DES Science Requirements

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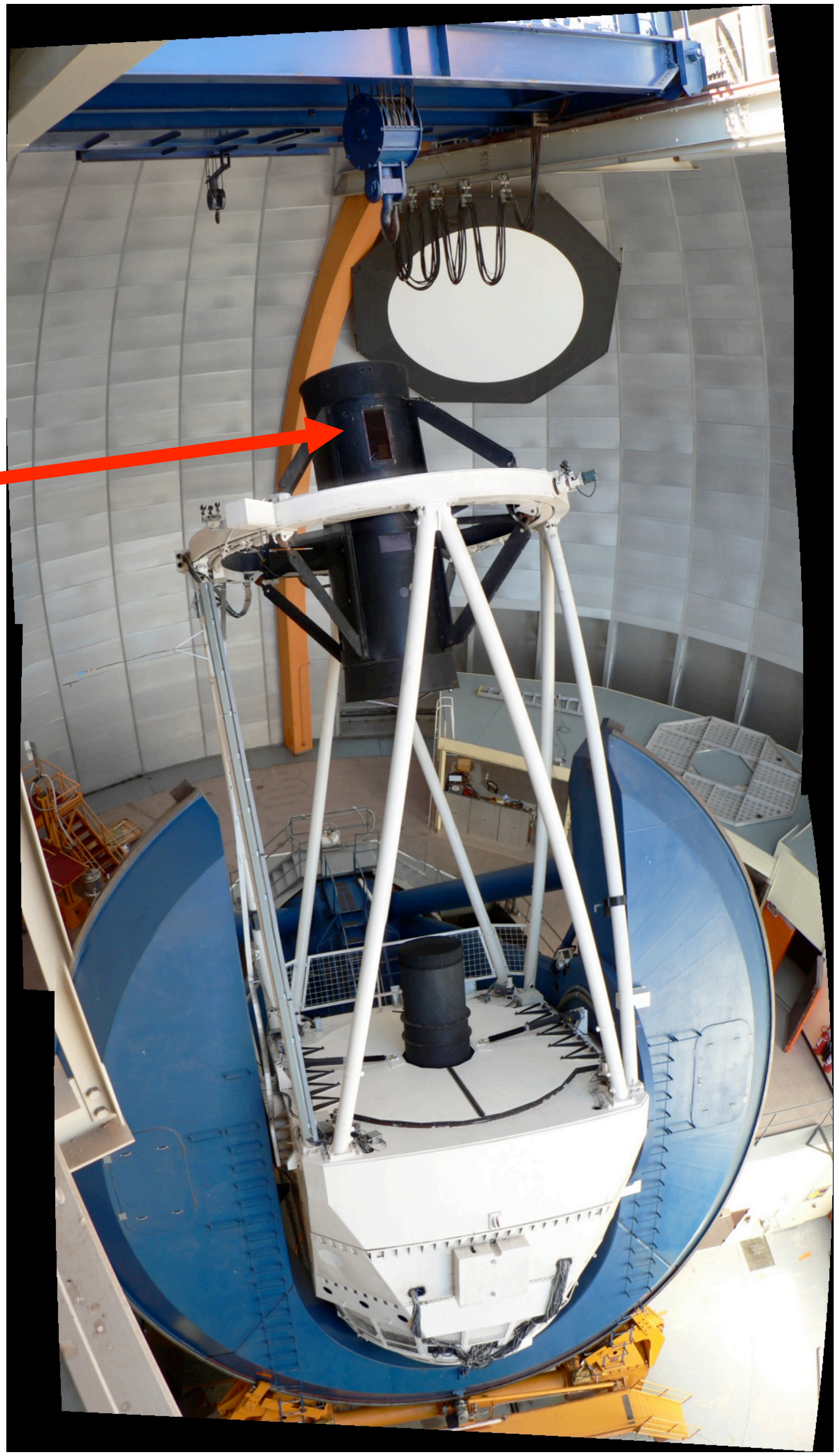
The Dark Energy Survey (DES)

