark Energy Camera and prime focus cage.

2. THE DARK ENERGY CAMERA

Figure 1 shows a schematic of the DECam design. A hexapod is used to support and position the DECam corrector barrel and CCD imager in the prime focus cage. The 5 DECam lenses are supported by a two part steel structure called the barrel. The filter changer and shutter are located between the third and fourth lenses of the corrector and the vacuum vessel that houses the CCDs bolts to the end of the barrel. The thermally controlled crates that house the CCD readout electronics bolt to the CCD vacuum vessel.

The DECam is an assembly of components from many institutions from all over the world. The heart of the DECam, the CCD focal plane, contains a total of 74 250 micron thick fully depleted CCDs[4,5] developed by LBNL: 62 2kx4k CCDs for science images and 12 2k x 2k CCDs for guiding, alignment and focus. The bare silicon die were delivered to Fermilab and then assembled and tested in the Fermilab CCD facility[6]. The design of the CCD readout electronics[7,8,9] was a combined effort of engineers at Fermilab and in Spain and all of the final CCD readout electronics boards were produced by our collaborators in Spain. The thermally controlled crates that house the electronics were designed and fabricated by University of Illinois Urbana Champaign. The development of the programs to control the acquisition of images and interface to the observers[10] was led by Ohio State University. The development of the instrument control system was led by Argonne National Lab. The imager vacuum vessel and liquid nitrogen cooling system[11,12] were designed and constructed by Fermilab. The five lens optical corrector was assembled and tested[13] at University College London, while the structure to support the lenses was designed and constructed by Fermilab. The blanks for the lenses came from Corning Glass in New York and they were polished and coated[14] by SESO in France. The filter changer[15] was designed and constructed by University of Michigan. The DECam spectrophotometric calibration system (DECal) [16] was design and built by Texas A&M and the all sky cloud monitor (RASICAM) [17] was designed and built by Stanford University and SLAC. The hexapod (for focus and alignment with the primary mirror) was purchased as an assembly from ADS International in Italy. The software for analysis of the images[18] to direct the hexapod is being developed at SLAC. The shutter was purchased from Bonn University in Germany and the filters from Asahi Spectra in Japan. Prior to shipping, all of the DECam systems (except for the corrector optics) were installed and tested on a telescope simulator at Fermilab; this effort is described in reference [19].

The DECam project introduced a number of new approaches to the construction of a major instrument for a ground based telescope. The first was the decision to procure bare CCDs developed by LBNL and then to package and test them on site at Fermilab rather than procuring fully packaged and tested devices from a vendor. When the DECam project began only LBNL had produced the thick fully depleted red sensitive CCDs that would allow the DES to measure the red shifts of galaxies out to ~ 1 in a reasonable amount of time; the quantum efficiency of these devices is a factor of 5-10 greater than the traditional CCDs used in astronomy. This choice had risks associated with it: up to that point LBNL had produced CCDs that met the DECam requirements, but not yet in the production quantities needed for DECam. In addition, Fermilab, which had extensive experience with the construction of silicon vertex detectors for experiments at both Fermilab and CERN, had very little experience with CCDs. These risks were identified early in the project and an aggressive R&D program led to eventual success; this is discussed further in the section on lessons learned. Figure 2 (left) shows the CCD package developed at Fermilab for the DECam project. The bare die were assembled into these packages and tested in the CCD testing facility at Fermilab. Figure 2 (right) shows the number of bad pixels for the 62 CCDs installed in the DECam imager. The average is ~0.049% bad pixels and the worst CCD has 0.39% bad pixels.

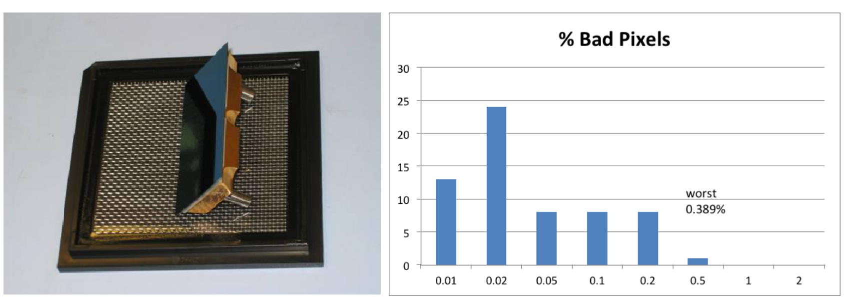

Figure 2. A CCD package and a plot of the number of pad pixels in the CCDs installed in the DECam focal plane.

