The Dark Energy Survey

Sarah Bridle (University College London)
DES Weak Lensing Working Group Co-Coordinator
The Dark Energy Survey

- Dark Energy
- DES Collaboration
- DES Science
- DECam
- Survey Strategy
- Data Management
- Status
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Concordance Model

75% Dark Energy

5% Baryonic Matter

20% Cold Dark Matter
Probes of Dark Energy

**Cosmic Shear**
- Evolution of dark matter perturbations
  - Angular diameter distance
  - Growth rate of structure

**Baryon Wiggles**
- Standard ruler
  - Angular diameter distance

**Supernovae**
- Standard candle
  - Luminosity distance

**Cluster counts**
- Evolution of dark matter perturbations
  - Angular diameter distance
  - Growth rate of structure

**CMB**
- Snapshot at ~400,000 yr, viewed from z=0
  - Angular diameter distance to z~1000
  - Growth rate of structure (from ISW)
Future Dark Energy Surveys
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The Dark Energy Survey

- Survey project using 4 complementary techniques:
  I. Cluster Counts
  II. Weak Lensing
  III. Large-scale Structure
  IV. Supernovae
- Two multiband surveys:
  5000 deg² grizY to 24th mag
  30 deg² repeat (SNe)
- Build new 3 deg² FOV camera and Data management system
  Survey 2012-2017 (525 nights)
  Facility instrument for Blanco
The DES Collaboration

Fermilab
University of Illinois at Urbana-Champaign/NCSA
University of Chicago
Lawrence Berkeley National Lab
NOAO/CTIO
DES Spain Consortium
DES United Kingdom Consortium
University of Michigan
Ohio State University
University of Pennsylvania
DES Brazil Consortium
Argonne National Laboratory
SLAC-Stanford-Santa Cruz Consortium
Universitats-Sternwarte Munchen
Texas A&M University

Over 120 members
plus students & postdocs

Funding: DOE, NSF;
UK: STFC, SRIF;
Spain Ministry of Science, Brazil:
FINEP, Ministry of Science, FAPERJ;
Germany: Excellence Cluster; collaborating institutions

plus Associate members at:
Brookhaven National Lab, U. North Dakota, Paris, Taiwan
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DES Science Committee

- SC Chair: O. Lahav
- Large Scale Structure: E. Gaztanaga & W. Percival
- Weak Lensing: S. Bridle & B. Jain
- Clusters: T. McKay & J. Mohr
- SN Ia: J. Marriner & B. Nichol
- Photo-z: F. Castander & H. Lin
- Simulations: G. Evrard & A. Kravtsov
- Galaxy Evolution: D. Thomas & R. Wechsler
- QSO: P. Martini & R. McMahon
- Strong Lensing: L. Buckley-Geer & M. Makler
- Milky Way: B. Santiago & B. Yanny
- Theory & Combined Probes: W. Hu & J. Weller
Four Probes of Dark Energy

- **Galaxy Clusters**
  - ~100,000 clusters to z>1
  - Synergy with SPT
  - Sensitive to growth of structure and geometry

- **Weak Lensing**
  - Shape measurements of 300 million galaxies
  - Sensitive to growth of structure and geometry

- **Baryon Acoustic Oscillations**
  - 300 million galaxies to z = 1 and beyond
  - Sensitive to geometry

- **Supernovae**
  - 30 sq deg time-domain survey
  - ~4000 well-sampled SNe Ia to z ~1
  - Sensitive to geometry

**Forecast Constraints on DE Equation of State**

Factor 3-5 improvement over Stage II DETF Figure of Merit
Cluster counts

- Elements of the Method:
  - Clusters are proxies for massive halos and can be identified optically to redshifts $z > 1$
  - Galaxy colors provide photometric redshift estimates for each cluster
  - Observable proxies for cluster mass: optical richness (DES), SZ flux decrement (SPT), weak lensing mass (DES), X-ray flux (eRosita)
  - Cluster spatial correlations help calibrate mass estimates

- $\sim 100,000$ clusters to $z > 1$
- Synergy with SPT
- Sensitive to growth of structure and geometry

Number of clusters above mass threshold:

- $\Omega_E = 0.7$, $\sigma_8 = 0.9$
- $\delta z = 0.05$
- $w = -1.0$
- $w = -0.8$
- $w = -0.6$

