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A Proposal to the DES Management Committee For A plan to obtain calibration data for the DES Footprint In the DES Filter System (v10-appendices included)

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Introduction

Paragraph1: This is a proposal to the DES Management Committee to endorse the PreCam Survey and the related DES calibrations activities (the calibrations-themed CTIO-1m runs and the white dwarf follow-up program).

Paragraph2: This paragraph will have an introduction that will describe what can be accomplished solely with DECam and the cost in scheduled nights of operations.

Paragraph 3: considerations that were given to alternatives choices of telescopes and a brief statement of what this proposal contains:

Paragraph 4: The participants.
Currently, the following six institutions have expressed an interest in contributing to the costs of the PreCam Survey: Argonne National Laboratory (ANL), DES-Brazil, Fermi National Accelerator Laboratory (Fermilab), SLAC National Accelerator Laboratory (SLAC), Texas A&M, and the University of Michigan Department of Astronomy (UM-Astronomy) and Department of Physics (UM-Physics). In addition DES External Collaborator J. Allyn Smith of Austin Peay State University [APSU]) and one of his undergraduate students have expressed interest in observing for PreCam if they can obtain travel funding.

Summary of the calibrations plan costs:

1. Science Case for calibration data with other telescopes

The four approaches to Dark Energy of the DES (weak lensing, large-scale structure, galaxy clusters, and supernovae) require that the fluxes of objects in one direction of the sky be precisely related to the fluxes of other objects that are separated on the sky by more than one radian. A gradient in the flux scale across the survey area would introduce spurious power in the clustering spectrum at large angles. If the flux scale varies from place to place, some galaxy clusters will be measured to be more or less luminous than they should be. Since the mass function for rich clusters is steep, a small photometric error can result in a substantial weakening of this test for Dark Energy. As a final example, the supernova light curves depend on a flux scale that can be related precisely from one redshift to another: the flux in one band at a given redshift appears in another band at a different redshift. Thus the fluxes in the five distinct DES bands need to be related to each other with high precision.

It is also important that the DES flux scale be precisely related to that of other surveys, partly because other surveys (such as VISTA) introduce more bands (necessary for the photometric redshifts), and other surveys sample different ranges of redshift (e.g. SDSS for supernovae).

These requirements boil down to three kinds of photometric calibration tasks:

1) ensure that the flux scale in a given band is uniform across the DES footprint;

2) ensure that the relative flux scale between the five bands is precisely known;

3) place the DES flux scale onto a recognized system that allows it to be related to other surveys.

The first kind of calibration ("relative" or internal calibration) can be achieved in two methods; using both establishes consistency. The first method is to determine, for each exposure, the relative sensitivity of the camera (the relationship between incident photon flux and measured analog-to-digital units for each pixel) to a hypothetical standard star at zenith. This step requires measuring how much flux was absorbed by the atmosphere (extinction). This information is normally, but not necessarily, obtained from measurements of stars with known fluxes within the field. The second method takes advantage of the large overlaps between individual DES pointings, and the fact that only a small minority of astronomical objects are variable, to establish the relative flux scale between neighboring fields, which is then propagated across the full footprint. The 4000-square-degree footprint of the DES corresponds to about 45 DECam fields placed side-to-side in the East-West direction. Since the East and West edges of the DES footprint are observed at different times of the year, it is possible that some systematic gradient in the flux scale could escape detection. In general, extra constraints on the self-calibration are required to stiffen the transfer of the flux scale across the footprint.

The second kind of calibration (relative flux between bandpasses) can be done using sources with known spectra in the DES cataloged data. DA white dwarf stars have this property: given a high-quality spectrum, their atmospheric parameters can be determined from a model atmosphere that fits the line profiles and the continuum shape, and the same model atmosphere predicts the flux at all wavelengths. There is at least one DA white dwarf star per square degree suitable for this purpose. This calibration program is limited by the ability to identify these stars, and the ability to obtain the follow-up spectra.

Also required is accurate knowledge of the total system throughput in the five bandpasses as a function of wavelength. In principle all the information required can be obtained from laboratory measurements of the filters and other optics, the quantum efficiencies of each of the CCD's, and knowledge of the wavelength-dependent part of the atmospheric extinction. A better approach is to measure the total system throughput directly on the telescope. The system throughput functions for each band, when convolved with the known spectra of the DA white dwarf stars, gives predicted relative fluxes in each band that can be compared with the observed fluxes.

The third kind of calibration, often called "absolute calibration," requires observation of stars deemed to be fiducial flux standards that are included in external catalogs. Such observations in effect allow the DES scale to be propagated outside of the DES footprint.

How calibration works:

The two methods for performing internal calibration (the first kind in the list above) are: a) using a parameterized model for the instrument, atmosphere, and source spectrum (aka all sky photometry, the traditional method) and b) using the observed flux ratios for the overlapping observations of the survey. The current plans for calibration of the survey use a hybrid method but for clarity the two methods will be presented as if they distinct.

The first method is the traditional one in astronomy, used in cases ranging from single observations to the SDSS. It seeks for each bandpass and each night a least squares solution to a model:

$$m = m_I + m_o + kX + a(B-V) + b(B-V)X + O(X^2) \qquad (1)$$

where m is the calibrated magnitude, m_I is the instrumental magnitude $m_I = -2.5\ log(\mathrm{DN})$, DN is the measured counts in an object, m_o is the zeropoint that takes m_I of, say, a 20th mag star to $m=20$, X is the airmass, k is the extinction coefficent, $(B-V)$ is a traditional measure of the color of the object and here stands for the color measured in DES bandpasses near the bandpass of interest, and a and b are, like m_o and k, parameters to be found in the least squares fit. The model contains terms for the instrument, m_o, the atmosphere, m_o and b, and terms for the spectrum of the object of interest convolved with the instrumental system response, a and b. The primary objective of this method is to solve for the extinction coefficient k so that observations taken at a variety of airmasses X may be combined to solve for a single zeropoint, m_o. In practice parameters m_o and k are correlated: if observations are taken at a single airmass the term kX is subsumed into m_o. Also in practice it is rare to observe enough standard stars to solve for the model parameters with an accuracy, as opposed to precision, of better than 2%. The terms with $O(X^2)$ with may be appreciable at 1%. A strength of this procedure is that since it produces a model for the night any observation taken that night may be calibrated, regardless of its spatial location.

The second method is a relative newcomer to astronomy but is particularly well suited for surveys. It seeks to solve simultaneously for the relative zeropoints of all images taken in a single bandpass in the survey, again using a least squares solution, solving:

$$m = m_o + \sum_i \Delta m_i \qquad (2)$$

where m is as before, m_o is the zeropoint, here defined to be m_I on a fiducial CCD, $\Delta m_i = m_{I,i} - m_o$, $m_{I,i}$ is the instrumental magnitude on CCD i, and m_I and DN are as before. This is better written as a matrix least squares problem:

$$\mathbf{y} = \tilde{\mathbf{A}}\mathbf{x} + \mathbf{n} \qquad (3)$$

where $\boldsymbol{x}$ is the vector of (relative) zeropoints to be soved for, $\mathbf{n}$ is the noise vector, $\mathbf{y}$ is the vector of the observed $\Delta m_{ij} = m_{I,i} - m_{Ij}$ and $\mathbf{A}$ is the observation matrix connecting overlapping CCD pairs. This is to be evaluated for all images taken in a given filter. There are 1666 hexes in a single tiling, and after the first year there will be 2 tilings per filter. There are 62 CCDs in a single camera image of a hex. Thus at the end of year one $\boldsymbol{y}$ is a 1666*2*62= 206548 length vector consisting of $\sum_j \Delta m_{ij}$ for a single CCD i of a single exposure with the overlapping CCD j's from another exposure. Define overlap to be images that overlap by more than 10^6 pixels. The Δm_{ij} are made by finding the single flux ratio value offset between all the objects in the overlap.The 206548x206548 observation matrix **A** consists of ones and zeros: ones where the CCDs from the target image overlaps other images. This matrix is very sparse and mostly banded which is important for efficient computations. Both vectors $\boldsymbol{x}$ and **n** are of length 206548 and element by element refer to the same CCD and exposure. In **n** are suitable noises, say the variance of the sky noise. The vector $\boldsymbol{x}$ is to be solved for and provides the zeropoints to add to the m_I to produce a flat map. There are many ways to solve for this map (see e.g., Tegemark ApJ 487 L87, 1997). Most use as weights the covariance matrix. The standard solution in linear algebra textbooks is:

$$\mathbf{x} = (\vec{\vec{\mathbf{A}}}^T \vec{\vec{\mathbf{C}}} \vec{\vec{\mathbf{A}}})^{-1} \vec{\vec{\mathbf{A}}}^T \vec{\vec{\mathbf{C}}} \mathbf{y} \qquad (4)$$

where **C** is the covariance matrix. The primary objective of this method is to use repeated observations of stars to find the zeropoints which produce the least squares residuals for the relative photometry over the survey map. This method argues that the atmosphere provides uncertain transmission; determining the transmission is unnecessary; what is necessary is placing all of the data on the same, albeit unknown, transmission; and that the entire data set can, at a later time, be placed onto a known flux calibration with a single number.