Although Fermilab has extensive experience designing, building and operating detectors for particle physics experiments, building a camera for installation on a telescope was a new step. To address this, the DECam project had a large emphasis on prototyping, integration and system testing. In addition to providing essential and realistic platforms for early diagnosis of problems and their cures, this approach also helped convince the technical reviewers that the project has a reasonable chance for success.

Early in the project we made the decision to construct a full sized prototype of the imager vessel based on the conceptual design (see Figure 3). This allowed us to gain experience operating the CCDs in a realistic environment and optimization of the grounding strategy. It also allowed the technical staff to gain experience with this large vacuum vessel and to demonstrate the vacuum performance with the multiple materials (kapton cables, G10 vacuum interface boards, large o-ring surfaces).

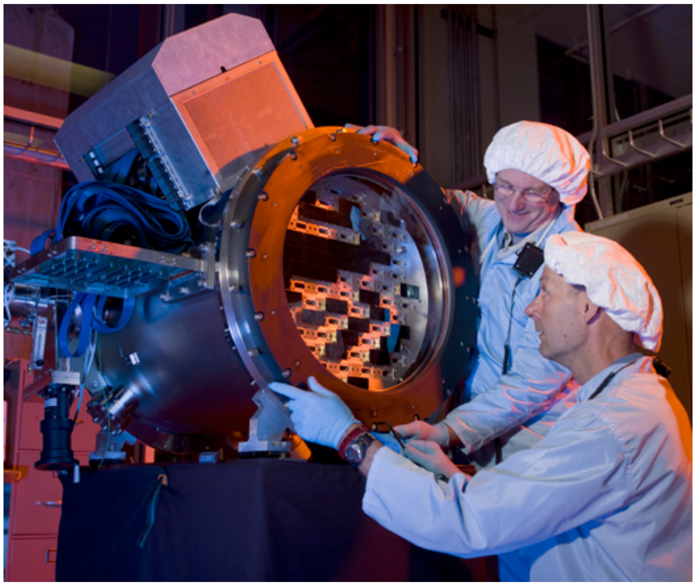

Figure 3. The prototype imager with engineering grade CCDS in May 2009.

Installation of the science grade CCDs[20] (see figure 4a) and full system testing of the imager was completed at Fermilab in August 2011. The imager was shipped[3] with the CCDs installed to CTIO in Nov. 2011, arriving on Nov. 23. By Dec. 6th the full flat field shown in Figure 4b was obtained.

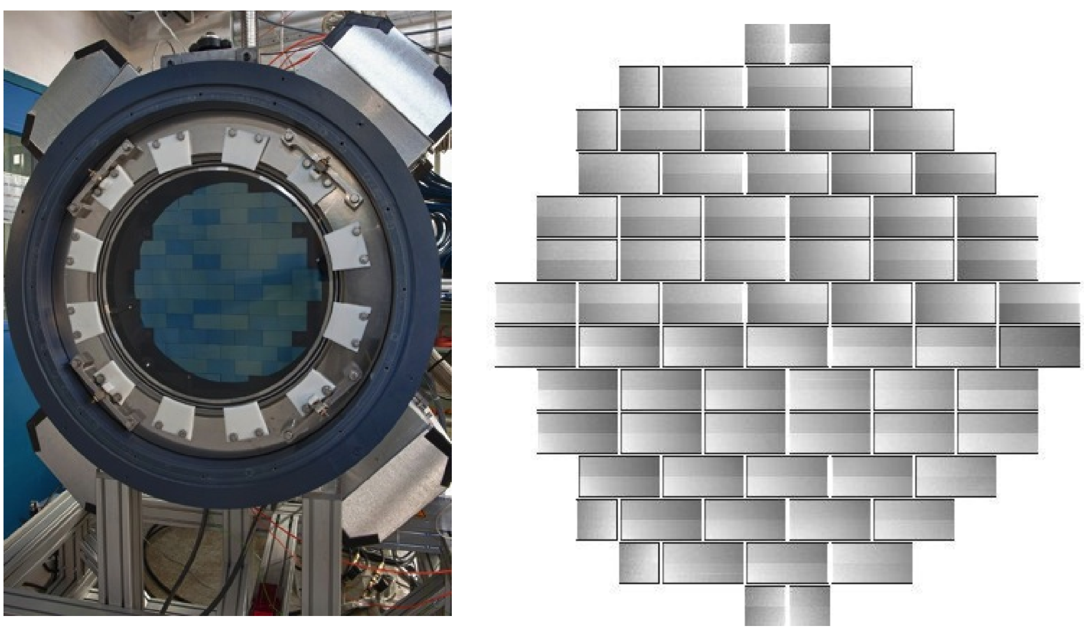

Figure 4 (left) shows the completed DECam imager at Fermilab and Figure 4 (right) shows a flat-field obtained after shipping with the imager in the Coude room of the Blanco Dome.

