The Dark Energy Survey – Overview and Recent Science Highlights

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• **New Instrument:**
  - Replaced the prime-focus cage on the CTIO Blanco 4m telescope in Chile with a new $2.2^\circ$ field-of-view, 570 Mega-pixel CCD camera + optics in 2012.

• **Survey:**
  - 525 nights during 2013-2018 (August - February)
  - 30% of the telescope time available to community
  - $1/4^{th}$ of southern sky ($5000 \text{ deg}^2$) in 5 optical and near-infrared filters ($g, r, i, z, Y$)
• **Multi-probe approach:**
  - Wide Field: Weak Lensing, Large Scale Structure, Cluster Counts
  - Time Domain: Supernovae

• **Survey Strategy**
  - 300 million photometric redshifts (grizY) over 5000 deg$^2$
  - + 2500 Sne (over 27 deg$^2$ fields) overlap with VHS+SPT+OzDES

• **Science Verification (SV):** 250 deg$^2$ to full depth
  - **Y1:** approx. 2000 deg$^2$, 40% dept, Median seeing FWHM approx. 0.9”
  - **Y2:** approx remaining 3000 deg$^2$
  - **Y3:** just ended

• **Over 60 DES papers on the arXiv**
The DES Collaboration

- 150 senior scientists
- 400+ collaborators
- 25 institutions, including 9 US universities

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

UK Consortium

ETH Zurich
Ludwig-Maximilians Universität

Spain Consortium

Brazil Consortium

OzDES Participation Consortium (Australia)

CTIO
Overlapping Imaging Surveys

Overlapping Spectroscopic Surveys

Credit: Alex Merson (UCL)
Gravitational Lensing: Weak and Strong

HST CLASH cluster MACS1206
• Tomographic (3 redshift bins) cosmic shear two-point measurement (Becker et al: arXiv:1507.05598)
• SV Data: 139 deg$^2$

Based on DES SV Shear Catalog: Jarvis et al. 2015
Comparison of jack-knife estimated covariance: Data vs. mock

Becker et al. 2015
• Cosmological Parameter Estimation: DES collaboration 2015 (The DES collaboration arXiv: 1507.05552)
• SV data: 139 deg$^2$
• 3 redshift bins
  • 0.3<z<0.55
  • 0.55<z<0.83
  • 0.83<z<1.3
• Marginalized over a set of nuisance parameters

MacCrann corresponding author

Flat priors: 0.2<h<1, 0.01<\Omega_b<0.07, 0.7<n_s<1.3

Nuisance parameters: shear calibration, photometric redshift calibration, intrinsic alignment, non-linear matter power spectrum
Systematics considered for WL analysis

\[ S_8 = 0.81 \pm 0.06 \]

The DES collaboration
arXiv: 1507.05552
Possibly (first) signature of DE in DES-SV data alone

$S_8$ is not sensitive to $w$

$S_8$ from DES is in between Planck and CFHTLenS values

WL image distortion: 1% effect, to be measured to 1%, to get $w$ to 1%

The DES collaboration arXiv: 1507.05552
Galaxy Clustering in DES SV Data

- Angular two-point correlation of $2.3 \times 10^6$ galaxies, SV data: 116 deg$^2$
- Five bins $0.2 < z < 1.2$
- Constraints on linear bias
- $i < 22.5$
- Two photo-z methods: template and machine learning

Recontres de Moriond 2016 - Cosmology - Jochen Weller

Crocce et al. arXiv 1507.05360
Clusters in Science Verification out to $z>1$

High redshift clusters discovered in DES Science Verification: contours show X-ray emission

courtesy: Kathy Romer
redMaPPer SVA1 Sample

Cluster density contrast
0.2 < z < 0.8

For $\lambda > 20$
(M $\sim 10^{14}$)

Redmapper: matched filter, red sequence
In SV: z-band for detection magnitude (in DR8 i-band), because DES performance and range

SV cluster catalog; Rykoff et al.
2016 arXiv:1601.00621

Redshift accuracy
$\sigma_z/(1+z) = 0.01$ (z<0.7)
0.02 (0.7<z<0.9)
Cluster distribution correlates strongly with large scale mass distribution

- redMaPPer clusters between 0.1 < z < 0.5

Vikram et al. 2015
arXiv:1504.03002

- Convergence maps of 139 deg² SV data

Background/Foreground sample
• "Weak Lensing by galaxy troughs in DES Science Verification Data" – Gruen et al. 2015 (arXiv: 1507.05090)
• Lensing signal around lines of sight with lowest and highest galaxy number density
• Choose cylindrical regions 5’…30’ radius, 0.2<z<0.5, troughs below 20th percentile in galaxy density (overdense 80th)
• SV Data
• Abundance of peaks, 139 deg$^2$
• Marginalised of multiplicative bias, redshift errors
• Modelling of intrinsic alignment, blending and source contamination by cluster members ($S/N>4$ significant corrections)
• Only $0<S/N<4$
Cross correlation of DES galaxies and mass fluctuations derived from the CMB

DES Gal-Gal (0.2<z<1.2) (cf. Crocce et al)

