The Dark Energy Survey

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Abstract. The Dark Energy Survey (DES) is a next generation optical and near infrared survey that will image 5000 deg$^2$ of the South Galactic Cap in five broad bandpass filters. In order to perform such a survey, a CCD camera of 3 deg$^2$ field of view is being assembled at Fermilab and will be mounted on the Blanco 4m telescope at Cerro Tololo (Chile). The survey will start in the fall of 2011 and will study the dark energy properties using four independent methods: galaxy clusters counts and distributions, weak gravitational lensing tomography, baryon acoustic oscillations and supernovae Ia distances. Obtaining the four measurements from the same data set will allow a strict control of the systematic uncertainties to obtain a robust and precise determination of the cosmological parameters.

1. Introduction
The current set of cosmological observations solidly establishes an amazing result, the cosmic acceleration. At cosmological distances, the receding velocities of galaxies are increasing. The implications of this observed fact are profound. Either gravity behaves far differently than what is expected from the general theory of relativity, or some mysterious fluid with negative pressure, the dark energy, fills the universe and produce repulsive gravity. Anyway, new physics is needed. Therefore, the cosmic acceleration puzzle motivates an important fraction of current research which will grow in the near future. Usually, the cosmic acceleration problem is called dark energy, but we should not forget that the observed effect can be due to an unexpected behaviour of gravity at very large scales.

The current standard model of cosmology, ΛCDM, describes the cosmic acceleration using a non-zero cosmological constant, the Λ of its name. CDM stands for Cold Dark Matter, the other dark component of the universe. This model is compatible with all the present cosmological observations [1]. However, in this model about 96% of the universe (dark energy but also dark matter) remains unexplained, despite the succesful theories of fundamental physics. It is generally expected that the next advance in knowledge about dark energy come from the observations, and a rich program of different cosmological surveys has already started and is planned for the future. One of the most important projects for the near future is the Dark Energy Survey (DES) [2].

2. The Dark Energy Survey
DES is a next generation survey aimed to unveil the nature of the dark energy. The DES collaboration consists of approximately 120 scientists from USA, UK, Spain, Brazil and Germany.

1 http://www.darkenergysurvey.org
The survey will image 5000 square degrees of the south galactic cap, using five wide bandpass filters, \( grizY \), from visible to near infrared, up to magnitude 24\textsuperscript{th}. These filters have been chosen to provide accurate photometric redshifts for all the detected objects. The area and location of DES have been chosen to overlap with the South Pole Telescope\textsuperscript{2} (SPT) [3], which will provide Sunyaev-Zeldovich effect measurements for a large number of galaxy clusters. To perform such a survey, three elements are needed: A telescope, a camera and a data management system. These elements will be described in the next sections.

3. The Telescope

The DES project has an agreement with the National Optical Astronomical Observatory (NOAO) to have the use of a significant amount of time on the Blanco 4m telescope of the Cerro Tololo Interamerican Observatory (CTIO), in Chile, which is shown in Figure 1. Correspondingly, DES provides a new advanced prime focus instrument. The DES survey will have 525 nights in five years to complete its observations. This means a 30\% of the telescope time. The rest of the time the instrument will be available for the community use.

![Figure 1. View of the Cerro Tololo observatory (left). The Blanco 4m telescope (right) is located inside the largest building. The black cylinder at the prime focus will be replaced by a new one containing the DES camera, DECam.](image)

4. DECam: The Dark Energy Camera

The camera for the DES survey is called the Dark Energy Camera (DECam). Its design was optimized to maximize the scientific potential and to minimize the construction time and cost. DECam will replace the entire prime focus cage of the Blanco telescope with a new one, containing the whole DECam system, see Figure 1.

The major components of DECam are a 520 Megapixel optical CCD focal plane, which is housed in a dewar that provides vacuum and cryogenics, a low noise CCD readout electronic system placed in crates around the main dewar that are actively cooled, a shutter, a filter system to house and exchange the DES filters, and a wide-field optical corrector (which gives a field of view of 2.2 degrees of diameter). The CCD vessel and corrector are supported by a hexapod that provides adjustability in all degrees of freedom. A scheme of the DECam structure is shown in Figure 2.