The DECam CCD readout system was based on the Monsoon system developed by NOAO, but modified to better match the needs of DECam. Reference [21] describes the system and lessons learned during the project. Thermally controlled crates housing the electronics are mounted to the imager and are shown in Figures 3 and 4.

Figures 5 and 6 show the readout noise and full well of the 62 DECam imaging CCDs as measured in the Coude room at CTIO in December 2011. All 62 imaging CCDs as well as the guide and focus CCDs (not shown in the plots) meet or exceed the DECam technical requirements.

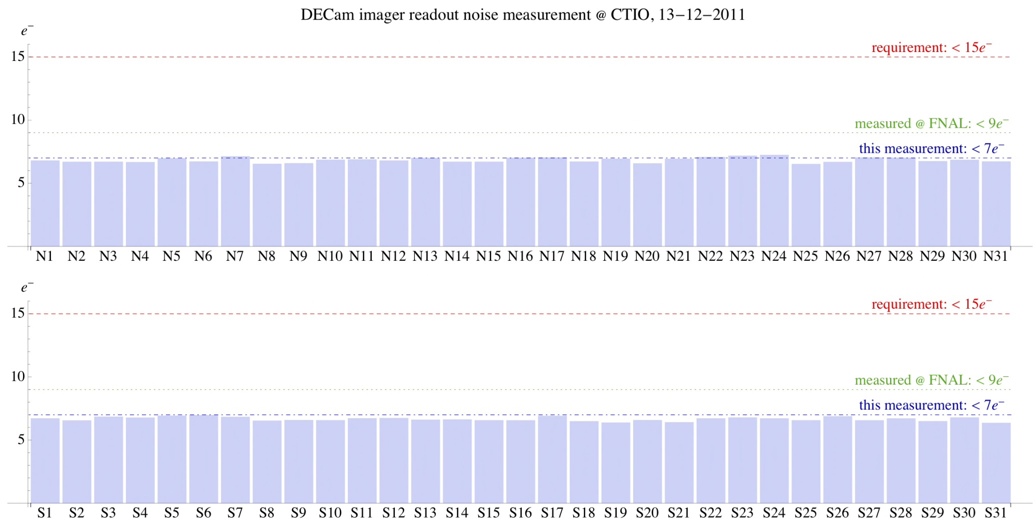

Figure 5 DECam CCD readout noise measured after arrival at CTIO in Dec. 2011

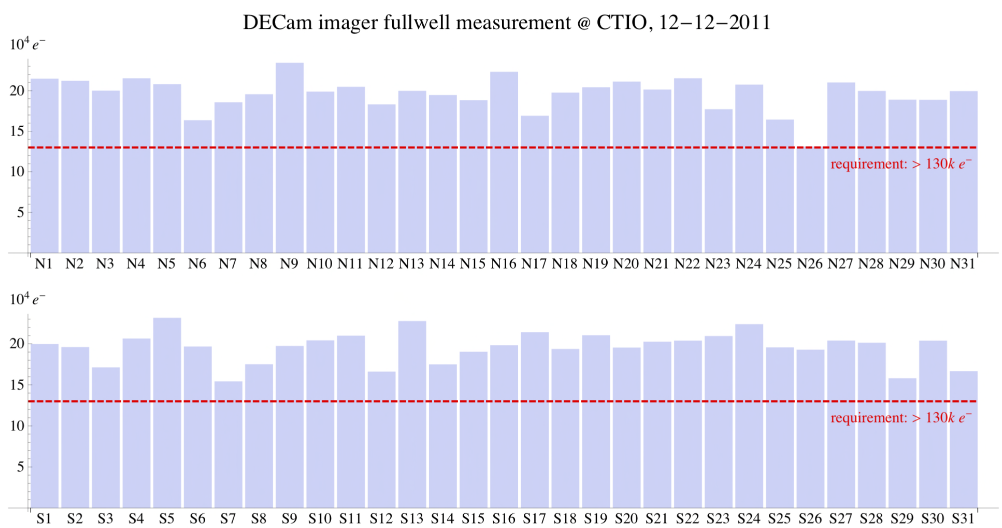

Figure 6 DECam CCD full well measurement after arrival at CTIO in Dec. 2011

The cooling of the DECam imager vessel uses a custom closed loop liquid nitrogen system[11] that pumps LN2 from a stationary tank in the dome to either the imager testing station in the Coude room, or up to the imager in the prime focus cage. A combination of vacuum jacketed hard pipe and flexible lines is used to navigate through the complex routes. The system and piping to the Coude room were installed at CTIO in July 2011 and was used in Dec. 2011 to make the plots in Figures 5 and 6. In Jan. and April 2012 we cooled down the imager for additional testing. We plan one more cool down in July 2012 just prior to installation of the imager onto the telescope. Reference [12] describes the system commissioning and performance at CTIO.