The first method is ambitious: it aims to perform all three types of calibration (internal to a bandpass, between bandpasses, and absolute). The second method is modest: it aims only to perfom one type of calibration, the internal to a bandpass relative calibration. The first method uses survey time to make ancillary observations for calibrations. The second does not. Both use ancillary telescopes to perform the type 2 and 3 calibrations. In particular, the second method needs an overall zeropoint for the map which it can take from the white dwarf standards.

For both methods the CCDs must be made spatially flat in photon response. The flux per pixel must be corrected for pixel size variation due to both the distortion due to the optics and to the distortion due to the CCD (the glowing edges). The flux per pixel inside a CCD must be corrected for λ dependent QE variation, using a flat field. Stable imperfections in this procedure, mostly due to unaccounted for stray light, are corrected by building a star flat for each CCD and using it as a second flat field. These must all be put into place during commissioning. And for both methods a system response measured in situ is required to make use of the white dwarf standards.

How DES calibration works:

The calibration plan for the DES uses a hybrid of methods 1 and 2 where all-sky photometry of method 1 is performed when possible. The implementation is due to Glazebrook and coworkers (Glazebrook et al MNRAS 266 65, 1994; see also MacDonald et al MNRAS 352 1255, 2004). Exposures taken on nights when all-sky photometry was performed have their zeropoints in $\boldsymbol{x}$ set to 0: the all sky photometry is explicitly set to truth (despite having dispersion known to be at the ~2% level).

Thus the original DES observation plan assumed that DECam itself would make the necessary calibration exposures (standard stars used for measuring atmospheric extinction and for determining the flux scale) during photometric time on nights of survey operations. Without a grid of standard stars dense enough to be sampled by each CCD amplifier, this approach requires special pointings of DECam, taking time away that could otherwise be used to cover more area of sky.

Likewise we will need Y band standards because there are currently no standards for the Y-bands. The white dwarf program described in the next section will provide about thirty spectro-photometric standards and the PreCam survey would provide roughly 100,000 photometric standards over the full DES footprint, corresponding to more than thirty such stars per pointing.

How a small calibration telescope helps the DES:

The all-sky photometry of method 1 relies on standard stars. There is currently no catalog of stars in the southern hemisphere that is anywhere close to having the requisite set of filter bands, density of stars on the sky, photometric precision, and photometric accuracy. However, options are available to use small telescopes at CTIO to create a grid of stars that can be used to calibrate the DES footprint.

The relative photometry of method 2 relies on purely internal consistency. There are internal means to check the solution, but stellar populations change with galactic latitude (and longitude!) and galaxy populations are noisy. The robustness and accuracy of the solution increases with the number of tilings of the survey area but in years 1 and 2 the survey will have only 2 or 4 tilings available. The same option to use small telescopes at CTIO presents a means of improving the calibration in the early years of the survey and of checking the calibration in the later years of the survey.

The small telescope option requires more resources but it is ultimately superior for the following reasons:

1) Observing time that DES would otherwise use to observe standard stars is saved, allowing that much more time for science.

2) The calibration using the standard stars of method 1 is fundamentally better because of the scarcity of standard stars observations in space and time. In the original plan, standard stars are observed only at the beginning, middle, and end of each night, a coarse time sampling when the aim is 2% photometry. Since the atmosphere can change on faster time scales, this uncertainty leads to an irreducible calibration error for a given night. Further, the existing standard stars (with the exception of stripe 82) are sparsely sampled on the DECam focal plane, as opposed to having several on every CCD. Since the calibration can vary across the 2.2-degree field-of-view, this uncertainty also leads to another irreducible calibration error.

3) The calibration using the relative photometry of method 2 is fundamentally of more use to the collaboration because the calibration will be better in survey year 2 and especially year 1 when the number of tilings from the main survey can be supplemented by the small telescope data.

Furthermore, let us assume that we can develop a method of producing 1% photometry using the small telescope and that we can map a significant portion of the DES survey area using it. Then:

4) The DES calibration will be better because it can be tested against an external reference standard to check for gradients in photometry East to West or North to South.

Lastly, operating a small DECam CCD mosaic camera on a small telescope at CTIO allows the DECam CCD's, control electronics, and other parts of the data stream to be critically evaluated. The calibration effort thus serves as a DECam precursor that will allow important system components to be understood earlier and better.

1.1 The Ancillary Telescope Programs

The PreCam Survey:

The PreCam Survey will be an early survey of the bright stars in the DES survey area that will span the DES footprint. Observations will be made with a small mosaic camera of DECam CCDs and the DECam *grizY* filter system, PreCam, which will be placed on the University of Michigan Department of Astronomy Curtis-Schmidt telescope. Some of the benefits that the PreCam Survey would provide to the DES include:

- extinction standards throughout the DES footprint, permitting better nightly photometric solutions during DES operations;
- improved global calibrations, helping DES achieve its requirement of 2% global relative calibrations sooner and helping DES achieve its long-term goal of 1% global relative calibrations;
- good transformations relations between the SDSS and DES photometric systems;
- *Y*-band standard stars;

At the present time we are considering two observing strategies for the PreCam Survey. Both strategies require 100 scheduled nights on the Curtis-Schmidt.

The first strategy, the Full Footprint Strategy, will cover the full DES footprint in 1.5 passes (one pass with 50% overlaps) in each of the 5 DES filters. The Full Footprint aims to provide a 2% calibrated star catalog over the entire survey area. This strategy excels at providing standards for extinction measurements for every image of the DES survey.

The second strategy, the Rib and Keel Strategy, would cover rectilinear grid in RA and DEC inside the DES footprint. Each field in this grid would be observed 10 times in each of the 5 DES filters. The Rib and Keel aims to provide a 1% calibrated star catalog over an unfilled but spatially widespread portion of the survey area. The strategy excels at providing widespread connected regions of better than DES requirement photometry for DES calibrations.

The choice between the two strategies will be based on which best helps meet both the DES calibration requirements and goals and the DES time to completion requirements and goals.

The White Dwarf Follow-up Program:

The purpose of the white dwarf follow-up program is to define a "golden sample" of pure hydrogen atmosphere (DA) white dwarf spectrophotometric standards within the DES footprint. This golden sample will provide flux and color calibration for the DES photometry by comparing the magnitudes with model spectra.

A set of candidates for this golden sample is currently being drawn up by DES External Collaborator J. Allyn Smith of APSU and his undergraduate student Melissa Butner. In order to refine this set of candidates, photometric follow-up with the CTIO 1-m will cull variable stars and non-white dwarfs. They have already performed some imaging follow-up on the Calypso telescope at Kitt Peak National Observatory (KPNO). A related project (*u*-band Observations of the Blanco Cosmology Survey; PI: J. Allyn Smith) has received observing time at CTIO in August and December 2009. Further details can be found in the document, "Proposal for the Formation of a White Dwarf Calibrations Sub-group within the DES Calibrations Effort" (DES-doc-2505).

Once this culling has been done , spectra are required to constrain the model atmospheres that yield the desired fluxes at each wavelength. (The spectra will also confirm that each candidate is in fact a DA white dwarf.) Surface gravity information is determined from line profiles, and effective temperature information is determined partly from the continuum shape as well as from the lines. Since the lines are broad, only moderate-resolution spectra are needed, but it is important to cover a wide range of wavelengths. The signal-to-noise ratio per R = 4000 resolution element should be at least 20 to constrain the model atmosphere well. More information is given in Section 3.4 concerning the spectroscopic data.

The CTIO-1m Observations:

We propose to use the CTIO 1-m telescope, which is run by the SMARTS[1] Consortium, with PreCam in order to obtain the measurements of the transformation relations between the SDSS and the DES photometric systems, the calibration of DES *Y*-band standards and the initial follow up on white dwarf candidates as discussed in section 1.3. We may propose to use the CTIO 1-m for engineering tests of the DECam system and variety of other short- and longer-term calibration tests.

[1] Small and Moderate Aperture Research Telescope System; see http://www.astro.yale.edu/smarts/

In April 2008, October 2008, and June 2009 we made observations with the CTIO 1-m using a single DECam CCD camera, which were devoted primarily to on-sky engineering test of a 2kx2k DECam CCD and the DECam guiding strategy. Future runs will be more-and-more devoted towards calibrations.

