Preface

Emphasis on calibrating single-epoch observations.

 * Coadd calibrations require good single-epoch calibrations

 * Much of additional refinement to coadd calibrations is
   based on averaging over calibration quantities from
   single-epoch measurements.

I. Overview/Background

   A. Instrumental Calibrations

      1. bias frames

      2. dark frames

      3. dome flats

      4. system response measurements
         (a) illuminated flat screen method (CCDs+filter+optics combined)
         (b) lab-based measurements of individual components (cross-check)

      5. star flats

      6. linearity curves

      7. gain, readnoise, saturation limit measurements
         (a) lab tests
         (b) see also linearity curves.

      8. "victim" exposures (for cross-talk measurements)

      9. bad pixel maps

         (a) from dome flats

         (b) from lab tests

     10. scattered light tests

         (a) bright stars, planets

         (b) moon

11. fringe frames (as necessary)

    (a) produced from z- and Y-band science images

    (b) no special observations required

12. shutter timing maps (short/long exposure sequences)

B. Photometric Monitoring

1. photometricity flag produced by all-sky thermal-IR cloud camera

2. Other?
   a. Bore-sited thermal-IR camera?
   b. z-band H2O absorption feature monitor?

C. Nightly Absolute Calibration

1. Standard star observations

   (a) SDSS Stripe 82

   (b) Smith et al. Southern u'g'r'i'z' Standards

   (c) Extinction standards from PreCam

2. Photometric Equations:

   g = -2.5log10(counts/sec) + a_g + b_g*((g-r) - (g-r)_0) + k_g*X

   r = -2.5log10(counts/sec) + a_r + b_r*((g-r) - (g-r)_0) + k_r*X

   i = -2.5log10(counts/sec) + a_i + b_i*((i-z) - (i-z)_0) + k_i*X

   z = -2.5log10(counts/sec) + a_z + b_z*((i-z) - (i-z)_0) + k_z*X

   Y = -2.5log10(counts/sec) + a_Y + b_Y*((z-Y) - (z-Y)_0) + k_Y*X

   where g,r,i,z,Y = the calibrated mags
      (g-r),(i-z),(z-Y) = the calibrated colors
      (g-r)_0,(i-z)_0,(z-Y)_0 = fiducial (reference) colors

a = photometric zeropoint
b = instrumental color term coefficient
k = first-order extinction
X = airmass

Colors used in color terms based on general DES observing strategy:
g and r observed together during dark time.
i, z, Y generally observed during bright time.

3. During the Data Challenges, the b terms are fit nightly, although one can fix them to a constant value (one per CCD).

4. TBD: What CCD or set of CCDs defines the DES "natural" (b=0) system? In case of time-dependent instrumental color terms, we may wish to choose a given CCD or set of CCDs on a given date (e.g., the start of the survey) as defining the DES "natural" system.

D. Intermediate Calibration

1. applying the results of the photometric equation to the data

E. Global Relative Calibration

1. Zeropoint offsets

2. Refined Star Flats

F. Global Absolute Calibration

1. White dwarfs + total system response

G. Final Calibration

1. Applying global absolute calibration to the data

II. Data Collection

A. Before Commissioning

1. Creation of a golden sample of DA White Dwarf spectrophotometric standards
   - CTIO-1m, Curtis-Schmidt, spectroscopic follow-up, HST(?)

2. Initial SDSS<->DES transformation equations
   - CTIO-1m, Curtis-Schmidt

3. DES z- and Y-band standards
   - CTIO-1m, Curtis-Schmidt

4. New standards need to be added to the standard_stars table in the DESDM database.

5. The DESDM photometric standards module need to be updated for the transformation equations (or just modify all the SDSS-based standards in the standard_stars table with the tranformation equations)

6. A new software module -- the Global *Absolute* Calibrations Module (GACM) needs to be written to make use of the DA White Dwarf spectrophotometric standards (and the DECam system response). Currently, one of J A Smith's undergraduates at APSU is looking into this.

B. During Commissioning

1. Daily

a. Afternoon

(i) 10 bias frames

(ii) 30 dark frames, composed of:
(a) 10 science-length exposures (typically 100 sec each)
(b) 10 faint-standards-length exposures (typically 30sec each)
(c) 10 bright-standards-length exposures (typically 5sec each)

(iii) 50 dome flat frames, composed of:
(a) 10 dome flats in g
(b) 10 dome flats in r
(c) 10 dome flats in i
(d) 10 dome flats in z

(e) 10 dome flats in Y

b. Evening Twilight

(i) 3 standard star fields between 12deg and 18deg twilight
(a) one at low airmass (X=1.0-1.2)
(b) one at high airmass (X=1.8-2.0)
(c) one at medium airmass (X=1.4-1.6)
(d) at least one in SDSS Stripe 82 for full coverage of DECam focal plane (all CCDs)
(e) with PreCam, we can reduce this set of standard star field observations to maybe just the low- and high-airmass observations

c. Night

(i) 3 standard star fields around night's midpoint (~1AM local time)
(a) one at low airmass (X=1.0-1.2)
(b) one at high airmass (X=1.8-2.0)
(c) one at medium airmass (X=1.4-1.6)
(d) at least one in SDSS Stripe 82 for full coverage of DECam focal plane (all CCDs)
(e) with PreCam, we can eliminate this set of standard star field observations

d. Morning Twilight

(i) 3 standard star fields between 18deg and 12deg twilight
(a) one at low airmass (X=1.0-1.2)
(b) one at high airmass (X=1.8-2.0)
(c) one at medium airmass (X=1.4-1.6)
(d) at least one in SDSS Stripe 82 for full coverage of DECam focal plane (all CCDs)
(e) with PreCam, we can reduce this set of standard star field observations to maybe just the low- and high-airmass observations