Procurement of the DECam lenses and assembly of the DECam corrector were an in-kind contribution to the DECam project, with funding primarily from the Science and Technologies Facilities Council (STFC) in the United Kingdom. A detailed description of the assembly and alignment effort is provided in reference [13]. The corrector was shipped to CTIO, along with a rotary table, alignment gear and a laser alignment system, in Dec. 2011 and was reassembled and tested in the Blanco dome in Jan. 2012. Figure 7 shows the mating of the two pieces of the DECam corrector, the top piece holds three lenses while the bottom piece holds the first and largest lens. See Reference [14] for a description of the lens fabrication.

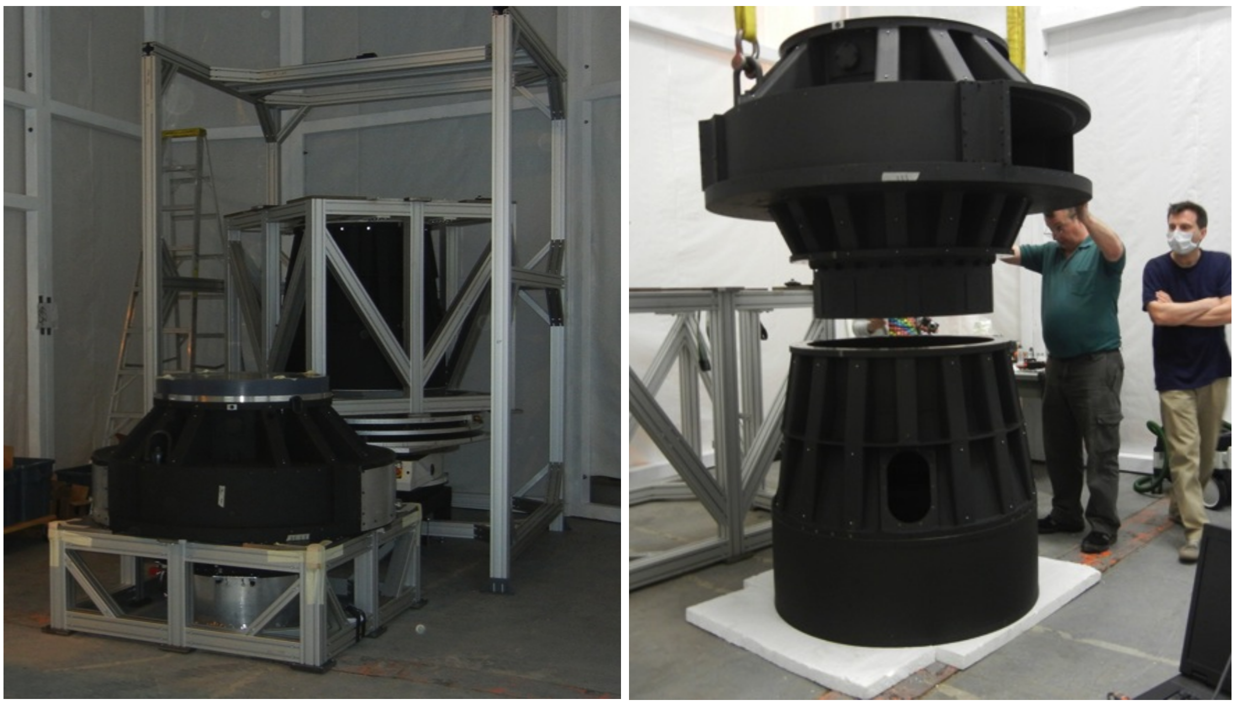

Figure 7 a) The two pieces of the corrector barrel in their shipping frames with the rotary table and optical alignment frame setup on the ground floor of the Blanco Telescope dome and b) corrector assembly.

The DECam filters presented a challenge to existing filter coating technology due to their large size (620mm diameter fused silica substrates with a clear aperture of 600mm) and tight requirements on uniformity and transmission. To allow the maximum time for development of the filters we placed the order as soon as possible within the constraints of the DECam funding profile. Although the procurement ended up taking longer than hoped, all the filters have now been delivered to CTIO and are of excellent quality, meeting or exceeding the DECam requirements. Figure 8 shows the installation of one of the filters into its filter cell in the clean room inside the Coude room in the Blanco dome.