DARK ENERGY SURVEY

- Proposal:
  - Perform a 5000 sq. deg. survey of the southern galactic cap
  - Measure dark energy with 4 complementary techniques
- New Instrument:
  - Replace the PF cage with a new 2.2 FOV, 520 Mega pixel optical CCD camera + corrector
- Time scale:
  - Instrument Construction 2008-2011
- Survey:
  - 525 nights during Oct.–Feb. 2011-2016
  - Area overlap with SPT SZ survey and VISTA VHS survey



Use the Blanco 4M Telescope at the Cerro-Tololo Inter-American Observatory (CTIO)

Basic Survey Parameters

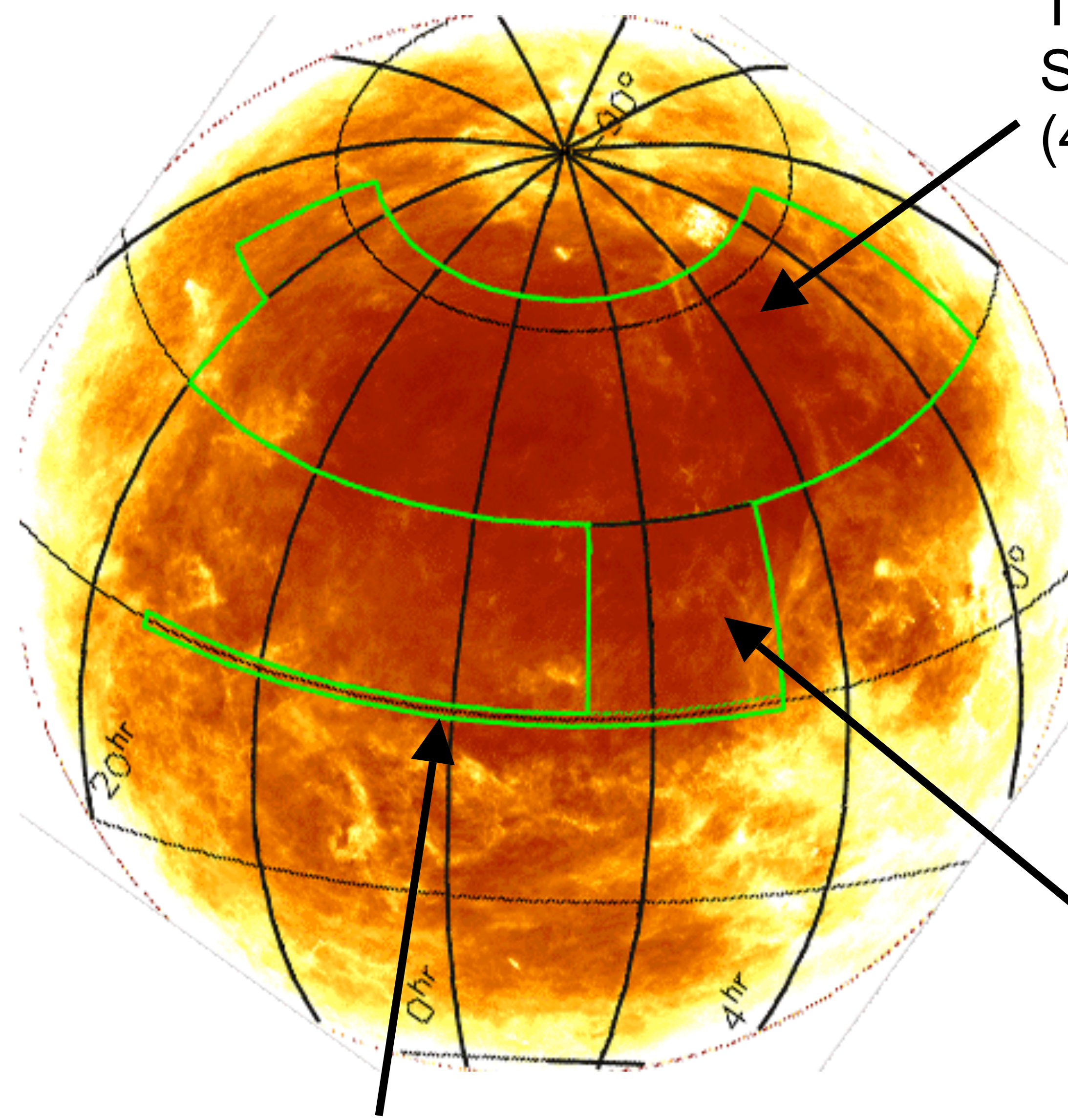
Sensitivity
- Galaxies: 10σ *grizY* = 24.6, 24.2, 24.4, 23.8, 21.5 (galaxies)
- Point sources: 5σ *grizY* = 26.0, 25.5, 25.7, 25.2, 22.8 (stars)