1.2 DES Requirements

The DES photometric system is defined as the system response functions $T_b(\lambda)$ for the five bands $b=(g, r, i, z, y)$. The magnitude in a band b is thus

$$m = -2.5\log\left(\frac{F_b}{3631Jy}\right) \qquad (5)$$

where F_b is object flux convolved with the system response,

$$F_b = \int F_\nu(\lambda)\mathrm{T}_b(\lambda)d\lambda \qquad (6)$$

$F_b(\lambda)$ is the flux of an object at the top of the atmosphere, $T_b(\lambda)$ are the normalized system response functions,

$$\mathrm{T}_b(\lambda) = \frac{\lambda^{-1}S_b(\lambda)}{\int \lambda^{-1}S_b(\lambda)d\lambda} \qquad (7)$$

and $T_b(\lambda)$ are the system response functions. The system response includes the transmission of a standard atmosphere at a fiducial airmass of 1.2. The system response S_b need only be measured relative to the response at a fiducial wavelength as the absolute normalization cancels in equation (7). In the wide area survey, our need to establish our magnitude zeropoint, as in eq (5), is not as well motivated as our need to establish our relative magnitudes $m_1 - m_2 = -2.5\log(F_{b1}/F_{b2})$ inside a bandpass, and our need to establish colors $m_b - m_c = -2.5\log(F_b/F_c)$ across bandpasses.

<u>Requirements from the SRD:</u>

R-17 For each of the *g, r, i, z*, and *Y* bandpasses of the wide-area survey, the rms fluctuations in the spatially varying systematic component of the magnitude error in the final co-added catalog must be smaller than 2% over all scales smaller than 4 degrees.

R-18 The relative magnitude zeropoints between bandpasses averaged over the survey must be known to 0.5%. The magnitudes will be on the natural instrument system.

R-19 The magnitude zeropoint of the individual bandpasses and individual images, averaged over all images in the survey must be known to 0.5%. This is not a requirement on knowing the absolute energy flux.

R-20 The system response curves (CCD + filter + lenses + mirrors + atmosphere at 1.2 airmasses) must be known with sufficient precision that the calculated *grizY* magnitudes of an object with a precisely calibrated spectrum agree with the measured magnitudes to within 2%. When averaged over 100 object samples uniformly distributed over the focal plane, the residuals in magnitudes due to uncertain system response curves should be < 0.5%.

G-4 A goal of the survey is to achieve **R-17** at the enhanced level of 1% for the final co-added catalog.

How the primary survey meets the requirements:

The DES imaging survey itself can be used to meet **R-17** using the internal photometry of method 2. Calibration data taken during the survey nights can be used to perform the all-sky photometry of method 1 and so aim to achieve **R-18** and **R-19**, though with 2% precision available night to night it will have to incorporate averaging of observations to reduce the scatter and reaching 0.5% seems difficult.

A program of understanding the results of the system response measuring engine will be needed to meet requirement **R-20**.

How the ancillary surveys help the DES meet its requirements:

The PreCam survey can provide standards for the main survey distributed so as to relieve the need for the main survey to spend time observing standards not in needed survey imaging fields. The all-sky photometry of method 1 can then be used to aims at **R-18** and **R-19** with a significant savings of time. The PreCam survey would help meet **R-17** during the scientifically important first year of the survey, acting as additional tilings in the internal photometry solution. Lastly, a 1% photometric precision PreCam survey would serve as a important check on the photometry of the main survey, serving as a concrete means to test whether we are meeting **R-17**.

Requirements **R-18** and **R-19** are thought to be best achieved by the white dwarf follow-up program.

2. The PreCam Instrument[2]

The PreCam instrument will be a mosaic of DECam CCDs in science packages (same as DECam). The choice of 2Kx2K or 2Kx4K CCDs depends partly on relative yields, and partly on the optimal survey time and coverage. The table presented below assumes the camera is mounted on the University of Michigan Curtis-Schmidt telescope, with a slew time of 30s. It does not include commissioning. It illustrates that the best configuration is a set of four 2Kx4K CCDs, which is slightly better than six 2Kx2K CCDs but significantly better than the original proposal of four 2Kx2K CCDs. These numbers assume no vignetting, which depends on the optimization of the new folding flat mirror, discussed later. Each configuration gives a pixel scale of 1.4 arcsec/pixel.

Configuration	Readout Time	Area	Survey Time
Four 2Kx2K	10s	2.56 sq. deg.	88 nights
Six 2Kx2K	10s	3.84 sq. deg.	59 nights
Four 2Kx4K	20s	5.12 sq. deg.	49 nights

The current camera, electronics, and filter box is shown in Figure 1. Argonne National Lab has approved an FY2009 LDRD grant for $30K for the design and machining of the camera, and a conceptual design has begun. In addition, funding for an ANL post-doc has been secured, with the primary responsibility being the PreCam project. The HEP division at ANL has designed and constructed two previous CCD dewars, of approximately the same size as needed for PreCam. The important differences requiring redesign are the use of a custom FNAL Vacuum Interface Board that is DECam electronics compatible, and the use of LN2 instead of a cryo-tiger for CCD cooling. These are not trivial changes, but good examples of dewars with these features exist. The current conceptual design is shown in Figure 2. Construction of the camera is expected to begin in October, with testing to start at ANL in December with current SDSU III electronics, and testing with Monsoon beginning in February.

2.1.1 Electronics and cables

There are currently four air-cooled prototype DECam Monsoon crates at FNAL. The current schedule shows these being replaced by production crates starting in 3 months, and finishing in 6-9 months. One of the two crates being used for electronics testing will become available for PreCam, along with its Master Control Board, 12-Channel board, and Clock board. A new Vacuum Interface Board will be constructed by FNAL, based on 4-CCD VIBs developed and used for NOAO Monsoon. The cables from the CCD to the new custom Vacuum Interface Board will come from current spares and from the MCCD vessel as those cables are changed to production cables on the same time scale as the electronics. The cables from the VIB to the Monsoon cards will also come from current spares and the MCCD vessel as they are replaced.

[2] This section provided by Steve Kuhlmann of Argonne National Lab.

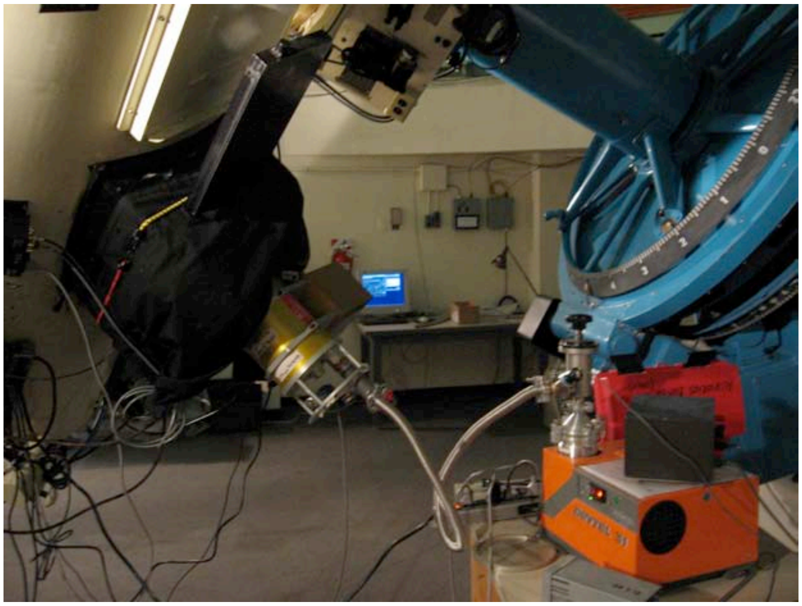

Figure 1: Current camera, filter box, and tilt/focus assembly on the Curtis-Schmidt (July 2009).

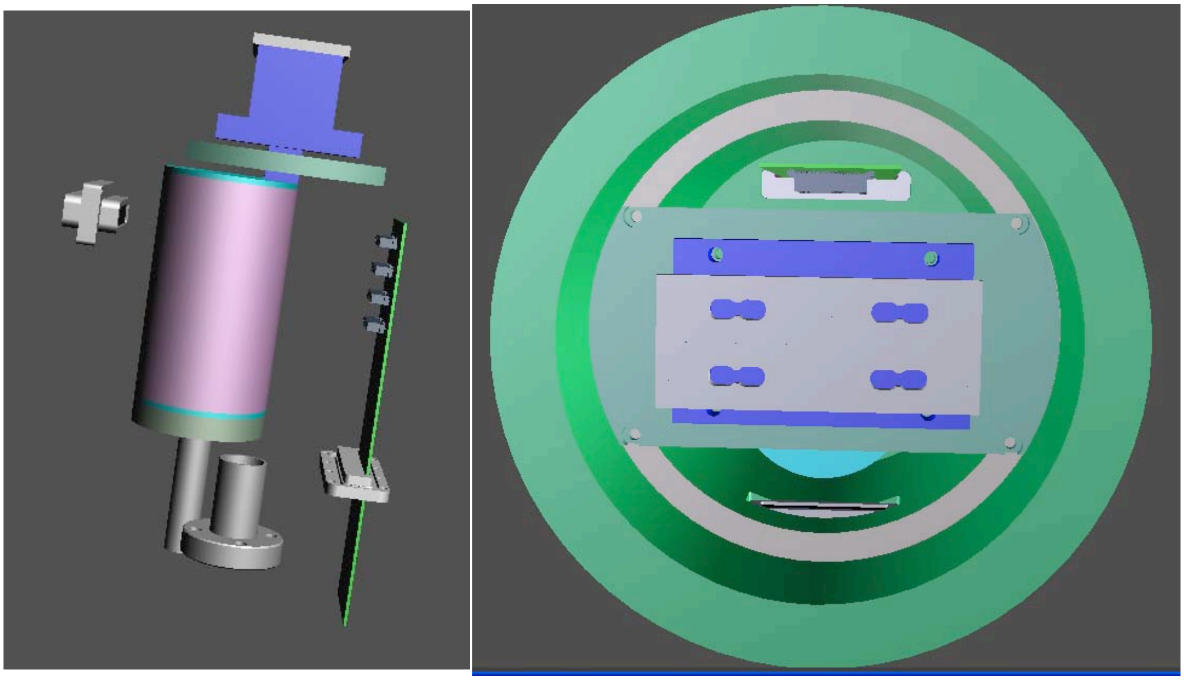

Figure 2: Current conceptual design of the PreCam camera (July 2009). The left figure shows the outer housing removed to display the LN2 chamber and Vacuum Interface Board. The right figure shows the front window removed, highlighting the focal plane for four CCDs.