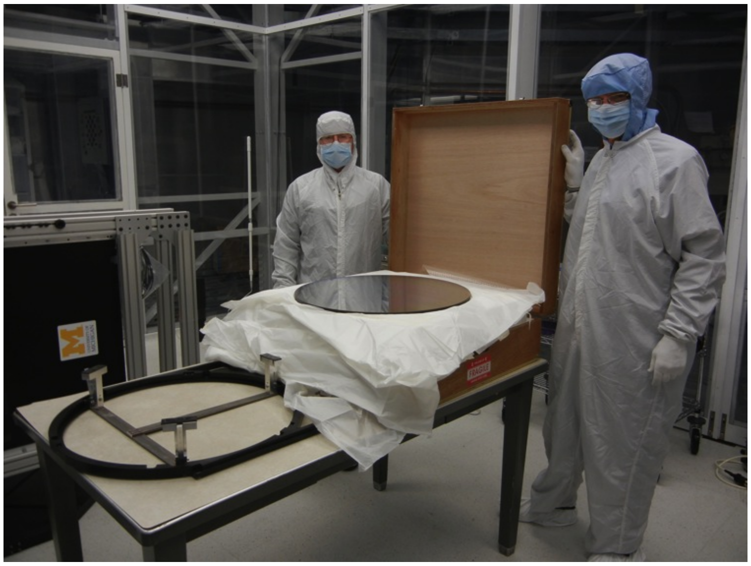

Figure 8 Jan. 2012 DECam filter ready for installation in filter cell in the clean room at CTIO.

The DECam project had a strong emphasis on integration and testing prior to delivery to CTIO in order to minimize the work required on site at the Blanco telescope. We constructed a replica of the top end of the Blanco at Fermilab (see Figure 9). This telescope simulator was used to develop and test installation procedures as well as providing a testing platform for all DECam components, except the optics, as a system and in all orientations[21].

The DECam observer interface programs have been developed and tested in a series of Mock observing runs. The first was on the telescope simulator in Feb. 2011. These were followed by two mock observing runs with the imager in the Coude room at CTIO in Jan. and April 2012. Feedback from experienced observers has been incorporated and the programs are ready for operation on the telescope[10].

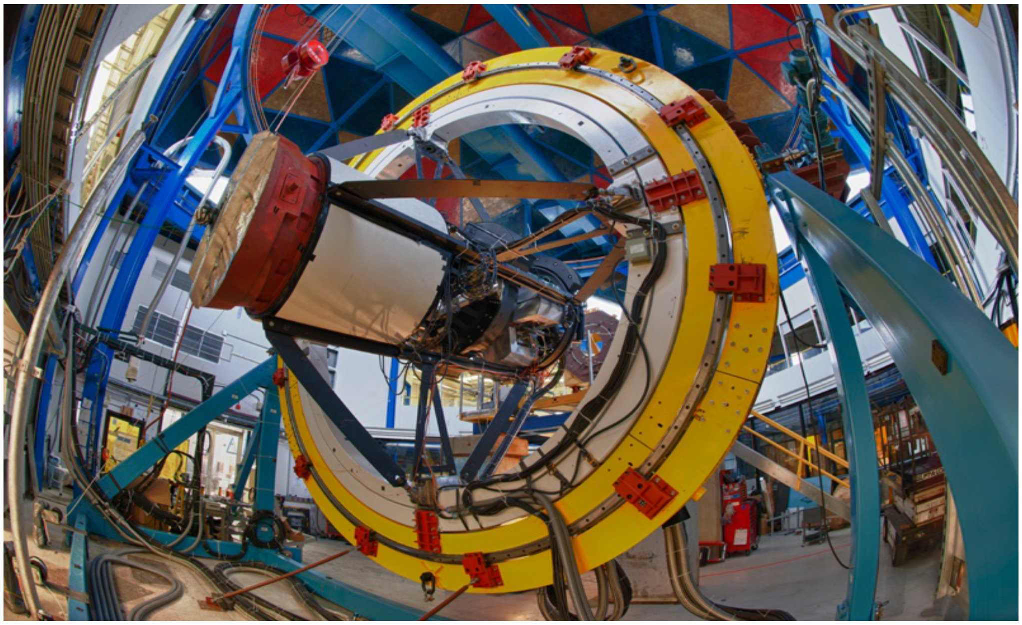

Figure 9. The telescope simulator at Fermilab with DECam installed in Feb. 2011.

3. PROJECT SCHEDULE AND FUNDING

The funding for the construction DECam came primarily from the US Department Of Energy (DOE) with important contributions from the participating Universities and non-US funding agencies. The National Science Foundation (NSF) provides funding for CTIO operations, improvements to the telescope as well as the primary funding for the DES data management system. Reviews of the progress on all fronts were generally joint DOE-NSF reviews. For the DECam project, these joint reviews satisfied the requirements of the DOE Critical Decision process. In Nov. 2005 DECam received CD-0 approval (mission need) from DOE and in October 2008 received approval to begin full construction (CD-3). Table 3.1 shows the baseline and actual dates for each of the DOE Critical decisions.