Area
- ~5000 degree^2
- Repeated area of 15 degree^2

Image quality
- <0.9 arcsec FWHM
- Stable across full field-of-view

Photometric precision
- <2% absolute

Survey Area



Dark Energy Survey Science Program

DARK ENERGY SURVEY

DES will use Four Probes of Dark Energy

- Galaxy Cluster Counting: N(M,z)
  - Redshifts and masses of ~100,000 clusters to z>1
  - Of which ~10,000 will have SZE measurements from SPT
  - Sensitive to growth of structure and expansion
- Weak Lensing
  - Shape measurements of 200 million galaxies
  - Sensitive to growth of structure and expansion
- Baryon Oscillations
  - 200 million galaxies to z = 1 and beyond
  - Sensitive to expansion
- Supernovae
  - ~15 sq deg SN 1a survey
  - 3000 SN 1a to z ~1.2
  - Sensitive to expansion

The four probes are complementary and will provide insight into the systematic uncertainties

DES Forecasts: Power of Multiple Techniques

DARK ENERGY SURVEY

$$w(z) = w_0 + w_a(1-a) = w_p + w_a(a_p - a)$$

$$\text{DETF FoM} \equiv 1/(\sigma_{w_a} \cdot \sigma_{w_p})$$

Assumptions:

Clusters:

σ_8=0.75, z_{max}=1.5,

WL mass calibration

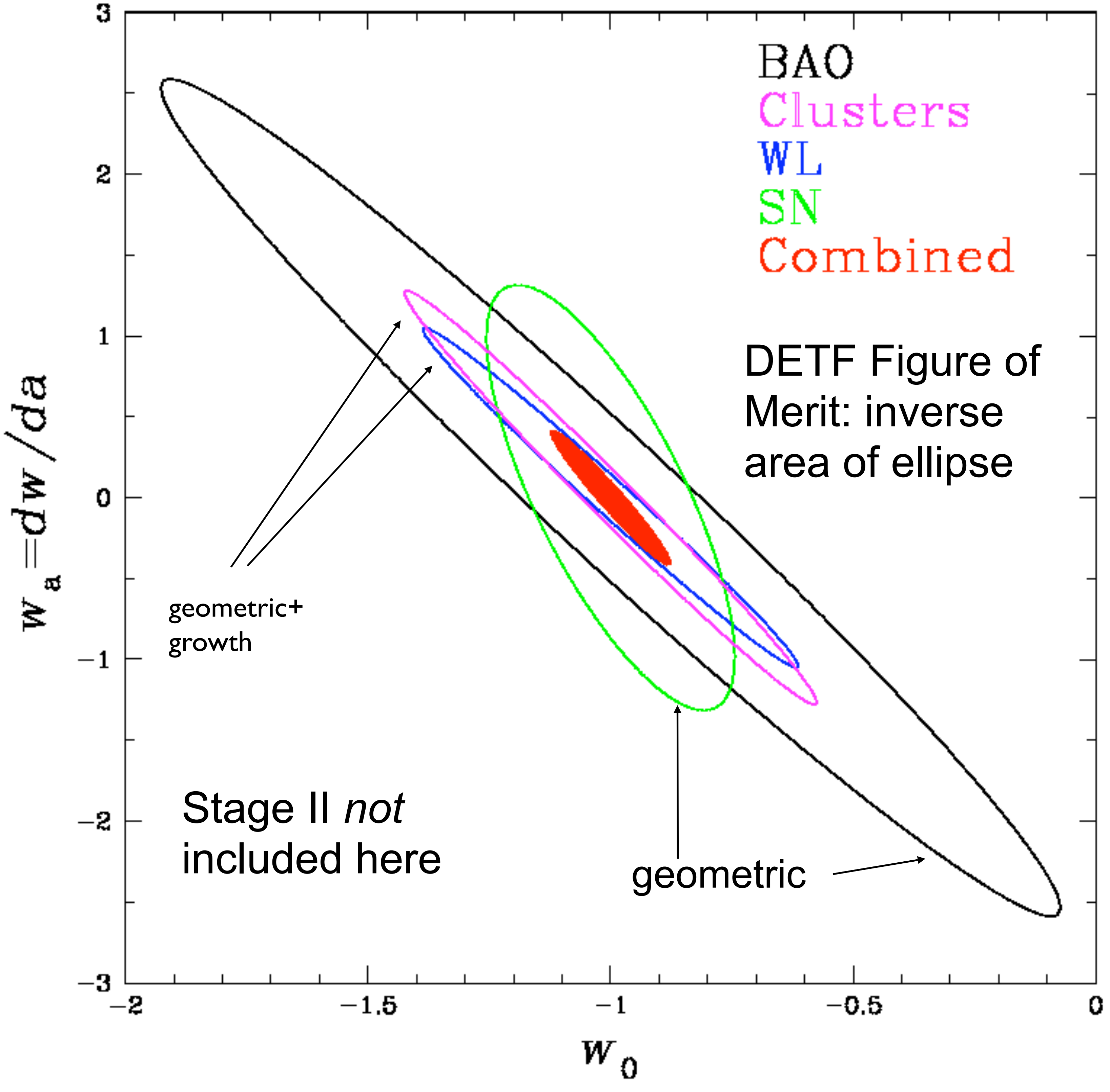
BAO: ℓ_{max}=300

WL: ℓ_{max}=1000

Statistical+photo-z systematic errors only

Spatial curvature, galaxy bias marginalized, Planck CMB prior

Factor 4.6 relative to Stage II



DES Science Objectives and DES Requirements

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Objectives are high level criteria that provide the scientific motivation for the project and underlie its basic design parameters.

1. The *principal science objective* is to achieve *a factor of 3* increase in the DETF FoM relative to the DETF-estimated FoM for Stage II, using a combination of four dark energy probes.
2. An *enhanced objective* is to achieve *a factor of 4 to 5 increase* in the DETF FoM relative to the DETF-estimated FoM for Stage II.
3. An additional objective of DES is to understand and improve the control of systematic errors in all four dark energy probes.

Requirements are testable criteria that must be met in order for the project to meet its objectives. They exist at various levels and should flow down to the requirements and specifications for DECam and DESDM.

Goals are verifiable criteria that add value to the requirements and are achievable, but meeting them is not deemed necessary to project success in meeting its objectives. Meeting enhanced goals should enable the enhanced objectives to be met.

Level 1 Requirements I: Survey

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The DES Science Requirements flow from the science objectives. The Level I requirements involve survey design parameters that are necessary for DES to achieve the desired statistical precision on the DETF FoM using the four dark energy probes.

There are nine Level I requirements. These two describe the survey:

R-4 The DES wide-area survey will be carried out in 5 optical passbands *grizY* and reach g = 24.6, r = 24.1, i = 24.3, z = 23.8, and Y=21.5 AB at ≥ 10 S/N in 1.5" apertures, with ≥ 97.5% completeness (excluding areas occulted by stars) and 95% purity over at least 90% of the survey area. Positions should be accurate to 100mas.

We go deep, and we need to coadd.
The catalog needs to be complete and pure, the positions accurate.

R-5 The Supernova Survey area, depth, and cadence will be designed to obtain well measured light curves of ~3000 SNe Ia out to redshift z~1.2 with statistical and systematic errors small enough to achieve the Supernova FoM objective, using up to 10% of the photometric survey time and larger fraction of the non-photometric time.

"Statistical and systematic errors small" drives many photometric requirementds.

R-4 is central to the survey. A multitude of requirements trace back to this.

Level 1 Requirements II: Quality

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The DES Level 1 requirements defining survey quality.

R-6 The photometric calibration of the survey must be accurate to 2%.

