Dark Energy Survey (DES)

Cluster counts, weak lensing & Supernovae Ia all in one survey...
The DES Collaboration will build and use a wide field optical imager (DECam) to perform a wide area, deep photometric survey.

The scientific goal of DES is to constrain the Dark Energy equation of state (w parameter) and its evolution with time, using 4 different methods: cluster counts, galaxy power spectrum, weak lensing & supernovae Ia.

The expected statistical error on w is ~5% and on dw/dt is ~30%. However the real challenge is controlling the systematics!
The instrument: *DECam*

- It is a **520 (!) Mpix** optical CCD imager, mounted on the **prime focus** of the **4m CTIO Blanco** telescope.
- The detector will have a very wide (**3 deg^2**) foV.
- Will survey **5000 deg^2** of southern sky in 4 filters (**g,r,i,z**)
- The timeline for the survey is **2009-2014** (5 years/525 nights)
4 methods for probing Dark Energy

1) Cluster counts as a function of redshift

2) Cluster angular correlation.

3) Weak lensing survey.

4) SN Ia luminosity distances.
1) Cluster counts as a function of redshift.

This task will be done in collaboration with the South Pole Telescope (SPT) Sunyaev-Zeldovich cluster survey (the 2 surveys share 4000 deg$^2$ of sky in common).

The SPT will measure the mass of tens of thousands of galaxy clusters and the DES will provide the photometric redshifts.

The goal is to measure the number of clusters in a redshift bin with mass larger than a threshold as a function of redshift, which depends sensitively on the cosmological parameters.

\[
\frac{d^2 N}{dzd\Omega}(z) = \frac{d^2V}{dzd\Omega} (z)n_{\text{com}}(z) = \frac{c}{H(z)} D_A^2 (1+z)^2 \int_0^\infty dM f(M,z) \frac{dn}{dM}(z)
\]
4 methods for probing Dark Energy

1) Cluster counts as a function of redshift.
2) Cluster angular correlation.
3) Weak lensing survey.
4) SN Ia luminosity distances.
2) Cluster angular correlation.

- The DES survey will image ~300 million galaxies over a volume of ~10 Gpc$^3$ (much larger than the ~1Gpc$^3$ of SDSS).

- Measuring features in the angular power spectrum of galaxies (such as the BAO wiggles) provides you with “standard rulers”.

SDSS power spectrum from photometric data (Padmanabhan et al. 2007)
4 methods for probing Dark Energy

1) Cluster counts as a function of redshift.
2) Cluster angular correlation.
3) Weak lensing survey.
4) SN Ia luminosity distances.
3) Weak lensing

- DES will measure the shape of ~300 million galaxies and will be able to study the Weak Lensing of galaxies in different redshift bins (weak lensing tomography).

- The clustering of Dark Matter (shear-shear autocorrelation) and the clustering of galaxies with respect to Dark Matter (galaxy-shear crosscorrelation) are powerful probes of cosmological parameters.
4 methods for probing Dark Energy

1) Cluster counts as a function of redshift.
2) Cluster angular correlation.
3) Weak lensing survey.
4) SN Ia luminosity distances.
4) SN Ia luminosity distances

- DES will use 10% of its time in repeat imaging of 40 deg$^2$ of sky to find ~2000 SuperNovae type Ia.
- Constraints produced by SN Ia luminosity distances are almost perpendicular to CMB constraints on the $w$-$\Omega_m$ plane.
The big enemy: **systematics**

1. Cluster counts as a function of redshift. **systematics:**
   - Need to understand very well the *selection function* of Sunyaev-Zeldovich cluster surveys.
   - Need to know the mass-SZ decrement relation.

**remedies:**
- Detection of clusters in the optical DES data (that are subject to different systematics) can help determine the selection function.
- Simulations, and weak lensing mass measurements can help calibrate the mass-SZ decrement relation.
The big enemy: *systematics*

2) Cluster angular correlation. *systematics:*

- Need to understand how galaxy number relates to density of matter (*galaxy bias*).
- Need accurate photometric zero point over the whole survey area.
- Accurate photo-z distances.