Table 3.1 DOE Critical Decisions Dates

Description	CD-2 Baseline Date	Actual
CD-0: Approve Mission Need (Ground-Based Dark Energy Experiment)	November 22, 2005	November 22, 2005
CD-1: Approve Alternative Selection and Cost Range	October 10, 2007	October 10, 2007
CD-2: Approve Performance Baseline	May 2008	April 29, 2008
CD-3a: Approve Limited Construction	June 2008	May 20, 2008
CD-3b: Approve Start of Full Construction	January 2009	October 24, 2008
CD-4: Approve Project Completion	September 2012	June 4, 2012

Delivery and post shipping testing of the DECam imager and corrector optics was completed in Jan. 2012. Delivery of the final DECam filter occurred in April 2012 and completion of the project close out documentation occurred in May. DOE office of High Energy Physics held its final review of the DECam construction project and signed the CD-4 (project complete) documentation on June 4th.

Installation of DECam on the on the Blanco telescope is the responsibility of CTIO and is not part of the DECam construction project. Installation began on Feb. 20, 2012 when CTIO shutdown the Blanco telescope. The DECam cage containing the DECam corrector optics and hexapod was installed and aligned in May 2012 and we anticipate installation of the imager to occur in August with commissioning to begin in Sept. 2012.

The final cost of the DECam instrument to DOE was $34M out of the baselined cost of $35M. Approximately $7M of in-kind contributions were provided by the DES collaborating institutions in the form of the corrector optics and corrector assembly, the production front-end electronics, the filter changer, the all-sky cloud camera as well as technical effort in many areas.

3.1 DECam project milestones

The DECam project was defined by a hierarchical set of milestones that covered both the DOE funded tasks and the contributions from the collaborating institutions. The seven Level 1 milestones were the highest level and were monitored by DOE. These are shown in Table 3.2. In addition, 60 Level 2 milestones were used by the Fermilab and DECam project management to track the progress on a finer scale. The Level 3 milestones (93) provided early indications of schedule slippages on an even finer scale. As part of the CD-2 Baseline review in 2008, all the L1, L2 and L3 milestones were baselined with roughly 12 months, 6 months and 1 month of schedule contingency respectively. A change control process was used to track and document schedule slips (contingency usage) with respect to the L1, L2 and L3 milestones. Status against these milestones was reported in monthly meetings with Fermilab management and in written monthly reports to DOE headquarters.

Table 3.2 DECam Project Level 1 Milestones

Description	CD-2 Baseline Date	Actual
All Lens Blanks Complete	August 2008	January 31, 2008
Version 2 CCD Processing and Packaging Review Complete	December 2008	June 2, 2008
CCD's from 30th Production Wafer Delivered to Fermilab	July 2009	January 26, 2009
128 CCDs Tested and Graded	March 2010	October 19, 2009
Prime Focus Cage Complete	July 2010	June 1, 2010
Camera and Telescope Simulator Tests Complete	March 2011	February 22, 2011
Acceptance Testing (prior to shipping) Complete	September 2011	August 31, 2011

The project was baselined with one year of schedule contingency and was completed with four months of schedule float. The major elements of the project which took longer than originally scheduled included: design and construction of the telescope simulator, design and procurement of the corrector barrel, polishing and coating the five lenses of the optical corrector, and procuring the five filters.

As predicted by the project reviews, the polishing and coating of the lenses was the least predictable schedule element. The length of the operation was primarily driven by the technical difficulty of achieving such demanding figure specifications on large lenses. The coating of the lenses also took longer than originally anticipated. The DECam lenses are among the largest manufactured and all of them meet the project specifications.

Production of the CCDs and CCD packages by LBNL and Fermilab was a significant technical challenge and predicted by every project review to be schedule risk. As a result, this received substantial attention very early in the project and did not take longer than scheduled. In addition it ended up producing a nearly factor of two more science grade devices than anticipated.

The mechanical construction of the barrel and telescope simulator slipped, due to shortage of engineering resources and to underestimates of the design and engineering effort required. The engineering shortage led to serializing design tasks that were parallel in the original schedule. However, this ultimately did not delay any final milestones.

