THE DARK ENERGY SURVEY
STATUS & SCIENCE PROSPECTS

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DARK ENERGY & ACCELERATED EXPANSION

- Radiation ($w = 1/3$)
- Cold Dark Matter ($w \sim 0$)
- Dark Energy ($w = ?$)
- Inflation

$\ddot{a}/a = -(3p + \rho)$

Equation of state parameter:

$p = w(a) \rho$

$w(a) = w_0 + w_a (1 - a) + \cdots$

This is how well we know Dark Energy parameters today. (Komatsu et al. 2010)

$w_0 = -0.93 \pm 0.12$

$w_1 = +0.38 \pm 0.65$

$\Omega_\Lambda = 0.72 \pm 0.02$

Present

13.7 billion years ago

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DARK ENERGY & ACCELERATED EXPANSION

\[ p = w(a) \rho \]

\[ w(a) = w_0 + w_a(1 - a) + \cdots \]

\[ \frac{\ddot{a}}{a} = -(3p + \rho) \]

spacetime geometry
(scale factor)

energy content
(equation of state)

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ASTROPHYSICAL OBSERVABLES

\[ D_L(z) \] Luminosity distance: \textbf{standard candle}
1. supernovae (SNe)

\[ D_A(z) \] Angular diameter distance: \textbf{standard ruler}
2. baryon acoustic oscillations (BAO), cosmic microwave background (CMB)

\[ G(\rho, z) \] Growth of structure: \textbf{galaxy clustering}
3. weak gravitational lensing (WL)
4. galaxy cluster abundance (Clusters)

Planck results will be used in DES analyses.

DES is sensitive to Dark Energy via 4 probes.
**DARK ENERGY SURVEY**

**DECam**

- 3 sq deg FOV, 570 Mpix optical CCD camera
- Facility instrument for CTIO Blanco 4-m telescope in Chile
- First light: Oct 2012

**Survey**

- 5000 sq deg grizY to 24th mag at 0.9 arcseconds seeing overlapping with: SPT, VISTA
- 30 sq deg repeat (SNe)
- 525 nights: 2012-2017
<table>
<thead>
<tr>
<th>SKY SURVEYS</th>
<th>SDSS</th>
<th>DES</th>
<th>LSST</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2001-2014</strong></td>
<td>2012-2017</td>
<td>2021-20??</td>
<td></td>
</tr>
<tr>
<td>Imaging and spectroscopy</td>
<td>Imaging (with plans for spectroscopic follow up)</td>
<td>Imaging</td>
<td></td>
</tr>
<tr>
<td>10,000 deg$^2$ up to z ~ 0.4</td>
<td>5,000 deg$^2$ up to z ~ 1.4</td>
<td>20,000 deg$^2$ up to z ~ 2</td>
<td></td>
</tr>
<tr>
<td>1 galaxy/sq-arcmin</td>
<td>10 galaxies/sq-arcmin</td>
<td>30 galaxies/sq-arcmin</td>
<td></td>
</tr>
<tr>
<td>2.5-m telescope</td>
<td>4-m telescope</td>
<td>8.4-m telescope</td>
<td></td>
</tr>
<tr>
<td>120 Mpix camera</td>
<td>570 Mpix camera</td>
<td>3000 Mpix camera</td>
<td></td>
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Our field is experiencing a transition similar to the Tevatron–LHC transition seen in the collider world.
COLLABORATION

150 scientists, 25 institutions

US: Fermilab, UChicago, LBNL, UIUC/NCSA, Michigan, ANL, TAMU, OSU, UPenn, UCSB, SLAC, Stanford

Brazil: UFRGS, ON, CBPF

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

Germany: LMU

Spain: CIEMAT, IFAE, IEEC/CSIC

Switzerland: ETH Zurich

darkenergysurvey.org
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DECam replaces the old Mosaic camera on the CTIO 4-m telescope in Chile.
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**DECAM**

**CCD focal plane** is housed in a vacuum vessel *(the imager)*

Hexapod provides focus and lateral alignment capability for the corrector-imager system

Barrel supports the **5 lenses** and imager

**LN2** is pumped from the telescope floor to a heat exchanger in the imager: cools the CCDs to -100 C

**CCD readout electronic crates** are actively cooled to eliminate thermal plumes

Filter changer with **8 filter capacity and shutter** fit between lenses C3 and C4
Red Sensitive CCD wafers, designed by LBNL, processed at DALSA and LBNL:

- QE > 50% at 1000 nm
- 250 microns thick
- Readout 250 kpix/sec
- 2 RO channels/device
- Readout time ~17 sec

CCDs are packaged and tested at Fermilab.
From Dec 2011 to Jan 2012

We checked out the imager at CTIO!
DES SCIENCE: SN

First results: \( \sim 100 \) SNe. Measured \( w \).
(Riess et al. 1998, Perlmutter et al. 1999).

4000 SNe up to \( z \sim 1.2 \)

30 sq deg

DES expected sensitivity. Large and deep sample for measurement of \( w(a) \).
First results: mean spectroscopic redshift $\sim 0.35$. Measured $\Omega_m$ (Eisenstein et al. 2005).

