Dark Energy Survey

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UCLA Dark Matter 2012
Discovery of Dark Energy

What is Dark Energy? Cosmological Constant or something else?

\[
\mu = m - M = 5.0 \log \frac{d_L}{10 \text{pc}}
\]


2011 Nobel prize
Perlmutter, Schmidt & Reiss
Nature of Dark Energy?

\[ w = \frac{P}{\rho} \quad \text{Equation of State} \]
\[ w = w_0 + w_a(1 - a) \]
The Dark Energy Survey (DES) is a next generation optical imaging survey that will observe 300 million galaxies over 5000 deg$^2$ of the southern sky using DECam, a new 520 Megapixel CCD camera on the 4-meter Blanco telescope at the Cerro Tololo Inter-American Observatory.

DES study dark energy by joining four complementary techniques, including:

- The mass function and clustering of Galaxy Clusters
- The power spectrum of Weak Gravitational Lensing shear
- The statistical signature in the galaxy distribution Baryon Acoustic Oscillations
- The distance-brightness relation of Type Ia Supernovae
an international collaboration of ~100 scientists from ~20 institutions

US: Fermilab, UIUC/NCSA, University of Chicago, LBNL, NOAO, University of Michigan, University of Pennsylvania, Argonne National Laboratory, Ohio State University, Santa-Cruz/SLAC Consortium Texas A&M University

UK Consortium:
UCL, Cambridge, Edinburgh, Portsmouth, Sussex, Nottingham

Spain Consortium:
CIEMAT, IEEC, IFAE

Brazil Consortium:
Observatorio Nacional, CBPF, Universidade Federal do Rio de Janeiro, Universidade Federal do Rio Grande do Sul

DES Collaboration
Cosmological Probes - Galaxy Clusters

Galaxy Clusters: largest gravitationally bound structures, abundance depends on the growth of structure
Cosmological Probes - Galaxy Clusters

\[
\frac{d^2 N(z)}{dz d\Omega} = \frac{c}{H(z)} D_A^2 (1 + z)^2 \int_0^\infty f(M, z) \frac{dn(z)}{dM} dM
\]

\[\Omega_{\text{DE}} = 0.7, \quad \sigma_8 = 0.90\]
\[\delta z = 0.05\]

from Mohr, 2005

Allen, Evrard & Mantz

10^{14} M_\odot

10^{15} M_\odot

ACO

BCS

RCS1

MACS

400d

ACT

SPT

DES

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Dark Energy Survey
Galaxy Clusters from SDSS

![Cluster Counts vs. Richness (N_{200})](image1)

![Mean Cluster Mass vs. Richness (N_{200})](image2)

![Contour plots of cosmological parameters](image3)
Fig. 8.— $\Delta \Sigma$ from 25 to 30 $h^{-1}$Mpc in 12 bins of $N_{200}$. The signal measured around random points is subtracted from these profiles (see Figure 6). The correction for clustering of sources with the lenses is also applied (see Figure 7). The errors are from jackknife re-sampling.

Sheldon et al, 2007
Dark Energy Survey - DETF figure of merit

We note that considerable uncertainties in the systematic error levels remain for each of the methods. Some of those will be pinned down by further theoretical work, e.g., via N-body simulations, while others will likely only be determined once we have the large DES data set in hand and carry out internal and external cross checks of each method. On the other hand, we find that the forecast combined FoM for DES appears to be robust to changing the level of systematic uncertainty in any of the dark energy probes.

Figure 1: 68% CL forecast DES constraints in the $w_0$–$w_a$ plane from the four probes: BAO (black), clusters (magenta), weak lensing (blue), and SNe (green), each combined with the Planck CMB prior; the filled, red region shows the constraints from combining the four methods. All other cosmological parameters and the nuisance parameters for each method have been marginalized. To better show the degeneracies for each method, in this plot we have not included the DETF stage II constraints, unlike in Table 1.