2.1.2 DES Filters

Texas A&M will contribute a set of 10 cm square, DES *grizY* filters as part of its admission contribution to the DES Collaboration. The cost of the filter set has been quoted to be ~$20K. The filters will be used with both Curtis-Schmidt and the CTIO 1-m whenever PreCam is used. The cost of a 4-inch set of DES *grizY* filters has been quoted to be ~$20K. It is currently expected that Texas A&M will contribute this set of filters as part of its application to the DES Collaboration.

2.1.3 Illumination System and Flat Field Screen

Texas A&M has also offered to provide a new flat-field screen and illumination system for the Curtis-Schmidt telescope based on the flat-field screen and illumination system being designed and built for the Blanco 4m for the Dark Energy Survey. This new flat-field screen and illumination screen would serve the same purpose as a traditional dome flat system, but with improved components and a more controlled operation. As currently planned, the new system would make use of LEDs as an illumination source and a new, highly reflective Lambertian screen. Texas A&M is currently testing such a system on a 0.5m telescope on campus and will be testing in on the Las Campanas Swope 1m and Du Pont 2.5m in January 2010.

2.1.4 Data Acquisition System

The DAQ hardware will be a computer with a S-Link card that receives a fiber from the Monsoon Crate Controller, same as DES and currently used on MCCD. The first choice for DAQ software will be a minimal SISPI system, the backup will be Panview which is currently being used for tests on the CTIO 1m telescope.

2.2 Summary of PreCam Costs

Camera and Electronics Parts List	Cost	Institution
Pfeiffer TSH071E Economy Pumping Station and Gauge	$6,673	DES
Lakeshore Model 331S-T2 Cryogenic Temperature Controller	$3,174	DES
DAQ computer	$2000	DES
Monsoon Crate	in-kind	FNAL
DECam Master Control Board	in-kind	FNAL
DECam 12channel board	in-kind	FNAL
DECam Clock board	in-kind	FNAL
Vacuum Interface Board	$10K+layout	FNAL
CCDs	in-kind	FNAL
Cables from focal plane to VIB and cables from Monsoon to VIB.	in-kind	FNAL
Camera vessel and focal plane raw materials and engineering/machining	$30,000	ANL
Opto-Sigma Fused Silica 10cm Window, 15mm thickness, 045-0435	$735	ANL
Positronic Industries Hermetic Connector (XAVAC50M) for temperature control	$350	ANL
PT103 Omega RTDs same as DECam (5 including spares)	$225	ANL
HTR-25 Lakeshore cartridge heaters, same as DECam (4 including spares)	$216	ANL

3. The Telescopes

3.1 Curtis Schmidt Telescope[3]

Figure 3: The Curtis-Schmidt Telescope at CTIO. (Photo from Pat Seitzer's presentation at the July 21, 2008 DES Calibrations Workshop.)

The Curtis-Schmidt telescope, shown in Figure 3, is owned by the University of Michigan Department of Astronomy and is located on the Tololo Plateau near the Blanco 4m telescope. This *f*/3.5 telescope has a 0.91m primary mirror and a 0.61m corrector. It is 100% dedicated to the NASA program MODEST (**M**ichigan **O**rbital **DE**bris **S**urvey **T**elescope) to perform an optical study of artificial space debris in geosynchronous orbit. Pat Seitzer of University of Michigan is the Principal Investigator of this NASA program.

[3] The material in this section is based on a talk by Pat Seitzer presented at the July 21, 2008 DES Calibrations Workshop in Ann Arbor, Michigan; see DES-doc-1923-v1.

NASA funds 100% of the costs, including mountain share costs, operating costs, capital improvements, and travel.

The telescope currently has a 100 mm diameter Prontor shutter, a computer-controlled filter bolt with five 4x4-inch square filters, and computer-controlled focus. In March 2005, the telescope drives were modernized using NASA funds. This upgrade was performed by DFM engineering and resulted in dome control (opening, closing, rotation) and telescope positioning and tracking being computer controlled via a TCP/IP connection. Maximum slew rate is now tested to be 1.8deg/sec. The telescope is not currently set up for remote operations, but this may change in the future.

NASA has provided funds for a new CCD camera with a 4kx4k E2V deep-depletion CCD with 15-micron pixels. It will have a pixel scale of 1.4 arcsec/pixel and cover a field-of-view of 1.6 deg x 1.6deg. Commissioning is expected to start in late-2009

The University of Michigan has offered the period between December 2010 and January 2011 to DES in exchange for reimbursing Michigan for the costs associated with the mountaintop operations of the Curtis-Schmidt and for providing a new flat field screen and illumination system and a new folding flat as capital improvements to this telescope. Pat Seitzer, the UM PI responsible for the telescope, will also provide the expertise and oversight of operations. Details of Michigan's expectations for cost reimbursement are presented in Section 4.1, Summary of Curtis-Schmidt Observing Costs.

Summary of Capital Costs for the Curtis-Schmidt[4]

The purpose of the folding flat is to reduce vignetting at the edges of the field, Texas A&M has offered to provide a new folding flat for the Curtis-Schmidt telescope. Currently, the illumination over a 1.3deg x 1.3deg detector appears to vary by about 25% from center to corner. Increasing the size of the folding flat, however, will come at the expense of additional blockage of the main beam, resulting in lower overall throughput. A Zemax model based on the technical drawings of the Curtis-Schmidt will be performed in order to find the optimal design for the new folding flat.

The work would be done by a mechanical engineer and a technician/student at Texas A&M. Design would take about 1 month, and assembly and testing would take about 1 month. Purchase parts would be a mirror ($2K), raw materials ($0.5K), machining ($1K, probably done in the Texas A&M Physics Department machine shop), and travel ($3K), for a total estimated cost of $6.5K.

Texas A&M has also offered to provide a new flat-field screen and illumination system for the Curtis-Schmidt telescope based on the flat-field screen and illumination system being designed and built for the Blanco 4m for the Dark Energy Survey. This new flat-field screen and illumination screen would serve the same purpose as a traditional dome flat system, but with improved components and a more controlled operation. As

[4] Information based on e-mails from and discussions with Darren DePoy.

currently planned, the new system would make use of LEDs as an illumination source and a new, highly reflective Lambertian screen. Texas A&M is currently testing such a system on a 0.5m telescope on campus and will be testing in on the Las Campanas Swope 1m and Du Pont 2.5m in January 2010 (DLT: check dates with Darren).

It is planned that J.-P. Rheault of Texas A&M would design, deploy, and test the Curtis-Schmidt system in 1 month of effort. Purchased part costs would be a screen ($0.5K), illumination sources ($0.5K), control system ($0.5K), and travel ($3K), for a total estimated cost of $4.5K.

Table 1: Summary of Curtis-Schmidt Capital Costs

Type	Basis of Estimate	Amount
Folding Flat	Cost Estimate from Darren DePoy	$6.5K
Flat Field + Illumination System	Cost Estimate from Darren DePoy	$4.5K
TOTAL		**$11K**

3.2 CTIO 1m Telescope[5]

Figure 4: The CTIO-1m telescope. The dewar and electronics for a DECam 2k x2k CCD are mounted on the telescope in this photo from April 2008. (Photo credit: Douglas L. Tucker)

The Yale 1m telescope at CTIO, shown in Figure 4, is an *f*/10 Ritchey-Chretien closed-tube design built by Boller & Chivens in 1965. It has a plate scale of 19.6 arcsec/mm and an unobstructed optical-path field-of-view that is 1 degree in diameter. The telescope was originally based at the Bethany Observing Station near New Haven, Connecticut, but it was moved to CTIO in 1974. It is currently situated next to the Curtis-Schmidt telescope on the Tololo Plateau. It is one of several telescopes operated by the SMARTS consortium, which also runs the 0.9m, 1.3m, and 1.5m telescopes on Tololo. NOAO is a partner in SMARTS, and currently retains ~25% of the observing time on this suite of 4 telescopes, which general observers can apply for via the normal NOAO observing

[5] The material from this section was drawn largely from the CTIO and SMARTS webpages.

proposal process. The CTIO-1m is run in classical observing mode (as opposed to queue or service observing mode), in which the scientist is physically present at the telescope and performs the observations for his/her program him/herself.