The procurement of the five optical filters slipped compared to the original baseline but did not delay the beginning of installation, because filters are not required until the commissioning phase. There were multiple reasons for the slippage. These are the largest such filters ever procured and the project specifications included high transmission as well as tight uniformity. No vendor had demonstrated capability to produce such filters. The vendor's construction and commissioning of a new production facility took longer than expected and was interrupted by the events of March 2011 in northeast Japan. Testing and further refinement of processing for the g filter, the most difficult wavelength range to produce, also took longer than expected. The final filter was delivered to CTIO in April 2012. All 5 filters meet the project requirements for uniformity and most significantly exceed the project requirements for transmission.

3.2 Funding Profile

The funding tables below presents the DOE funding profile for the DECam project. OPC is the category of funding that covers the R&D, prior to construction of the components that end up in the final product. The TEC category covers the final design, engineering and equipment.

Table 3.3 DECam Project DOE Funding Table (Millions of Dollars)

	FY2006	FY2007	FY2008	FY2009	FY2010	FY2011	Total
DOE TEC			**1.65**	**9.19**	**8.61**	**4.00**	**23.45**
DOE OPC	2.28	4.76	3.95	0.71	0	0	11.70
DOE TPC	**2.28**	**4.76**	**5.60**	**9.90**	**8.61**	**4.00**	**35.15**

3.3 Staffing Profile

Figure 11 shows the actual staffing profile for the DECam project in full time equivalent (FTE) units per fiscal year. The key is defined as follows: TD is the Machine Shop time, PPD_SD is software designer, PPD_MT is mechanical technicians, PPD_ME_FEA is mechanical engineering including Finite Element Analysis, PPD_ET is electrical technicians, PPD_ENG_PHY is engineering physicists, PPD_EE is electrical engineers, PPD_Design covers design and drafting, PPD_BUD_SCHED is the project office and PPD_CD covered computing support for the DECam databases and software.

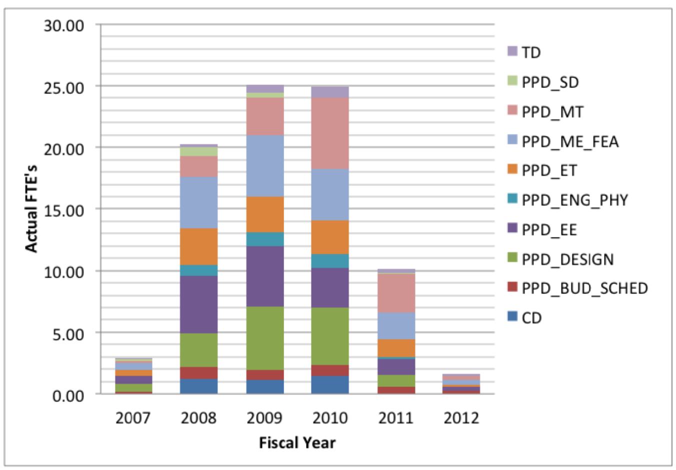

Figure 11 DECam project staffing profile

3.4 Safety Record

No accidents or injuries happened on the DECam Project. The largest challenges were constructing the telescope simulator in the confined space of Lab A at Fermilab and developing safe handling procedures for LBNL CCDs (equipment safety).

Standard Fermilab safety procedures and policies were followed, including the use of Integrated Safety Management principles, clear Job Hazard Analysis standards, and standing safety committees which conducted Operational Readiness Reviews of custom equipment and frequent safety walk-throughs/inspections of the work areas.

Equipment safety was an issue for the project, since the project was dealing with CCDs, detectors which are very sensitive to damage from electrostatic discharge (ESD). As these detectors had not been used at Fermilab before, the project had to purchase new equipment and develop new procedures for handling these detectors. The project also discovered a vulnerability to excessive exposures to light and subsequently designed and implemented controls and procedures to prevent damage during camera operation.

4. LESSONS LEARNED

The DECam Project has been completed within the specified cost and schedule baselines, and has provided an instrument and auxiliary systems that meet the technical specifications. The project recognized from the beginning that there were several areas of major technical risk, and in general these risks were well managed. There were also issues related to adequate technical staffing which became cost and schedule risks.

4.1 Management

The decision to procure bare CCDs developed by LBNL and then to package and test them on site at Fermilab rather than procuring fully packaged and tested devices from a vendor was noted early in the project as introducing both schedule and technical risk. However, the high quantum efficiency provided by the LBNL CCDs was important for DES to reach it science goals and similar devices were not available commercially at that time. An aggressive R&D program and a conservative approach to the CCD design led to successful CCD production, on time and on schedule, and with almost a factor of two in science grade spares. When the DECam project began, LBNL had produced and packaged a few CCDs that met the DECam requirements, but had also made progress improving the design with higher substrate voltage (and thus reduced charge diffusion) and with smaller pixels. We decided to concentrate the DECam R&D resources on improving the CCD production yield. This had many benefits in addition to the excellent yield of the final production runs[22]. The advantages included 1) spreading the costs over multiple years rather than requiring one large contract, due to the incremental procurement of CCDs from LBNL and the gradual development of the CCD packaging and testing facility at Fermilab, 2) production of mechanical and engineering grade CCDs early in the project that were extremely useful in developing and testing all aspects of the handling and packaging steps prior to risking the science grade devices, and 3) the technical staff gained years of experience of operating the CCDs and had sufficient time for testing and optimization of the CCD readout electronics.