2. Weekly

a. Illuminated Flat Field System Response Measurements.

b. Linearity Tests

(i) Dome flat:

10sec-1sec-10sec-2sec-10sec-4sec-10sec-8sec-10sec-16sec-10sec-32sec-10sec-64sec-10sec-128sec-10sec-256sec-10sec-512sec-10sec-1024sec-10sec-...(until saturation)

(ii) A field in SDSS Stripe 82 under photometric conditions
(a) a 40-sec exposure in r should saturate at about r=15 under conditions of good seeing

c. Astrometric Tests

(i) Observe a rich open cluster or a globular cluster in each filter (probably will require multiple pointings)

d. Star Flats

(i) Observe a field in Stripe 82 under photometric conditions in all 5 DES filters

(ii) Observe any field (perhaps one in Stripe 82) multiple times under photometric conditions in a 5x5 grid pattern in all 5 DES filters (maybe move this 5x5 grid star flat to "Once During Commissioning", since it is very time intensive)

e. Victim (cross-talk) exposures

(i) observe a field with lots of bright stars (nearby open cluster?)

f. Scattered moonlight tests

(i) observe fields at varying distances from the moon: 60deg, 50deg, 40deg, 30deg, 20deg, 10deg

(ii) preferably at different lunar phases (hence, a "weekly" test during commissioning)

(iii) preferably under a variety of sky conditions (photometric to heavy cirrus)

g. shutter timing maps (short/long exposure sequences)

3. Once During Commissioning (but re-do occasionally during operations)

a. create bad pixel maps

b. scattered star light tests

(i) observe fields at varying distances from a bright (1st mag?) star:
20deg, 10deg, 5deg, 2.5deg, 1.25deg

(ii) preferably during a night in which sky conditions are changing (ranging from photometric to heavy cirrus)

C. During Operations

1. Daily

a. Afternoon

(i) 10 bias frames

(ii) 30 dark frames, composed of:
(a) 10 science-length exposures (typically 100 sec each)
(b) 10 faint-standards-length exposures (typically 30 sec each)
(c) 10 bright-standards-length exposures (typically 5 sec each)

(iii) 50 dome flat frames, composed of:
(a) 10 dome flats in g
(b) 10 dome flats in r
(c) 10 dome flats in i
(d) 10 dome flats in z
(e) 10 dome flats in Y

b. Evening Twilight

(i) 3 standard star fields between 12deg and 18deg twilight
(a) one at low airmass (X=1.0-1.2)
(b) one at high airmass (X=1.8-2.0)
(c) one at medium airmass (X=1.4-1.6)
(d) at least one in SDSS Stripe 82 for full coverage of DECam focal plane (all CCDs)

(e) with PreCam, we can reduce this set of standard star field observations to maybe just the low- and high-airmass observations

c. Night

(i) 3 standard star fields around night's midpoint (~1AM local time)
(a) one at low airmass (X=1.0-1.2)
(b) one at high airmass (X=1.8-2.0)
(c) one at medium airmass (X=1.4-1.6)
(d) at least one in SDSS Stripe 82 for full coverage of DECam focal plane (all CCDs)
(e) with PreCam, we can eliminate this set of standard star field observations

d. Morning Twilight

(i) 3 standard star fields between 18deg and 12deg twilight
(a) one at low airmass (X=1.0-1.2)
(b) one at high airmass (X=1.8-2.0)
(c) one at medium airmass (X=1.4-1.6)
(d) at least one in SDSS Stripe 82 for full coverage of DECam focal plane (all CCDs)
(e) with PreCam, we can reduce this set of standard star field observations to maybe just the low- and high-airmass observations

2. Weekly

a. Star Flat tests (these basically come for free if we continue to observe fields Stripe 82 as part of the nightly standard star observations)

3. Monthly (many/all of these could eventually be moved to "annually")

a. Illuminated Flat Field System Response Measurements

b. Linearity tests

c. Gain, readnoise, and saturation tests

4. Annually

a. Victim (cross-talk) exposures

b. Bad pixel maps

c. shutter timing maps (short/long exposure sequences)

d. 5x5 grid pattern star flat
   (i) must be done under photometric conditions
  (ii) must do a grid pattern for all 5 filters, but
       not necessary to do the grid pattern for all 5 filters
       on the same night.

D. Post-Survey (TBD)

III. Analysis of Calibration Data (TBD)

IV. Failure Modes

A. A CCD dies and is replaced.

1. Make measurements of linearity, readnoise, gain for new CCD (perhaps *all* CCDs).

2. Measure linearity curve for new CCD (perhaps *all* CCDs).

3. Take "victim" (cross-talk) exposures for new CCD (perhaps *all* CCDs).

4. Illuminated Flat Field System Response Measurements.

B. A filter breaks.

1. Re-calculate instrumental color terms ("b" terms) with Photometric Standards Module at next photometric night (color terms might be measured nightly in any case)

2. Illuminated Flat Field System Response Measurements.

3. Re-do star flats

    a. Stripe 82 Star Flat

    b. 5x5 grid pattern star flat

C. Shutter fails.

1. Re-do shutter timing maps (short/long exposure sequences)

DES Photometric Calibrations Flow Diagram (v2.2)