\textsuperscript{2} http://pole.chicago.edu
Figure 2. Scheme of DECam (left), where all its components can be seen. A prototype of the dewar is shown at the right, including several CCDs in the focal plane and the corresponding readout electronics.

The major DECam systems are complete, and are in process of assembly at Fermilab.

To have a good detection efficiency for high redshift objects, CCDs that are extremely sensitive at the red part of the spectrum are used. They are fully depleted, 250 µm thick CCDs, that have been developed at the Lawrence Berkeley National Laboratory. The quantum efficiency of these devices in the $z$ band is larger than 50%, almost an order of magnitude higher than traditional thinned devices.

The DECam focal plane will contain 62 CCDs of 2048x4096 pixels for scientific imaging, and 12 CCDs of 2048x2048 pixels for guiding, alignment and focus. A prototype of this focal plane, within the dewar and partially instrumented, can be seen in Figure 2.

5. The DES Data Management System
The DES data management system is being developed to process the raw DECam images into science ready data products, and make those data available to the DES collaboration and to the public community. The design of the data management system is driven by the scientific goal of the DES project and also by the need to automatically and reliably process, calibrate and archive the survey dataset.

The data management system must be able to process and archive around 400 Gb of data every night, for a total of $\sim 1$Pb at the end of the survey. Including the processed and reduced data, the total amount will be on the several Pb size. The DES data management system consists of an integrated archive, a processing framework, an ensemble of astronomy codes and a data access framework. It uses community high performance computing resources. Image and catalog data are tracked within a distributed archive, and data movement among archive nodes employs high efficiency grid tools. Operators control the system, submit processing requests and monitor data quality using portals. Collaboration scientists and the public retrieve data using the archive portal or web service, as shown in Figure 3.
6. Scientific Objectives and Forecasts

The main goal of DES is, as has been stated before, to study the nature of the dark energy. More precisely, the measurement of the parameter $\omega$ of the dark energy equation of state to a precision of $< 5\%$ and its variation with the redshift to a precision of $\sim 30\%$ in each of four separate and independent techniques. These results will be then combined to a final constraint of much higher precision. Obtaining all the measurements with the same system makes possible to cross-compare results and control the systematic errors.

The four methods DES will use to study the dark energy are:

- Galaxy cluster counting and spatial distribution of clusters at $0.1 < z < 1$.  
- Weak lensing measurements on several redshift shells up to $z \sim 1$.  
- Baryon acoustic oscillations and general study of the power spectrum of galaxies.  
- $2000$ supernovae Ia at $0.3 < z < 0.8$.

These are the main scientific goals. However, DES will be able to make other dark energy studies. For example, the cross-correlation of the cosmic microwave background measurements with the galaxies identified by DES, which will also probe the dark energy using the integrated Sachs-Wolfe effect, and many others. These additional studies will give more constraints and better precision to the final measurement.

6.1. Galaxy Cluster Distribution

Clusters of galaxies are considered a very promising cosmological tool, because the formation of its gravitational potential wells is only due to the dynamics of dark matter to a good approximation. The redshift distribution, the spatial distribution, and the evolution of the mass function of clusters of galaxies are sensitive to $\omega$.

DECam will be able to identify and measure the redshifts of clusters of galaxies out to $z \sim 1$. This range includes all the time where the dark energy is important to describe the expansion history of the universe and even goes beyond that limit. The survey will identify $\sim 20000$ clusters, and their redshifts will be determined photometrically with enough precision to do
cosmology. Moreover, the overlap of the DES area with the SPT area allows the use of the Sunyaev-Zeldovich (SZ) effect to detect clusters out to large distances, increasing the sensitivity to the dark energy parameters.