The current facility instrument on the CTIO-1m is the Y4KCam imaging camera built by Ohio State University and deployed in July 2005. The CCD for the Y4KCam is a blue-sensitive STA 4064x4064 CCD with 15-micron (0.289 arcsec) pixels mounted in an LN_2 dewar. It has a 12-position filter wheel and uses a corrector lens (doubling as the dewar window) that provides a nearly undistorted 20x20-arcminute field of view. The filter wheel accommodates 4-in square filters, and the current installed suite of filters are a standard Kitt Peak BVR_cI_c set, an SDSS *ugriz* set, and a *U*+$CuSO_4$ filter.

The telescope is controlled using a custom Comsoft PC-TCS/DCS system that includes full automation of the dome. A new CTIO-built autoguider (with a fixed-position CCD guide camera) was installed in early 2004.

Summary of Capital Costs for the CTIO-1m

(DLT: Check with Darren.) An adapter will need to be designed and constructed in order to mount the PreCam onto the CTIO-1m telescope. Furthermore, due to differences in the focal plane curvature between the Curtis-Schmidt and the CTIO-1m, it may be necessary to provide a corrector plate

It would also be beneficial to deploy a new flat field screen and illumination system – like the one planned for the Curtis-Schmidt – for the CTIO-1m telescope. There are, however, no plans to do so at the time of this writing (8 Sep 2009). If such a system were constructed for the CTIO-1m telescope, it is likely that J.-P. Rheault of Texas A&M would also design, deploy, and test this system. Due to its similarity to the planned Curtis-Schmidt system, it should take less than 1 month of his effort. As with the planned Curtis-Schmidt system, purchased part costs would be a screen ($0.5K), illumination sources ($0.5K), control system ($0.5K), and travel ($3K), for a total estimated cost of $4.5K.

Table 2: Summary of CTIO-1m Capital Costs

Type	Basis of Estimate	Amount
PreCam Mount Adaptor + Corrector Plate	TBD	$5K
Flat Field + Illumination System	Cost Estimate from Darren DePoy	$4.5K
TOTAL		**$9.5K**

3.3 Spectroscopic Observations of DA White Dwarf Candidates

(DLT: Maybe re-name this section Magellan II or move it to Section 4 "Observations"?)

The typical DA white dwarf (Section 1.3) will have a magnitude of approximately 17.5; obtaining a large sample of these moderately faint stars with good S/N requires a large telescope. Fortunately, The University of Chicago expects to have access to the Magellan Telescopes at Las Campanas starting as early as the first semester of 2010. The Clay Telescope (Magellan II) is instrumented with the Magellan Echellette Spectrograph (MagE) that features very good throughput, especially in the blue, from 0.31 micron to 1.0 micron. It has a fixed resolution R = 4100 (for the 1-arcsecond slit), which is ideal for constraining model atmospheres for these stars. It is not yet known how much time can be obtained on this instrument each year, but since the requirements on the spectra are not difficult to satisfy, it is likely that other telescopes and instruments can be identified if necessary.

Summary of Capital Costs for the Spectroscopic Observations of DA White Dwarf Candidates

No capital costs are foreseen for this program.

4.1 The PreCam Survey

Full Footprint Plan

The goal of the Full Footprint Plan is to observe the entire 5000 sq deg of the DES footprint in single pass, with large overlaps, in *grizY* down to 1.5 mag fainter than the point-source saturation limit of a nominal 100-sec DES science exposure.

Details of the PreCam Survey exposure time calculations can be found in Table 3.[6] Consider, for instance, the PreCam exposure time calculation for *r*-band. The expected saturation limit for point-source photometry in a nominal 100-sec DES science exposure is $r \approx 16.3$ (Column 4 of Table 3). To permit a sufficiently large magnitude overlap with the unsaturated bright end of the DES point-source photometry, the PreCam Survey point-source photometry should extend 1.5 mag deeper, or to $r \approx 17.8$ at S/N=50 (Column 5). The PreCam magnitude limit for a S/N=50 point source drives the PreCam Survey exposure time (for *r*-band, this is 51 sec; Column 2), which in turn determines the PreCam Survey's point-source saturation limit ($r \approx 13.2$; Column 3) and point-source S/N=5 detection limit ($r \approx 20.7$; Column 6). Table 3 also tabulates the estimated number of useable PreCam Survey stars per square degree at the South Galactic Pole ($b^{II} = -90°$), where "useable" refers to stars with magnitudes between the nominal DES saturation limit and 1.5 mag fainter; e.g., for *r*-band, it is estimated that there are 265 stars per square degree at the Galactic Pole between r=16.3 and r=17.8. Note that, since these estimates are for the Galactic Pole, they represent lower limits to the actual number of stars per square degree expected in a typical PreCam exposure.

Table 3: Exposure Calculations for Point Sources in the Baseline PreCam Survey

Band (1)	PreCam Exposure Time [seconds] (2)	PreCam saturation limit (3)	DES saturation limit (100s exposure) (4)	PreCam mag limit (S/N=50) (5)	PreCam detection/ mag limit (S/N=5) (6)	# Stars per sq deg, DES sat to PreCam S/N=50) (7)
g	36	12.8	16.3	17.8	20.9	186
r	51	13.2	16.3	17.8	20.7	265
i	65	13.4	16.2	17.7	20.5	344
z	162	14.1	16.0	17.5	20.1	317
Y	73	11.6	14.3	15.8	18.5	150

To summarize our *r*-band exposure time example, we want PreCam to measure stars brighter than r=17.8 with a S/N ≥ 50. To do this, we need a PreCam exposure time of 51 seconds in *r*. Such an exposure time will typically provide at least 265 stars per square degree between the saturation (brightness) limit of a nominal DES science exposure (r=16.3) and the S/N=50 magnitude (faintness) limit of a PreCam r-band exposure (r=17.8).

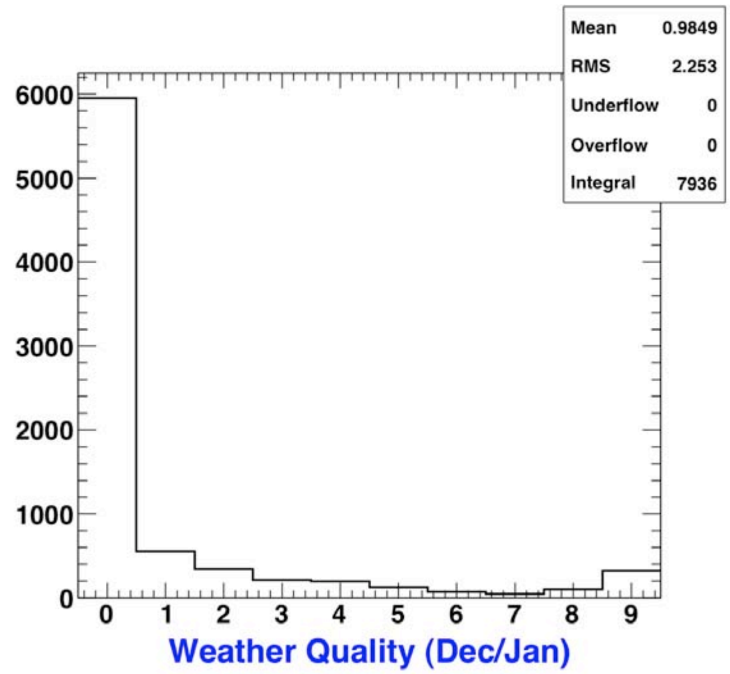

Figure 5: A plot of the sky conditions (0=clear->8=overcast; 9=unknown) for the months of December and January from CTIO's 30-year archive. According to this chart, the observer-estimated sky conditions are ~78% photometric in December and January. (Credit: S. Kuhlmann)

To estimate the total time to completion for the Full Footprint Plan, we will assume a baseline mosaic camera that is composed of 4 DECam 2k x 2k CCDs, which have a readout time of 10 sec. The total exposure time for all five filters is 387 sec; including readout time expands this number to a total of 437 sec (7.28 min) per pointing. Survey efficiency dictates that we avoid large slews; for the PreCam, most slews should be less than 5 deg. Pat Seitzer has measured the slew time of the Curtis-Schmidt to be 17 sec for a 5 deg slew; for our estimate, we conservatively assume an average slew time of 30 sec. This brings our total to 467 sec per pointing. As noted in Section 3.1 PreCam when mounted on the Curtis-Schmidt will provide a field-of-view of 2.56 sq deg; thus it would require 1953 pointings to cover the 5000 sq deg of the DES footprint. However, if a

[6] See also http://des-docdb.fnal.gov/cgi-bin/ShowDocument?docid=3091

filled PreCam footprint is to achieve good global relative calibrations (as for DES, but with a single pass), then a substantial overlap between fields is necessary. Assuming the overlap increases the number of pointings by 50%, the total number of exposures (single pass) is at least 2930. At 1 pointings per 467 sec and at 7 hours per night, the survey footprint could be covered in 54 full nights. The actual number of nights needed to be scheduled will be larger, accounting for non-optimal RA accessibility for given observing runs, calibration exposures for PreCam itself, bright-time avoidance for *g* and *r* exposures, the fact that not all exposures are science-quality, etc. These inefficiencies may amount to a factor of 1.25. Finally, not all of the scheduled nights will be photometric, which may require an additional factor of 1.3 (see Figure 5, which shows that December and January are photometric 78% of the time, based on CTIO 30-year records). To cover the footprint once will therefore realistically require at least 88 scheduled nights. (We note that we expect to have a ~10-night run in July or August 2010 for commissioning; the costs of this commissioning run are not included in the estimates in this section). In total (excluding commissioning), we expect a baseline PreCam Survey using a 2x2 mosaic of DECam 2kx2k CCDs to require about 90 scheduled nights.