Redshift

Volume Growth

$\Delta/\sigma$ [4x$10^3$ deg$^2$]
Large Scale Structure

Galaxy Angular Correlation Function in Photo-z bins
-> baryon acoustic oscillations

Systematics: photo-zs, correlated photometric errors, non-linearity, scale-dependent bias

- 300 million galaxies to z = 1 and beyond
- Sensitive to geometry

Fosalba & Gaztanaga
Total Neutrino Mass
DES+Planck vs. KATRIN
$M_\nu < 0.1 \text{ eV}$ \hspace{1cm} $M_\nu < 0.6 \text{ eV}$

Lahav, Kiakotou, Abdalla and Blake (2010) 0910.4714
IV. ~4000 well-sampled SNe Ia to z ~1

DES SN Survey

10 DES fields
Visit once every ~4 days.
2 deep + 8 shallow (30 deg^2)
  deep: 6600 sec per visit (griz)
  shallow: 800 sec per visit (griz)

good z-band efficiency (~4x higher than CFHT/MegaCam) and target high-z SN Ia
→ good rest-frame g-band light curves of z~1 SN Ia.

~4000 well-sampled SNe Ia to z ~1
Weak Lensing
Just one Equation from General Relativity

\[ \hat{\alpha} = \frac{4G M}{c^2 b} \]
Universe was 0.2 Gyr old

Credit: Springel et al. (2005)
Universe was 1 Gyr old
Universe was 4.7 Gyrs old
Today (13.6 Gyr)
COSMOS:
The Largest ever Survey with HST

Credit: NASA, ESA and R. Massey (California Institute of Technology)
In 3 Dimensions

3.5 billion years ago

5 billion years ago

6.5 billion years ago
COSMOS \[\rightarrow\] DES

One DES image (3 sq deg)
Cf whole DES survey 5000 sq deg
Four Probes of Dark Energy

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  - 30 sq deg time-domain survey
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**Forecast Constraints on DE Equation of State**

- Factor 3-5 improvement over Stage II DETF Figure of Merit
  - Planck prior assumed
The Shear Measurement Problem

The Forward Process.

Galaxies: Intrinsic galaxy shapes to measured image:

Intrinsic galaxy (shape unknown) → Gravitational lensing causes a shear \((g)\) → Atmosphere and telescope cause a convolution → Detectors measure a pixelated image → Image also contains noise

The GREAT08 Challenge Handbook (Bridle et al. 2008)
A Typical Galaxy

Results of the GREAT08 Challenge (Bridle et al. 2010)
See GREAT10 - ongoing
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Dark Energy Camera

Mechanical Interface of DECam Project to the Blanco

Optical Corrector Lenses

Hexapod: optical alignment

Filters & Shutter

CCD Readout
Optics

- **Field of view:** 2.2° diameter
- **Good image quality across FOV**
- **Optical elements being aligned in barrel at UCL, will ship to CTIO Aug/Sept**

S. Kent (FNAL)
The 5 lenses are nearly ready

Polishing & coating coordinated by UCL (with 1.7M STFC funding)
DECam CCDs

- 62 2kx4k fully depleted CCDs: 520 Megapixels, 250 micron thick, 15 micron (0.27") pixel size
- 12 2kx2k guide and focus chips
- Excellent red sensitivity
- Roughly twice the number of science-grade CCDs packaged and ready to install

Developed by LBNL
Filters

- Filter contract awarded to Asahi in 2009
- 620mm substrate, 600mm clear aperture
- Asahi has built and commissioned a huge coating chamber as well as custom cleaning, polishing and testing equipment
- i and z filters completed and about to ship to Chile. 1 side of Y done
• DECam mounted on Telescope Simulator at Fermilab in early 2011
• DECam both DES survey instrument and CTIO facility instrument
• The CTIO Director has scheduled the telescope shutdown to start on Nov. 8.
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DES Observing Strategy

Sept-Feb observing seasons
80-100 sec exposures
2 filters per pointing (typically)
  \(gr\) in dark time
  \(izy\) in bright/grey time
Photometric calibration: overlap tilings, standard stars, spectrophotometric calibration system, preCAM
2 survey tilings/filter/year
Interleave 10 SN fields in \(griz\) if non-photometric or bad seeing or time gap (aim for \(~5\) day cadence)
Photometric Redshifts

- Measure relative flux in multiple filters: track the 4000 Å break

- Estimate individual galaxy redshifts with accuracy $\sigma(z) < 0.1$ (~0.02 for clusters)