DES expected sensitivity. Can measure $w$ by probing deeper.
**DES SCIENCE: CLUSTERS**

Current results: 6000 clusters, $z \sim 0.35$

Measured $\Omega_m$ (Rozo et al. 2010)

100,000 galaxy clusters, $z \sim 1$

DES expected sensitivity. Measure $w$ with deep & wide survey.
Current results: 275 sq deg, 24th magnitude. Measured $\Omega_m$.

(Lin et al. 2011)

5000 sq deg
300M glxs

DES expected sensitivity. Source galaxies in first bin only. Can measure $w$ by going wider.
DES PROJECTED LIMITS

5000 deg$^2$, 0.9” seeing, 24$^{th}$ mag (redshift~1.4)

300M galaxies, shapes, 100K clusters, 4K SNe

4 combined probes

3-5x improved Dark Energy measurement
TIMELINE

DECam

Oct 2010 - Feb 2011: tests on telescope simulator at Fermilab

Mar-Dec 2011: integration and shipping to Chile

Jan-Sep 2012: installation and commissioning

late 2012 onward: available for DES and community

Survey

Fall 2010: PRECam survey collected calibration data

2011-2012: Data pipeline development, survey strategy design

2012-2017: science data taking

Science

2012: Blind Cosmology Challenge on simulated data

2013: Analyses start

2014: First results

DESpec

2012: Concept for a wide-field spectrograph to follow up DES

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CONCLUSIONS

**DES** is a galaxy survey designed to study dark energy.

Data taking will start in 2012 and is planned for 5 years.

We expect to improve current measurements by a factor of 3-5 and shed some light on dark energy.

DECam installation in Chile (June 2012)
BACKUP SLIDES
And picked up a few new collaborators
(some cuter than others)
QUANTUM VACUUM & DARK ENERGY

$\Omega_m$ Matter energy density
$\Omega_k$ Geometrical curvature
$\Omega_\Lambda$ Dark energy density, if vacuum,

\begin{align*}
\Omega_\Lambda &= 1 - \Omega_m - \Omega_k \\
w_0 &= w = -1, \ w_a = 0
\end{align*}

This is how well we know Dark Energy today. Combining multiple probes (Komatsu et al. 2010).

$w_0 = -0.93 \pm 0.12$

$w_1 = +0.38 \pm 0.65$

$\Omega_\Lambda = 0.72 \pm 0.02$

Equation of state consistent with cosmological constant (\$\Lambda\$)

What about the energy density? Ask a theorist...
COSMOLOGICAL CONSTANT PROBLEM

Simple calculation: $\Omega_\Lambda = 10^{120}$

Well, that can’t be right.

Through some not yet understood mechanism (symmetry?) the vacuum energy is cancelled and $\Omega_\Lambda$ is identically zero.

Well, that can’t be right either...
We have measured $\Omega_\Lambda \approx 0.7$
By applying the VT cluster finder on mock catalogs, we can measure the selection function for our cluster catalog.

We apply that selection function back to the cluster number counts to obtain the mass function.
CLUSTERS LENSING

Measure clusters mass-richness relation (tool for cosmology)

Requires a cluster catalog
COSMIC SHEAR

- Statistical measure of shear pattern, ~1% distortion
- Radial distances depend on geometry of Universe
- Foreground mass distribution depends on growth of structure

Slide from J. Frieman
COSMIC SHEAR

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Slide from J. Frieman
COSMIC SHEAR AND COSMOLOGY

\[ \xi_{\pm}(\theta) \equiv \xi_{tt}(\theta) \pm \xi_{\chi\chi}(\theta) = \frac{1}{2\pi} \int_0^\infty d\ell \, \ell \, P_\kappa(\ell) J_0(\ell \theta), \]

convergence power spectrum: matter fluctuations after projection along line of sight

correlation functions

\[ P_\kappa(\ell) = \frac{9}{4} \Omega_m^2 \left( \frac{H_0}{c} \right)^4 \int_0^{\chi_{\text{lim}}} \frac{d\chi}{a^2(\chi)} \int_0^{\chi_{\text{lim}}} d\chi' n(\chi') \frac{f_K(\chi')}{f_K(\chi)} \left[ \int_\chi^{\chi'} \frac{f_K(\chi' - \chi)}{f_K(\chi')} \right]^2, \]

power spectrum: 3D matter fluctuations growth of structure

Galaxy redshift distribution

distances geometry

COSMOLOGY PARAMETERS

Slide from H. Lin
Final result uses our most conservative method/sample (in terms of error bar, photo-z errors, and B-modes):

$$\Omega_m^{0.7} \sigma_8 = 0.252^{+0.032}_{-0.052}$$

- Power spectrum
- $\xi_+ \text{ correlation function}$
- $\xi_E \text{ E-mode correlation function}$
At 275 deg², we are the largest area survey used for cosmic shear detection so far.
CONSTRAINT VS. NUMBER OF GALAXIES

Blue lines indicate constant numbers of galaxies.

- LSST
- Euclid
- DES
- Hyper Suprime-Cam
- CFHTLenS
- SDSS coadd (Lin et al. 2011)
- CTIO
- SDSS coadd (Huff et al. 2011)
- COSMOS
- LSST coadd
- CFHTLS

Survey Area (deg²) vs. Number of galaxies per arcmin² used for lensing.

- 1 million
- 10 million
- 100 million
- 1 billion