We anticipate that the 90 scheduled nights necessary for completing the PreCam Survey would require two observing seasons (December 2010/January 2011 and December 2011/January 2012). If, due to poor weather, conflicts with the NASA debris program, or other issues, the schedule is reduced by half (~45 nights), we could still accomplish many of our PreCam goals by reducing the PreCam Survey coverage of the DES footprint by up to 50%. In this case, the same survey strategy (single pass, but with large field-to-field overlaps) could be pursued, but the DES footprint would be surveyed in a 50%-unfilled "cross-hatch," with grid lines crossing the DES footprint in lines of constant RA and in lines of constant Dec.

The Rib and Keel Plan

The Rib and Keel Plan is an alternative proposal for the PreCam Survey strategy that is currently under discussion. It gets it inspiration from the SDSS Apache Wheel observations, which form the basis of the recent "über-calibratration" of the SDSS (N. Padmanabhan et al. 2008, *ApJ*, 674, 1217). In the Rib and Keel Plan, the goal is to achieve 1% relative photometry in the manner of the SDSS Stripe 82 over a sparse grid within the DES footprint. An example grid is shown in Figure 6; the term "Rib and Keel" refers to the fact that the grid pattern is reminiscent of the support structure of a ship's hull. The idea is to observe a 500 sq deg cross-hatch (10% of the DES footprint) multiple times to yield a very robust grid with sub-percent calibrations. The baseline plan is to observe each grid line ~10 times, with the intersection points observed ~20 times each. The DES photometry would then be tied to this extremely well calibrated framework. This plan assumes the same exposure times (36 sec in *g*, 51 sec in *r*, 65 sec in *i*, 162 sec in *z*, and 73 sec in *Y*) and the same number of pointings (2930) as the Full Footprint Plan described above, and thus it requires the same number of scheduled nights (90).

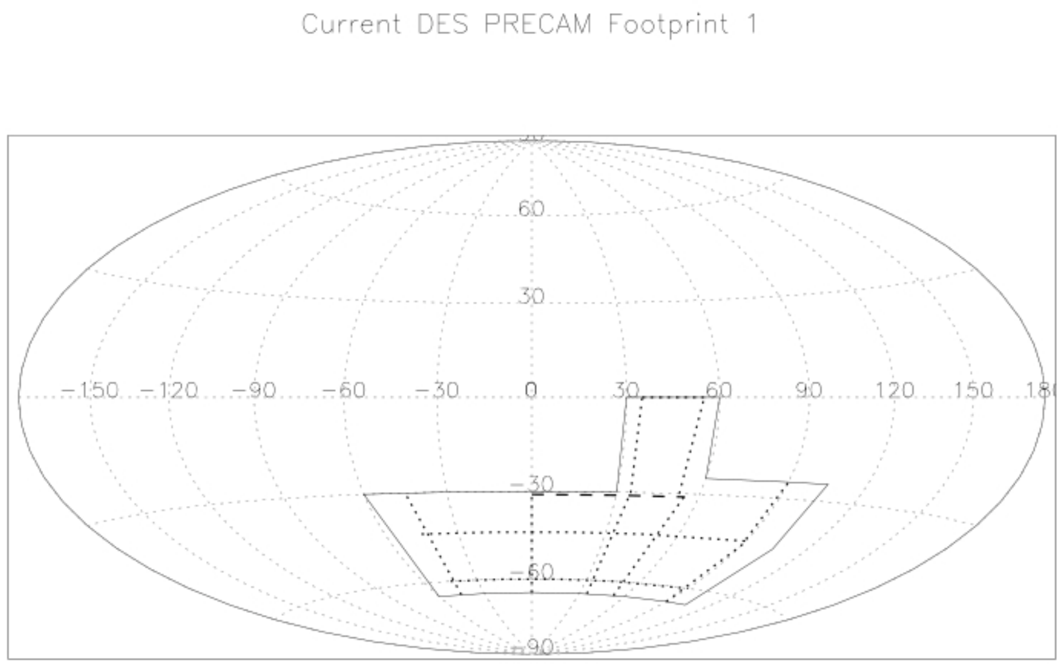

Figure 6: One option for the Rib and Keel Plan. The solid lines demark the DES footprint. The dotted and dashed lines are one option for the grids that the PreCam would observe under this strategy. (Credit: Melissa Butner)

In the case that the effective number of nights is reduced by half (~45 nights), many of the goals of the Rib and Keel Plan can still be accomplished by reducing the number of repeat observations from ~10 to ~5. With ~10 repeat observations, it is estimated that the grid can robustly achieve sub-percent relative calibrations; with just ~5 repeat observations, the grid might only achieve 1% relative calibrations.

More details of the Rib and Keel Plan can be found at this URL: http://des-docdb.fnal.gov/cgi-bin/ShowDocument?docid=3404 .

Summary of Curtis-Schmidt Observing Costs

The operating costs of the PreCam Survey consists of two components; the costs of operating the Curtis Schmidt telescope incurred by the University of Michigan, the mountaintop share costs, hardware maintenance costs, and the travel costs incurred by the DES members and participants when the they travel to CTIO to observe. Table 4 summarizes these costs. The mountaintop share costs and the hardware maintenance costs are based on actual costs incurred by the NASA debris program.

In the current funding plan, each institution would pay the travel costs of its own observers and would contribute to the Curtis-Schmidt mountaintop operations costs. Currently, there are five institutions intending to participate in the observing (ANL, Fermilab, SLAC, Texas A&M, and UM-Physics); so the average share of the costs associated with travel + mountaintop operations to each of these five institutions would be ~ ($102.5K)/5 = $20.5K. (DES-Brazil also plans to send an observer, but will also be fulfilling the critical role of processing the PreCam data and dealing with costs associated with that role).

(DLT: Pat is also asking for $29K, which includes 1-month of salary, one trip to Chile (to help with the engineering/commissioning run), and a few minor items. Should those costs go here, or elsewhere?)

Table 4: Summary of Curtis-Schmidt Observing Costs for 90 Scheduled Nights

Type	Basis of Estimate	Amount
Mountain Share Costs	NASA figure from P. Seitzer	$26K*
Maintenance Costs	NASA figure from P. Seitzer ($150/night)	$13.5K
Travel Costs	Travelocity+CTIO webpage (~3 observers each half-month, $3.5K/15-night-trip)	$63K
TOTAL		**$102.5K**