Our forecasts are based on Fisher matrix calculations. For the fiducial cosmological model, we take the matter density $\Omega_{m} h^2 = 0.14$, dark energy density $\Omega_{DE} = 0.73$, $w_0 = -1$, $w_a = 0$, matter power spectrum amplitude $\sigma_8 = 0.75$, baryon density $\Omega_{b} h^2 = 0.024$, spectral index $n_s = 1$, and spatial curvature $\Omega_k = 0$, consistent with current WMAP constraints. We allow each of these parameters, including the spatial curvature, to vary, but we impose massless neutrinos, no tensor contribution to the CMB, and no running of the scalar spectral index. We assume that the primordial perturbations are adiabatic and Gaussian, as expected in the simplest classes of inflation models. The forecasts assume a Planck prior for the CMB, as adopted by the DETF. For each dark energy probe, we derive marginalized 68% CL constraints on $w_0$ and $w_a$ using the Planck prior and the survey parameters and assumptions outlined in the following sections. We then combine the Fisher matrices for all four probes to derive the combined marginalized constraints. The results are shown in Fig. 1 and displayed in Table 1.

In addition to measuring the effective dark energy equation of state and determining whether it is consistent with Einstein’s cosmological constant, we plan to address the fundamental question of whether cosmic acceleration is caused by dark energy or by a modification of General Relativity (GR) on large scales. Such a modification is expected to alter the growth rate of large-scale structure in a manner not captured by a single.
Victor Blanco 4 meter Telescope @ CTIO
# DES Survey Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Survey Area</td>
<td>5,000 sq. deg.</td>
</tr>
<tr>
<td>Survey Time/Duration</td>
<td>525/5 (nights/years)</td>
</tr>
<tr>
<td>Median Site Seeing Sept. – Feb.</td>
<td>0.65 arcsec</td>
</tr>
<tr>
<td>Median Delivered Seeing with Mosaic II on the Blanco</td>
<td>0.9-1.0 arcsec (V band)</td>
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<tr>
<td>Limiting Magnitude: 10σ in 1.5&quot; aperture assuming 0.9&quot; seeing, AB system</td>
<td>g=24.6, r=24.1, i=24.3, z=23.9</td>
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<tr>
<td>Limiting Magnitude: 5σ for point sources assuming 0.9&quot; seeing, AB system</td>
<td>g=26.1, r=25.6, i=25.8, z=25.4</td>
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</tbody>
</table>
Dark Energy Camera

Figure 1: DECam Reference Design
Dark Energy Camera
Dark Energy Camera @ CTIO

Marcelle Soares-Santos
Dark Matter Distribution

Diemand et al., 2008 Via Lactea II

abundance of sub-halos vs. Mass
Dwarf Galaxies
Dwarf Spheroidal Galaxies

Figure 1. A color-magnitude (CM) filter used to suppress noise from foreground stars while preserving the signal from dwarf galaxy stars at a specified distance. Far left and middle right: CM filters for an old and metal-poor stellar population at a distance modulus of 16.5 and 20.0, respectively. The solid lines show Girardi isochrones for 8 and 14 Gyr populations with [Fe/H] = -1.5 and -2.3. Middle left and right: These CM filters overplotted on stars from a 1 deg$^2$ field to illustrate the character of the foreground contamination as a function of dwarf distance.

Figure 2. Far left: Map of all stars in the field around the Ursa Major I dwarf satellite, $M_V = -5.5, d = 100$ kpc. Middle: Map of stars passing the CM filter projected to $m - M = 20.0$ showing the middle right pane of Figure 1. Far left: Spatially smoothed number density map of the stars in the middle panel. The Ursa Major I dwarf galaxy has a $\mu_V, 0$ of only 27.5 mag arcsec$^{-2}$ [63].

from Willman, 2009
Dwarf Galaxy reach with DES

Tollerud, Bullock, Strigari, Willman 2008

While our general expectation that there should be many more dwarf galaxies may be discovered by new, deeper surveys. However, some important caveats exist, they will have been missed by SDSS. In this sense, our predictions of Upcoming Surveys are upper limits, but to first order they are a representative number of the possibly detectable satellites. Hence, these estimates are conservative, as even more very low surface brightness systems exist, they will have been missed by SDSS. In this sense, our predictions of Upcoming Surveys are upper limits, but to first order they are a representative number of the possibly detectable satellites.