R-7 The effective areal density of galaxies useful for shape measurements n_{eff}, must be $n_{eff} \geq 8$ galaxies/sq-arcminute in the i bandpass, and 12 galaxies/sq-arcminute when using combined measurements from the r,i,z bandpasses.

R-8 The photo-z dispersion averaged over all galaxies with S/N >10 in two or more bandpasses should be $\sigma_z < 0.12$ for $0.1 < z < 1.5$ and for a 90% selectable sample of galaxies. The photo-z dispersion for clusters with more than 10 red sequence members, each with >10 measurements in two or more bandpasses, should be less than $\sigma_z = 0.02$.

The photometric calibration requirement is necessary for **R-8**, but also for such direct measures as the red sequence of clusters.

The neff directly scales with the WL figure of merit.

Photometric redshifts are central parts of all four key projects.

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Level 2 Requirements

The survey design parameters and external constraints at Level 1 flow down to Level 2 requirements. In order to meet the FoM objectives, these additional requirements must be met. These are subdivided into a number of categories: photometric calibration, astrometric calibration, image quality, photometric redshifts, catalog completeness, and survey parameters.

For our purposes we will focus on three of these:

Astrometric Calibration has three requirements, **R-14**, **R-15**, and **R-16**.

Photometric Calibration has four requirements, **R-10, R-11, R-12,** and **R-13**, and two goals, **G-4** and **G-5**.

Galaxy Catalog Completeness and Purity has 8 requirements: too many to list.

Astrometric Calibration

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The DES astrometric requirements

R-14 The absolute sky position of bright stars both in the individual images and the coadd should be measured to an rms of ≤100 mas in all bands on scales of 1 degree. Absolute positions will be reported in the J2000 system.

R-15 The centroid of the images of the same star in adjacent passbands of the coadd should agree to within 100 mas, over the range of airmasses allowed by the survey.

R-16 The rms of the centroids of each bright star in a set of all overlapping exposures that contain it should be no larger than 15 mas. The position measured in a coadd image must be mapped to the corresponding position in the overlapping input images with an accuracy of 15 mas or better. This requirement is for each bandpass individually.

Absolute astrometry

Relative to reference catalogs

Relative astrometry

The issue is differential refraction.
$x_1(i) - x_1(g,r,z,Y)$

Internal astrometry

The issue is centroid accuracy for the weak lensing analysis.
$x_1(i) - x_{2,3,4...n}(i)$
for single pass images contributing to a coadd tile.

Photometric Calibration I: Definition

DARK ENERGY SURVEY

The DES photometric system:

We define our photometric system as the normalized system response functions for the five bands b=(g, r, i, z, y) with AB zeropoints. The magnitude in a band $T_b(\lambda)$

$$m = -2.5 \log \frac{F_b}{3631 Jy}$$

"Absolute Calibration"

R-12

where F_b is object flux convolved with the system response,

$$F_b = \int F_\lambda(\lambda) T_b(\lambda) \lambda^2 d\lambda$$

$F(\lambda)$ is the flux of an object at the top of the atmosphere in $d\lambda$ units such as ergs/sec/cm^2/Å, $T_b(\lambda)$ are the normalized system response functions,

$$T_b(\lambda) = \frac{\lambda^{-1} S_b(\lambda)}{\int \lambda^{-1} S_b(\lambda) d\lambda}$$

"System Response"

R-13

and $S_b(\lambda)$ are the system response functions.

The system response includes the transmission of a standard atmosphere at a fiducial airmass of 1.2, along with the contributions of optics, filters, and CCDs. These equations imply that the magnitudes will be on the natural instrument system with AB zeropoints.

Implicit in this definition:

1) The magnitude should not depend on position. R-10

2) The actual zeropoint value 3631 Jy is irrelevant for colors. R-11

Phometric Calibration II: Requirements

DARK ENERGY SURVEY

The DES photometric requirements

R-10 For each of the *grizY* 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 scales from 0.05 to 4 degrees.

"Internal Calibration"

$m_i = -2.5 \log (f_{i1}/f_{i2}) + C$

R-11 The color zeropoints between the survey fiducial bandpasses (*g-r, r-i, i-z, z-Y*) must be known to 0.5%.