*This number might double for a two-year PreCam Survey

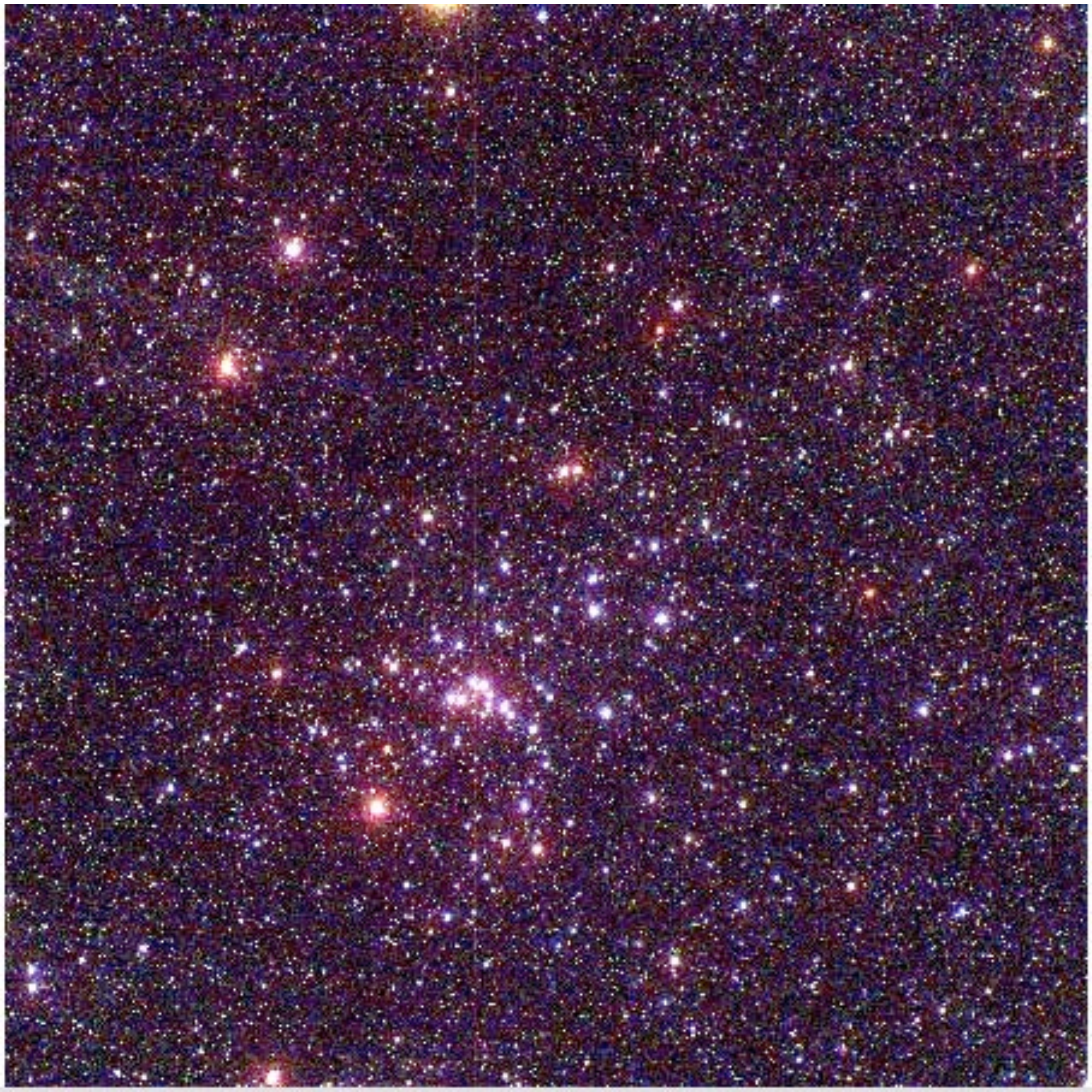

Figure 7: The open star cluster M48 on the University of Michigan Department of Astronomy's Curtis-Schmidt telescope and Tek2k#5 camera. With the Tek2k#5 camera, the field-of-view is 1.3 deg (at 2.3 arcsec/pixel). This color image was constructed from 30 second exposures in SDSS *g*, *r*, *i*, taken on the night of 6 March 2000. Analysis by Rider et al. (2004) of these data (in cross-comparison with data taken with the USNO-1m telescope at Flagstaff Station, Arizona and with the SDSS Photometric Telescope) indicates that the Curtis-Schmidt telescope is easily capable of achieving 2% photometry. (Photo Credit: J. Allyn Smith)

This is an orphan figure, but it is too useful to discard. Need to find a place for it.

4.2 CTIO-1m Observing Runs

When not in use on the Curtis-Schmidt, the PreCam camera can be mounted for DES observing runs on the CTIO-1m telescope. Observations will focus on the initial photometric calibrations of the DES *grizY* filter system, including initial measurement of the transformation relations between the SDSS *ugriz* and *u'g'r'i'z'* photometric systems (necessary, since the DES photometric standard stars will come primarily from the SDSS); initial calibration of DES *Y*-band standards (essential, since there are few *Y*-band standards in any photometry system, and none currently in the DES *Y*-band); and imaging follow-up of candidate DA White Dwarfs (see next sub-section). The CTIO-1m runs also permit a variety of short- and longer-term tests (e.g., tests of image persistence from saturated stars, DES *grizY* sky brightness measurements under a variety of lunar phases and sky conditions, etc.). Furthermore, observations with the PreCam on the CTIO-1m would be complementary to those on the Curtis-Schmidt, as the PreCam on the CTIO-1m would have a much finer pixel scale (0.3 arcsec/pixel compared to 1.4 arcsec/pixel), albeit at the expense of a smaller field-of-view (20 arcmin on a side as opposed to 1.6 deg on a side), and would thus provide a good cross-check on the Curtis-Schmidt data.

The CTIO-1m runs become even more important for DES photometric calibrations if the Curtis-Schmidt observations are substantially curtailed by weather or by scheduling. In this case, the CTIO-1m runs could completely take over the measurement of SDSS→DES transformation equations and the establishment of a set of DES *Y*-band standards before the start of the DES operations.

Observations for DES calibrations with the CTIO-1m are already in progress. Darren DePoy (DECam Project Scientist), Ricardo Schmidt (CTIO), and Marco Bonati (CTIO) have already deployed an imaging camera consisting of a single DECam 2k x 2k CCD for testing on the SMARTS-1m at CTIO. The purpose of this single-chip camera is for initial on-sky testing and calibration of a DECam CCD with DES filters. So far, we have had 3 observing runs, each one week long, scheduled on this instrument: one in April 2008, one in October 2008, and one in June 2009:

- http://www.noao.edu/perl/abstract?2008A-0137 (April 2008 Run)
- http://www.noao.edu/perl/abstract?2008B-0057 (October 2008 Run)
- http://www.noao.edu/perl/abstract?2009A-0154 (June 2009 Run)

Although DES filters are yet unavailable for this instrument, we have been able to use other, similar filter sets (e.g., SDSS and Thuan-Gunn filters) for initial engineering tests and site characterization. Figure 8 shows a *gri* composite color image of one of the DECam first light images taken during the April 2008 CTIO-1m observing run.
We intend to continue to request one-week observing runs on this instrument each observing semester (half-year) for the foreseeable future (at least through the end of FY2011). Previous runs have been dedicated primarily to the engineering tests, but future runs will focus more on photometric calibrations.

The CTIO-1m DECam 2kx2k observing runs are providing the first real on-sky tests of a DECam CCD.

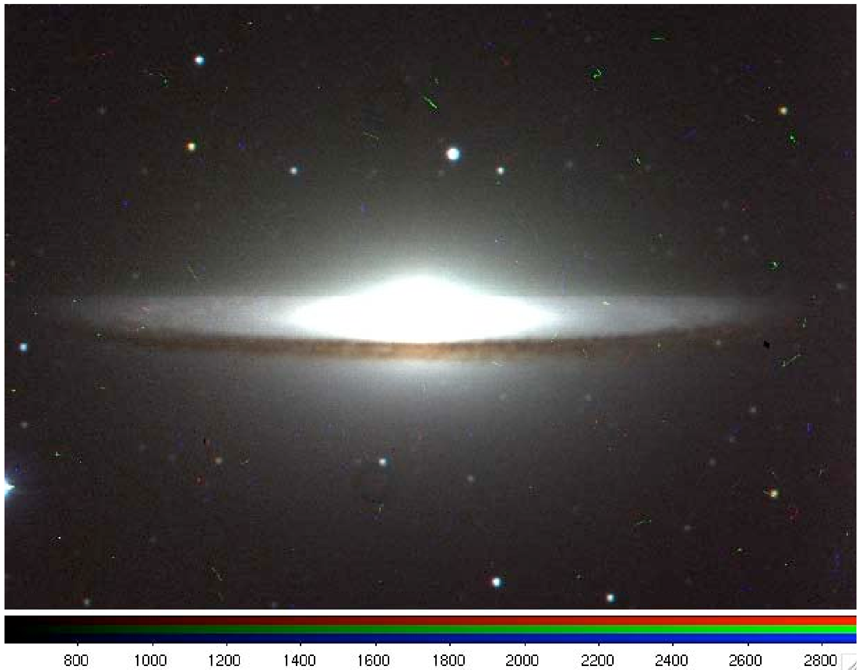

Figure 8: A *gri* image of M104 ("The Sombrero Galaxy") from some of the first on-sky tests of a DECam CCD from the April 2008 CTIO-1m run.

Summary of the CTIO 1-m Observing Costs

The costs are for the travel to the observing runs and the costs incurred by the SMARTS Collaboration for DES Calibrations observations. Assuming two 7-night observing runs per year over at least the next 2 years, two observers from the DES Calibrations Effort per observing run, and $3K/observer/run, it is estimated that the travel costs would be ~$24K over the FY2010 and FY2011. The current list of institutions that have expressed an interest in these calibrations-themed CTIO-1m runs are Fermilab, Texas A&M, Argonne, and SLAC. J. Allyn Smith of APSU has also expressed interest in helping out with this program. It is anticipated that, in general, each institution would fund its own observers, although there might occasionally be an observer from a smaller institution without adequate travel funding.

Travel and accommodations for a typical week-long CTIO observing cost about $3K per observer from the US. Assuming one weeklong observing run per semester over at least the next 4 observing semesters, two observers from the DES Calibrations Effort per observing run, it is estimated that the travel costs would be ~$24K over the FY2010 and FY2011. It is anticipated that, in general, each institution would fund its own observers, although there might occasionally be an observer from a smaller institution (e.g., APSU) without adequate travel funding.