Moreover, the co-added data would reveal all dwarfs in the Southern sky, >100 galaxies by this estimate. Note that this still assumes a single exposure, the adopted limiting magnitude is absolute magnitude for DR5 (assumed a limiting magnitude of 22.2) compared to a single exposure of LSST (24.5), co-added full LSST lifetime exposures of RCS-2 (24.8), and associated Missing Satellites Survey (22.6). The data points are SDSS and (27.5), DES or one exposure from PanSTARRS (both 24), and the SkyMapper version of this figure. See the electronic edition of the Journal for a color version of this figure.

## Table 4

<table>
<thead>
<tr>
<th>Survey</th>
<th>N (M_v)</th>
<th>r_lim</th>
<th>g_lim</th>
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<tr>
<td>PanSTARRS</td>
<td>30000</td>
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<td>61</td>
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<tr>
<td>Skymapper</td>
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<td>42</td>
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<tr>
<td>DES</td>
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<td>24</td>
<td>19</td>
</tr>
<tr>
<td>RCS-2</td>
<td>1000</td>
<td>24.8</td>
<td>3</td>
</tr>
<tr>
<td>LSST 1-exp</td>
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<td>93</td>
</tr>
<tr>
<td>LSST combined</td>
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<tr>
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<td>93</td>
</tr>
<tr>
<td>RCS-2</td>
<td>1000</td>
<td>24.8</td>
<td>3</td>
</tr>
</tbody>
</table>

## Discussion

5.1. A simplifying approximation that equates the complications of satellite detection cannot be correct in detail; we expect a dependence on properties such as Galactic latitude and color. However, we are leaving these issues aside for this first-order correction. Moreover, the detection limits from Koposov et al. (2008) apply only to objects with absolute magnitude for DR5 (assumed a limiting magnitude of 22.2) compared to a single exposure of LSST (24.5), co-added full LSST lifetime exposures of RCS-2 (24.8), and associated Missing Satellites Survey (22.6). The data points are SDSS and (27.5), DES or one exposure from PanSTARRS (both 24), and the SkyMapper version of this figure. See the electronic edition of the Journal for a color version of this figure.

5.2. The assumption that the satellite population is a major as well as local Group field galaxies. The data points are SDSS and (27.5), DES or one exposure from PanSTARRS (both 24), and the SkyMapper version of this figure. See the electronic edition of the Journal for a color version of this figure.

Fig. 10.—Expected luminosity functions for LSST per 4

Fig. 9.—Maximum radius for detection of dSph's as a function of galaxy absolute magnitude for DR5 (assumed a limiting magnitude of 22.2) compared to a single exposure of LSST (24.5), co-added full LSST lifetime exposures of RCS-2 (24.8), and associated Missing Satellites Survey (22.6). The data points are SDSS and (27.5), DES or one exposure from PanSTARRS (both 24), and the SkyMapper version of this figure. See the electronic edition of the Journal for a color version of this figure.
Fig. 1.— Mosaic of seven new strong lens systems discovered in the SDSS. Images are taken from the SDSS database. Systems are centered on the brightest LRG in each system. In each image North is up, East is to the left.

Kubo et al., 2010
Strong Lensing & Subhalos

McKean et al., 2007

Dalal & Kochanek, 2002

limits from anomalous flux-ratios
Conclusions

- Dark Energy Camera
  - Construction complete
  - Installation & Commissioning beginning now
  - First light this summer
- Dark Energy Survey
  - Start of survey this winter
  - 5000 sq. deg. over 5 years
- Study Dark Energy with Cluster, Weak lensing, SuperNova, BAO
- Study distribution of Dark Matter with:
  - Strong Lensing
  - Dwarf Galaxies