**remedies:**

- Use of bispectrum to infer galaxy bias.
- Multiple visits to each field. Checking consistency of results in different subsamples.
- Deep spectroscopic training set available.
The big enemy: *systematics*

- Weak Lensing.
  - *systematics*:
    - Multiplicative and additive shape noise (namely *seeing* and *psf anisotropy*).
    - Possible photo-z biases.

- remedies:
  - Site with good seeing, shear vs. galaxy size.
  - Repeat pointings on fields to effectively increase the density of stars to calibrate psf.
  - Deep spectroscopic training set available.
The big enemy: *systematics*

4) SN Ia luminosity distances.
   systematics:
   - SN evolution.
   - Photo-z accuracy.

remedies:
- Comparison of low- and high-z SN lightcurves.
- Photometric redshift of parent galaxy and photo-z of SN Ia themselves (new!)
Forecast Dark Energy Constraints

- Depends on priors and assumptions about the evolution of $w$.

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<thead>
<tr>
<th>Method/Prior</th>
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<th>WMAP</th>
<th>Planck</th>
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<td>Clusters:</td>
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<td>S-S + bispectrum</td>
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<td>Supernovae Ia</td>
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Statistical errors only!
Baryon Oscillations
Spectroscopic Survey
(BOSS)
Hunting the baryon “wiggles”...
What is it?

- Is one of the 4 surveys of SDSS-III (the other 3 being: SEGUE2, APOGEE, MARVELS)

- The scientific goal of BOSS is to measure the **Baryon Acoustic Oscillation** scale at low ($z < 0.7$) and high ($z \sim 2.5$) redshift, using Luminous Red Galaxies and Quasar Ly-α forest lines respectively.

- Measuring the BAO peak in the transverse and line-of-sight direction gives you the **angular diameter distance** and the **Hubble constant** at a given redshift.
Baryon Acoustic Oscillation (BAO)

- Galaxies tend to cluster more on a **150 Mpc** (comoving) scale.

\[ \langle dN_{\text{pair}} \rangle = \rho_c^2 \left( 1 + \Delta(x)\Delta(x + \xi) \right) dV_1 dV_2 \]

- Provides a “**standard ruler**” in the universe that allows us to measure the angular diameter distance at a given redshift.

SDSS correlation function from spectroscopic LRG sample (Eisenstein et al. 2005)
BAO studies use **Luminous Red Galaxies (LRGs)**, which can be seen at great distances and are composed by a single old population of stars.

The SDSS BAO peak detection was based on ~50,000 LRGs in the redshift range $0.16 < z < 0.47$.

The BOSS sample will consist of ~**1.5 million(!)** LRGs out to $z < 0.7$. 
Quasar Ly-α forest absorption

BOSS will also take the spectra of \(\sim 160,000\) Quasars at high redshift \((z \sim 2.5)\) and will probe the correlation function of the hydrogen gas clouds responsible for the Lyman-α forest.
The galaxy correlation function can be broken down into a **transverse**, and a **radial** component $\xi(\sigma,\pi)$.

The transverse component translates into an angle and the radial into a velocity, constraining the **angular diameter distance** and the **Hubble constant** respectively.

Anisotropic correlation function using 75 000 LRGs from SDSS DR6. (Gaztañaga, Cabré, Hui 2008)
Expected results

**BOSS**
- Aims at measuring the angular diameter distance and Hubble constant at a precision of \(~1\% \text{ at } z=0.35 \text{ and } z=0.6\), using LRGs.
- Aims at measuring the BAO scale at a precision of \(1.5\% \text{ at } z \sim 2.5\), using Quasar Ly-\(\alpha\) forest absorption.

**SDSS (present)**
- Measured the angular diameter distance to \(z=0.35\) with an accuracy of \(~5\%\).
- Measured the Hubble constant at \(z=0.24\) and \(z=0.43\) with \(~4\%\) error.