We also note that, if we need to buy into SMARTS for some of this time, the typical buy-in cost is ~$1.2K/night for nightly operations. If this turns out to be necessary, these SMARTS operating costs would amount to $33.6K for two 7-night observing runs per year over the next 2 years.

Costs for a new flat field screen and illumination system are described in Section 3.2; it is possible that the contribution of such a system could help offset buy-in costs to SMARTS.

Table 5: Summary of CTIO-1m Observing Costs for 4 Observing Runs

Type	Basis of Estimate	Amount
Travel Costs	Travelocity+CTIO webpage (2 observers for each week-long observing run, at $3K/trip)	$24K
SMARTS buy-in for operating Cost	Previous discussions with Charles Bailyn regarding buying in to SMARTS	$33.6K
TOTAL		**$57.6K**

4.3 Follow-up of Candidate White Dwarf Standards

(DLT: This section still needs some more melding with Rich's section of white dwarf follow-up.)

A series of short (4-night) observing runs will be needed for photometric and spectroscopic follow-up of candidate pure hydrogen atmosphere ("DA") white dwarfs. These follow-up runs will be used for creating a "golden sample" of white dwarf spectrophotometric standards in and near the DES footprint. The photometric follow-up will be used for culling the sample; the spectroscopic follow-up will be used both for culling the sample and for measuring stellar surface temperatures and surface gravities via spectroscopic line profiles (necessary for fitting the observed white dwarf spectrum to white dwarf atmosphere models).

Much of the imaging follow-up (primarily to ensure that the candidate white dwarfs are not variable) can be performed on the CTIO-1m as described in the previous sub-section, although some of the imaging for the fainter white dwarf candidates may need to be done on the Blanco 4m telescope, especially for u-band observations. Spectroscopy will also need to be done on larger telescopes, such as the Magellan II at Las Campanas, as described in Section 3.3 above).

Summary of Observing Costs: The costs of this program will be driven in large part by travel to observing runs. It is anticipated that there will be typically two 4-night observing runs per year over the next 2+ years, probably located at CTIO (using the Blanco-4m or one of the smaller telescopes at CTIO that are run by the SMARTS consortium), as well as on the Magellan II at Las Campanas, and that these observing runs will typically have two observers per run. At $2.5K/run/observer, it is expected that the total direct costs for travel over the next 2 years will be $20K.. Institutions that have expressed interest in participating these runs are APSU, Fermilab, SLAC, and University of Chicago. It is noted that the primary observers for this program (the head of the White Dwarf Calibrations Effort and his student) are from APSU and are currently seeking travel funding.

Table 6: Summary of White Dwarf Follow-up Observing Costs for 2010 and 2011

Type	Basis of Estimate	Amount
Travel Costs	Travelocity+CTIO webpage (2 observers for each week-long observing run, at $2.5K/trip)	$20K
TOTAL		**$20K**

5. Image Processing and connection to DESDM

The pixel scale of PreCam is 1.43 arcsec/pixel on the Curtis-Schmidt.
The PreCam Survey covers the 5000 sq deg of the DES footprint 1.5x in five filters.
Also assume that there is a 20% overhead for calibration and standard star observations.
A DECam image has 4 bytes/pixel.
1.2 x 5 filters x 1.5 tilings x (5000 sq deg * 3600 arcsec/deg x 3600 arcsec/deg x (1 pixel / 1.43x1.43 sq arcsec) x 4 bytes/pixel / (1024 bytes/kilobyte x 1024 kbytes/MB x 1024 MB/GB x 1024TB/GB) = 1.04 Terabytes.

We need at least twice that amount to hold both the raw and processed images:
2x1.04 Terabytes = 2.08 Terabytes.

Assume we actually need twice that amount for everything: 2 x 2.08 TB ~ 4 TB.

6. Management Plan

6.1 PreCam Survey

The Partner Institutions

Currently, the following six institutions have expressed an interest in being major partners in the PreCam Survey: Argonne National Laboratory (ANL), DES-Brazil, Fermi National Accelerator Laboratory (Fermilab), SLAC National Accelerator Laboratory (SLAC), Texas A&M, and the University of Michigan Department of Astronomy (UM-Astronomy) and Department of Physics (UM-Physics). The lead of the White Dwarf Calibrations Sub-group (DES External Collaborator J. Allyn Smith of Austin Peay State University [APSU]) and one of his undergraduate students have also expressed interest in observing for PreCam, perhaps for up to a month, but they have no travel funding.

Management Responsibilities

6.1 PreCam Design and Construction

Steve Kuhlman will lead the systems design and the constriction efforts and will the official point of contact with Pat Seitzer on the installation of PreCam on the Curtis Schmidt. Argonne will be the lead institution and will be responsible for the property accountability of PreCam. Fermilab will arrange the shipment of PreCam to Chile with AURA/NOAO.

6.2 PreCam Survey

6.3 CTIO-1m Observing Runs

The Partner Institutions

The current list of institutions that have expressed an interest in these calibrations-themed CTIO-1m runs are Fermilab, Texas A&M, Argonne, and SLAC. J. Allyn Smith of APSU has also expressed interest in helping out with this program.

Management Responsibilities

Darren DePoy leads this effort.

6.4 Follow-up of Candidate White Dwarf Standards

The Partner Institutions

The institutions that have expressed interest in participating in these runs are APSU, Fermilab, and SLAC.

Management Responsibilities

The white dwarf follow up observing program will be led by DES External Collaborator J. Allyn Smith of APSU.

Appendices

Appendix A: Other benefits

- a stellar catalog for the Quick Reduce Pipeline in the first year or two of DES operations;
- intensive, real on-sky tests of a DECam CCD mosaic camera ahead of DES operations;
- a realistic rehearsal for probably DES observers ahead of DES operations; and
- science data in the DES filters for bright objects (e.g., red giant stars in Milky Way star clusters or supernovae in nearby galaxies within the PreCam footprint) that would otherwise saturate (and thus be unusable) in the standard DES science exposures.

Appendix B WBS, Cost and Schedule

A spreadsheet containing an estimate of the total costs and labor for the baseline PreCam Survey is shown on the next two pages (Figure 13). The costs are all direct costs. No overheads are included. A copy of this spreadsheet in Excel format can be found at this URL:
http://home.fnal.gov/~dtucker/DESCalibWBS/PreCamWBS/PreCam-BOE.xls

The total estimated M&S direct costs of the baseline PreCam Survey is $152K. Note that a significant fraction – $66.5K – is due to travel associated with the observing runs (WBS 2.2.1.1 and 2.2.1.2). The next highest budget component of the M&S costs is the Curtis-Schmidt operating costs of $26K. (The Curtis-Schmidt is used ~200 nights per year, and the yearly operating costs are ~$52K; half that value is $26K.) Depending on negotiations for the use of the Curtis-Schmidt, there may be ~$45K in additional costs not currently included in the cost spreadsheet. These may be partially offset by the fact that the PreCam Survey should be able to use the same set of 4-in DES *grizY* filters that Texas A&M is planning to purchase for the CTIO-1m, which would save ~$20K from the PreCam Survey budget.

Figure 13: Printout of PreCam-BOE.xls.

Figure 13 (cont'd): Printout of PreCam-BOE.xls.

Discarded material

Other DES Calibration Activities
There are two other major DES calibration activities that are not in the scope of the three formal DES Projects (DECam, DESDM and CFIP and are therefore currently unfunded except on an ad-hoc basis. These are the calibration-themed CTIO-1m observing runs, and the white dwarf follow-up program. The costs associated with these activities are almost entirely due to travel associated with the observing runs.

Comments and Unfinished To Do Items

- Pat Seitzer suggests that hiring two local observers on a 7-night on/7-night off schedule might be more cost-effective than having visiting observers from the US, elsewhere. Other advantage: perhaps a more homogeneous data set using a trained duo of observers. Disadvantage: loses benefit to DES of training future DES observers. Discuss on September 9.
- Clarify text concerning the benefits of PreCam in global relative calibrations of first-year DES data. Rich Kron
- Additional detail for description of PreCam rib and keel: unfilled grid along lines of constant RA/constant DEC over the DES footprint (filling factor of 50%-90%) plus a few special pointings to hit star clusters within the DES footprint that would otherwise be missed (unfilled grid still very useful for global relative calibrations). Douglas? -- Done
- Need to update details of the baseline PreCam Survey time to completion. Steve Kuhlman needs to select the camera layout first.
- *From Rich Kron (8 June 2008):* It would be good to have two additional sections added to 3.1 and 3.2. that would address what is needed to mount PreCam onto each telescope. The idea is to address the question of whether this task is straightforward or whether a significant amount of work is needed. The idea is to present a comprehensive picture for the full project in the text, not just the WBS.

From Rich Kron (8 June 2008): The claim that 80% of the nights are photometric seems high to me. Indeed that is what the (old) CTIO users manual says, but I have checked a bunch of other sources (La Silla, Las Campanas), and something like 60 - 65% seems more realistic. What is the source of weather data that DES itself is assuming? Steve