A general shortage of engineering resources led to the appointment of a project engineer fairly late in the project. This shortage also led to outsourcing of some mechanical subprojects and increased the integration and coordination load on the project management. The lack of sufficient oversight and control over engineering and design resources increased the cost contingency and schedule float usage in the opto-mechanical area. After the project engineer was added, an assessment of the remaining tasks and allocation of resources was made, including shifting some effort to different tasks and adjusting others. This allowed completion of the project ahead of schedule and within the available contingency. The lesson to be learned is that adequate oversight of engineering and design resources is needed to control cost, schedule, and technical risks and could be particularly valuable early in a project.

4.2 Funding

The initiation of large contract or procurements can be limited by the project funding profile and this can introduce schedule risk. Although all the delivered products meet or exceed the DECam requirements, nearly all of them were delivered later that originally quoted by the vendors. Monthly updates from the vendors and periodic visits to the vendors were used to keep project management informed of the progress. All of the DECam systems required an increase in size and scale as well as changes, some more complicated than others, to previously delivered products. Project management addressed this risk by placing procurements early to allow as much schedule contingency as possible, within the funding profile limits of the project. This strategy was successful resulting in completion of the project within the total allowed schedule contingency. The lesson to be learned is that vendors will tend to underestimate how long it will take them to develop new products and that project funding profiles that allow early initiation of difficult procurements can reduce schedule risk.

4.3 Cost

The initial project contingency of 40 percent of the TEC cost proved sufficient. The major use of contingency was to provide more engineering and designer time for the opto-mechanical and electronic components. The CCD procurement, viewed as a major cost risk at the time of CD-2, did procure contingency CCDs, but finished with a Cost Performance Index (actual cost/budgeted cost of work performed) of 1.14 after the assignment of contingency funds due the unexpectedly high CCD yields in the final production runs.

4.4 Schedule

The production of a system of optical lenses such as the five lenses for DECam is quite difficult to schedule. The process of precision optical polishing is unavoidably lengthy and the high risk of schedule slip has no effective mitigation. The use of multiple vendors was considered but ultimately rejected, primarily due to the added complexity of coordination between the final figures of each lens. The lesson to be learned is to be sure to provide adequate schedule float on this type of procurement. This applies also, with somewhat lesser force, to the filter procurement. The DECam Project did have sufficient schedule float, but the lens and filter procurements provided a major source of schedule anxiety nonetheless.

4.5 Technical

(1) The provision of appropriate test and integration platforms is well worth the extra cost and time required. The telescope simulator was a significant source of cost and schedule contingency usage for the DECam Project, but was invaluable in providing the necessary confidence in imager, hexapod, and cooling system performance.

(2) Careful thought to the CCD procurement and packaging model was well repaid with a process that produced a set of CCDs within the cost and schedule allowance and a sufficient number of spares to mitigate operational risks.

(3) The low noise electronics and grounding in such a large system require particular attention and the detailed experience[21] from DECam is worth considering by any future project for which a low noise design will be required.

4.6 Safety and Quality

The DECam Project was completed with no injuries or accidents to personnel. Standard Fermilab safety procedures and policies were followed. In addition, safety was always a topic at the bi-weekly meetings. L2 managers and anyone working on the project were encouraged to bring up safety issues either at the meetings or at any time to project management. Devoting time to the discussion of safety every two weeks helped create an atmosphere of concern for the safety of personnel and equipment that engaged all project personnel and contributed to the excellent safety record for the project. Quality assurance on the project was provided by the attention given to well-constructed testing programs and prototyping.

4.7 Operations and Commissioning: Planning and Readiness

The DECam Project ended with delivering its equipment to CTIO and passing checkout tests on the floor of the observatory, prior to installation on the telescope. Installation and later commissioning are led by CTIO, with major participation by Fermilab and other DES collaborating institutions. The Project has learned that communication and collaboration between different institutions and agencies, with different management and safety cultures, is challenging. The work is best facilitated when the parties recognize the differences early and work together to maintain completely open and transparent communication and mutual respect.

5. CONCLUSIONS

The DECam project is complete, on budget and on schedule. Installation of DECam on the Blanco telescope is in progress and we expect the DES to start before the end of calendar 2012.

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