"Relative Calibration"

$m_i - m_z = -2.5 \log (f_i/f_z) + zp$

R-12 The i-band magnitude zeropoint relative to BD+17, and therefore the AB system, must be known to 0.5%.

"Absolute Calibration"

$m_i = -2.5 \log (f_i) + zp$

R-13 The system response curves (CCD + filter + lenses + mirror + atmosphere at 1.2 airmasses) must be known with sufficient precision that the synthesized *grizY* magnitudes of any astronomical object with a calibrated spectrum agree with the measured magnitudes to within 2%. When averaged over 100 calibrating objects randomly distributed over the focal plane, the residuals in magnitudes due to uncertain system response curves should be < 0.5%.

"System Response"

G-4 A goal of the survey is to achieve **R-10** at the level of 1% for the final catalog.

G-5 A goal of the survey is to achieve **R-10** over 160° of RA and 30° of Dec.

Phometric Calibration III: Interpretation

DARK ENERGY SURVEY

The DES photometric requirements can be expressed as

$\mathbf{m_{true} = m_{cat} + \delta_m(RA,Dec) + \Delta_{mi} + \Delta_i}$

where $\mathbf{m_{cat}}$ is the cataloged magnitude, $\mathbf{\delta_m(RA,Dec)}$ is the spatial variation of the internal zeropoint error about $\mathbf{\Delta_m}$, and $\mathbf{\Delta_m}$ is in turn broken up into the overall spatially independent offset from a perfect AB system, $\mathbf{\Delta_i}$, and the difference between that and this bandpass, $\mathbf{\Delta_{mi}}$.

In pedantic detail:

$\mathbf{m_{int} = m_{cat} + \delta_m(RA,Dec)}$

$\mathbf{m_{rel} = m_{int} + \Delta_{mi}} \quad = \mathbf{m_{cat} + \delta_m(RA,Dec) + \Delta_{mi}}$

$\mathbf{m_{abs} = m_{rel} + \Delta_i} \quad = \mathbf{m_{cat} + \delta_m(RA,Dec) + \Delta_{mi} + \Delta_i}$

The color version of this is useful, here for the m-i color:

$\mathbf{(m_m - m_i)_{int} = (m_m - m_i)_{cat} + \delta_{mi}(RA,Dec) + \Delta_{mi}}$

This is what we do when we use the stellar color locus to check on the calibration errors.

"Internal Calibration"

$\mathbf{\delta_m(RA,Dec)}$

"Relative Calibration"

$\mathbf{\Delta_{mi}}$

"Absolute Calibration"

$\mathbf{\Delta_i}$

Photometric Calibration IV: Implicit requirements

DARK ENERGY SURVEY

The DES photometric system:

We define our photometric system as the normalized system response functions $T_b(\lambda)$ for the five bands b=(*g, r, i, z, y*) with AB zeropoints. The magnitude in a band b is

$$m = -2.5 \log \frac{F_b}{3631 Jy}$$

where F_b is object flux convolved with the system response,

$$F_b = \int F_\lambda(\lambda) T_b(\lambda) \lambda^2 d\lambda$$

$F(\lambda)$ is the flux of an object at the top of the atmosphere in $d\lambda$ units such as ergs/sec/cm^2/Å, $T_b(\lambda)$ are the normalized system response functions,

$$T_b(\lambda) = \frac{\lambda^{-1} S_b(\lambda)}{\int \lambda^{-1} S_b(\lambda) d\lambda}$$

and $S_b(\lambda)$ are the system response functions.

I've already said that implicit in this definition is that the magnitude should not depend on position, and that relative color zeropoints are of interest. It should also be apparent that in a detailed flow down from this definition there would be statements such as:

"the magnitude is independent of seeing"
"the magnitude is astrophysically meaningful'
"the magnitude is independent of position on focal plan"

The first refers to the need for model and PSF magnitudes, the second to the need for imodel magnitudes, the third to the need for color corrections.

Galaxy Catalog Purity and Completeness I

DARK ENERGY SURVEY

The galaxy catalog purity and completeness requirements are central to the cataloging process and so to our algorithms workshop. There are 9 of these requirements.

Mask:

R-26 The survey area must be known to 1%, and the limiting magnitude inside each homogeneous patch of the survey known to 0.1 magnitudes.