- Precision is sufficient for Dark Energy probes, provided error distributions well measured.
VISTA Hemisphere Survey

VISTA
4.1 m primary mirror
1.5 deg field of view
16 2k x 2k HgCdTe

VHS
380 nights over 5 yrs
120 sec JHK exposures
Richard McMahon, PI

VHS limiting magnitudes [AB system; 5σ]

<table>
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<th>J</th>
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<td>21.9</td>
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DES collaborates with VHS: DES acquires Y imaging, VHS shares JHK data
Galaxy Photo-z Simulations

**DES+VHS***

10σ Limiting Magnitudes
- g: 24.6
- r: 24.1
- i: 24.0
- z: 23.8
- Y: 21.6

+2% photometric calibration error added in quadrature

Spectroscopic training sets comparable to DES depth exist

*Vista Hemisphere Survey

+VHS JHKs on ESO VISTA 4-m enhances science reach
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DES Data Management

http://cosmology.illinois.edu/DES/

- The DESDM system:
  - Process DES data at NCSA
  - Archive DES data over the long term
    - ~4PB total, ~350TB database
  - Distribute data to Collaboration
  - Distribute data to public
    - NOAO: Raw/reduced data after 1 yr
    - NCSA: Co-adds/catalogs at midpoint and end of survey

Exposure consists of 62 2kX4k CCD images - 3deg²
Survey is ~150,000 exposures over 525 nights
Each image
- 3 sq. deg.
- ~ 20 Galaxy clusters
- ~ 200,000 Galaxies
- 520 Mega pixels (62 CCDs)

Each night ~ 300 GB of image data

We will use 500 nights for the Dark Energy Survey

The large field of view lets us cover the sky in a reasonable amount of time.

courtesy of F. Valdes/NOAO
DECam Image Simulations

Populate N-body sims w/ galaxies drawn from SDSS+evolution+shapes
DECam Image Simulations

Series of Data Challenges to test Data Management System

Note bright star artifacts, cosmic rays, cross talk, glowing edges, flatfield ("grind marks", tape bumps), bad columns, 2 amplifiers/CCD.
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Project Structure & Timeline

• 3 Construction Projects:
  • DECam (hosted by FNAL; DOE supported)
  • Data Management System (NCSA; NSF support)
  • CTIO Facilities Improvement Project (NSF/NOAO)

  - NOAO Blanco Announcement of Opportunity 2003
  - DECam R&D 2004-8
  - Camera construction 2008-11
  - Final construction, testing, integration now on-going
  - Ship components to Chile this year
  - Installation of imager ~Nov/Dec 2011
  - First light on telescope: ~Jan 2012
  - Commissioning and Science Verification: Jan-April 2012
  - Survey operations begin: Sept 2012
DESpec: Spectroscopic follow up of DES

• Proposed Dark Energy Spectrometer (DESpec)
• 4000–fibre instrument for the 4m Blanco telescope in Chile, using DES optics and spare CCDs
• 10 million galaxy spectra, target list from DES, powerful synergy of imaging and spectroscopy, starting 2017-18
• DES+DESpec can improve DE FoM by 3-6, making it DETF Stage IV experiment
• DES+DESpec can distinguish DE from ModGrav
• Participants: current international DES collaboration + new teams
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The optics and CCD imager are positioned by the hexapod
Gravitational shear has the greatest potential
Big uncertainty largely due to shear measurement techniques
SKA calculations based on predictions by Abdalla & Rawlings 2005
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</table>
GREAT08 Breakdowns

- Galaxy type vs. $\sigma$
  - b or d
  - b+d
  - b+d offcenter

- PSF type vs. $\sigma$
  - Fid rotated
  - Fid
  - Fid x2

- SNR vs. $\sigma$

- $R_{gp}/R_p$ vs. $\sigma$

Legend:
- HB
- AL
- TK
- CH
- PG
- MV
- KK
- HHS3
- SB
- HHS2
- HHS1
- MJ
- UWSQM
Standard rulers
Baryon Acoustic Oscillations (BAO)

(images from Martin White)

Percival et al. (2007)
Why is the Universe Accelerating?

- Einstein’s cosmological constant
  \[ R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu} \]

- A new fluid called Dark Energy
  - Equation of state \( w = p/\rho \)
  - \( w = w_0 + w_a (1-a) + \ldots \)

- General Relativity is wrong