The dominant systematics errors of this measurement are the selection of the sample and the determination of the cluster mass. The selection of the clusters using methods as SZ or X-ray identifications, the detailed simulations, and the determination of masses using weak lensing allow the control of systematic errors.

6.2. Weak Gravitational lensing
DES will study weak lensing both using the shear-shear correlations and the galaxy-shear correlations, that are sensitive to \( \omega \) through geometry and through the growth of cosmic structure. Around 300 millions of galaxies will be measured.

The main systematic errors that affect this measurement are the separation of the different components of the shear (intrinsic or coming from the instrument) and possible biases in the photometric redshift. A extremely careful control of the focus and alignment, and detailed simulations of the whole system are necessary.

6.3. Galaxy Angular Clustering
Baryon acoustic oscillations are expected to have very small systematics in the determination of dark energy parameters, since they are not affected by astrophysical considerations on the measured objects. The characteristic length scale of these oscillations can be used as a standard ruler to probe the \( \omega \) parameter through a geometrical test. The angular power spectrum or the angular correlation function of galaxies are used as the observables for this test.

The main systematic uncertainties of this measurement arise from the bias for galaxies, the calibration of photometry and the possible biases in the photometric redshifts. To control them, the angular bispectrum, the measurement of clustering for different colors and type of galaxy, a careful calibration strategy and spectroscopic calibration sets will be used.

6.4. Supernovae
Supernovae of the type Ia are standarizable candles. They are sensitive to the dark energy properties through the luminosity distance. DES will identify and measure around 2000 supernovae Ia up to \( z \sim 0.8 \). The observations must be repeated over time, to obtain the luminosity curves of the supernovae. The selection of the required type of supernovae will be performed using color information.

The dominant systematic errors in the measurement are the possible evolution of supernovae with the redshift, the extinction in the host galaxy of the supernova and the calibration of the photometric redshift. There are several methods to control them, namely, the comparison of supernovae at high and low redshift, the information on color and host galaxy of the supernova and a spectroscopic subsample of supernovae to obtain precise calibrations.

6.5. Forecasts
The Dark Energy Task Force (DETF) defined a figure of merit to evaluate the sensitivity of a given measurement to dark energy [4]. The expected DES sensitivity for each measurement technique and for their combination is shown in Figure 4. To obtain this result, the equation of state of the dark energy is written as \( p/\rho = w_0 + w_a(1 - a) \). DES is a stage III project in the DETF classification. Therefore, an improvement of a factor 4 or 5 with respect to the current result is expected.
**Figure 4.** Expected DES sensitivity to dark energy parameters for an equation of state $p/\rho = w_0 + w_a(1 - a)$, in each of the measurement techniques: BAO (black), galaxy clusters (magenta), weak lensing (blue) and supernovae Ia (green). The combination of the four methods is also shown (red).

7. Schedule
All of the major components of DECam are complete. They will be assembled at Fermilab during the next few months, except the optics that will be send directly to CTIO. Then the full system will be tested till the end of 2010 with engineering grade CCDs and during the beginning of 2011 with the science grade CCDs. After that, it will be shipped to CTIO. The installation in the Blanco telescope will take place during the summer of 2011. The first light and the beginning of commissioning are expected for the autumn 2011.

8. Conclusions
DES will measure the dark energy using four independent and complementary methods: Galaxy clusters, baryon acoustic oscillations, weak gravitational lensing and supernovae Ia. Having all these measurements with the same system allows to set robust constraints and have a high control of systematic errors. The goal is to improve current measurements by a factor of at least 4 or 5.

In order to reach these results, a new instrument (DECam) is being assembled and will be installed in the prime focus of the 4m Blanco telescope in CTIO. It is a 520 Megapixels CCD camera for optical and near IR observations.

Using this instrument and telescope, a survey of 5000 square degrees in the south galactic cap will be performed, imaging this area with the grizY filters. It will last for 525 nights distributed in 5 years. The first light is expected for autumn 2011.

References
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