This is the job of the mangle mask.

Completeness:

R-27 The galaxy catalog completeness should be above 93% when the galaxy surface density is less than 50 galaxies/sq-arcminute.

Inside this hides a deblender requirement- the densest place we expect it to work is at 50 gals/arcminute.

Deblender:

R-31 The deblender must conserve flux, be consistent across bands, and handle the case of blended stars with a magnitude difference of less than 1 magnitude farther apart than the Rayleigh critera. The most stringent case is that for brightest cluster catalog purity and measurement accuracy. Less than 1% of brightest cluster galaxies at $i<22$ should have, after deblending, errors in their magnitudes of ≥ 0.1 magnitudes. Furthermore, at $i<22$ the misidentification rate of stars (including saturated stars) as galaxies must be $<1\%$.

The first line is generic galaxy science. The rest is specific to the cluster working group.

Galaxy Catalog Purity and Completeness II

DARK ENERGY SURVEY

Star-galaxy and junk-galaxy separation:

R-28 The true ratio of stars to galaxies on 100 sq-arcminute scales should match that calculated from the summed star/galaxy probabilities assigned to each galaxy to 1%. Likewise, the ratio of other false galaxy contaminants, such as satellite trails, to real galaxies should be known to 1%.

Overall performance. This does not demand that the S/G separator put out probabilities, just that it get its assignments right at this level.

R-29 After splitting a 90% selectable sample of "galaxies" into redshift bins of width 0.1 to $0.1 < z < 1.5$, the true ratio of stars to galaxies averaged over the survey area should match that calculated from the summed star/galaxy probabilities assigned to each galaxy to 1%. Likewise, in these bins the ratio of other false galaxy contaminants should be known to 1%.

As above, now broken up in redshift.

R-30 For each of the grizY bandpasses of the wide area survey, the rms fluctuations in spatially varying, unflagged artifacts and contaminants in the final coadded catalog must be smaller than 2% over scales from 0.05 to 4 degrees. After splitting a 90% selectable sample of "galaxies" into redshift bins of width 0.1 to $0.1 < z < 1.5$, the corresponding rms fluctuations in spatially varying, unflagged artifacts and contaminants in each bin should bess less than 5% om 0.05 to 4 degrees.

Now lets do it spatially.

These are all driven by LSS.

Galaxy Catalog Purity and Completeness III

DARK ENERGY SURVEY

This was a proposed requirement from the LSS working group, motivated by keeping the systematic errors less than the statistical errors:

> "For each of the grizY band passes of the wide-area survey, the rms fluctuations in the spatially varying systematic component of the magnitude error, or unexpected rms fluctuations from stars, artefacts and contaminants in the final co-added catalog must be smaller than 2% over scales from 0.05 to 4 degrees. After splitting a 90% selectable sample of "galaxies" into redshift bins of width 0.1 to $0.1< z <1.5$, the corresponding rms fluctuations should be less than 5% on scales from 0.05 to 4 degrees."

They are concerned about spatial fluctuations in the galaxy counts due to calibration issues.

It didn't make it into the final document in this form, but it does capture their concerns nicely.

Galaxy Catalog Purity and Completeness IV

DARK ENERGY SURVEY

The Cluster Working Group has this interesting idea of "catalog noise". In essence, they designed a requirement that says in requirement-ese what the SDSS took as its overall science software goal: the science software should not degrade what Nature and the telescope provides us.

Catalog Noise:

R-32 For an ensemble of clusters at arbitrary fixed mass, but with $\log(M) > 13.5$, the scatter in the richness-mass relation measured in the image simulations should be within 5% of the scatter in the richness-mass relation measured in the catalog simulations, for galaxies with $S/N > 10$ and clusters at $0.2 < z < 1.3$.

This is directly testable in the data challenges but not at all on the sky the way it is worded.

The idea it chases is the central one for the cluster working group acceptance testing. The catalog output of the image processing should be as good as the input catalog.

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Summary

The requirements can be summarized by saying we aim at a homogenous, deep, well calibrated survey.

The requirements are what are necessary, but we can and should aim for more.

We should aim to extract as much from the data as Nature provides, doing no harm to what the telescope and the camera delivers.