DES Gal – SPT mass (6-sigma)

DES Gal – Planck mass (4-sigma)

Measurement of growth 1.7 σ “tension”
Cross correlation of mass: DES-WL x CMB-WL

- SV Data; 139 deg$^2$
- Correlation of DES shear with CMB convergence


SPT: 2.9σ; Planck: 2.2σ

<table>
<thead>
<tr>
<th>Redshift Range</th>
<th>0.3 &lt; z &lt; 1.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\kappa_{\text{CMB}} \times \gamma_E$</td>
<td>$A$</td>
</tr>
<tr>
<td>ngmix $\times$ SPT</td>
<td>$0.88 \pm 0.30$</td>
</tr>
<tr>
<td>ngmix $\times$ Planck</td>
<td>$0.86 \pm 0.39$</td>
</tr>
</tbody>
</table>
New Dwarfs in the Milky Way

17 MW dwarf satellites from Y1+Y2 (in red):

Drlica-Wagner et al. 2015a,b
Bechtol et al. 2015a
+ Independent papers by a Cambridge team (Koposov et al. 2015)

From Ret 2’s spectroscopy (Simon et al. 2015)
M/L = 470 (M/L)_sun
Summary

- Promising first cosmological analysis from DES weak lensing and cross-correlations of galaxies
  - SV and Y1 Data (SV is public now)
- Marginal “evidence” for DE from DES alone
- First DES Galaxy Cluster Catalogue
- Not covered: SNe, Strong Lensing
- Promising “Non-Cosmological” Science: dwarf satellites, trans-neptunian objects (Planet 9), quasars, …
- 3 More DES Talks at this meeting:
  - GW follow up (Marcelle Soares-Santos)
  - photo-zs (Ben Hoyle)
  - kSZ (Kyle Story)
Additional SLIDES
<table>
<thead>
<tr>
<th>Property</th>
<th>$\chi^2$ [d.o.f. = 8]</th>
<th>$\Delta \xi_+/\sigma(\xi_+)$</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NGMIX (IM3SHAPE)</td>
<td>NGMIX (IM3SHAPE)</td>
<td></td>
</tr>
<tr>
<td>Signal-to-Noise</td>
<td>4.9 ( 5.2 )</td>
<td>0.05 ( 0.49 )</td>
<td>Signal-to-noise of galaxy detection</td>
</tr>
<tr>
<td>Galaxy Size</td>
<td>5.3 (10.7)</td>
<td>-0.3 ( 0.15 )</td>
<td>Galaxy size (deconvolved with PSF)</td>
</tr>
<tr>
<td>Galaxy Colour</td>
<td>7.3 ( 2.2 )</td>
<td>-0.31 ( -0.32 )</td>
<td>$g-z$ colour</td>
</tr>
<tr>
<td>Surface Brightness</td>
<td>7.8 ( 8.7 )</td>
<td>0.33 ( -0.32 )</td>
<td>Galaxy surface brightness</td>
</tr>
<tr>
<td>RA</td>
<td>7.0 ( 8.8 )</td>
<td>0.24 ( 0.28 )</td>
<td>Galaxy right ascension</td>
</tr>
<tr>
<td>Dec</td>
<td>4.0 ( 6.2 )</td>
<td>-0.24 ( -0.57 )</td>
<td>Galaxy declination</td>
</tr>
<tr>
<td>E(B-V)</td>
<td>5.1 ( 6.2 )</td>
<td>0.23 ( 0.06 )</td>
<td>Mean extinction</td>
</tr>
<tr>
<td>Air Mass</td>
<td>20.7 (13.8 )</td>
<td>0.31 ( 0.46 )</td>
<td>Mean $r$-band air mass</td>
</tr>
<tr>
<td>Exposure Time</td>
<td>4.7 ( 6.8 )</td>
<td>0.18 ( 0.3 )</td>
<td>Mean total $r$-band exposure time</td>
</tr>
<tr>
<td>Mag. Limit</td>
<td>4.4 ( 7.4 )</td>
<td>0.18 ( 0.45 )</td>
<td>Mean $r$-band limiting magnitude</td>
</tr>
<tr>
<td>Sky Sigma</td>
<td>1.7 ( 13.0 )</td>
<td>-0.02 ( -0.08 )</td>
<td>Mean $r$-band RMS sky brightness</td>
</tr>
<tr>
<td>Sky Brightness</td>
<td>5.0 ( 14.3 )</td>
<td>-0.05 ( -0.27 )</td>
<td>Mean $r$-band sky brightness</td>
</tr>
<tr>
<td>FWHM</td>
<td>6.4 ( 3.3 )</td>
<td>-0.23 ( -0.13 )</td>
<td>Mean $r$-band PSF FWHM</td>
</tr>
<tr>
<td>PSF $e_1$</td>
<td>16.8 (13.5 )</td>
<td>0.12 ( -0.37 )</td>
<td>Galaxy PSF $e_1$</td>
</tr>
<tr>
<td>PSF $e_2$</td>
<td>17.1 ( 7.5 )</td>
<td>-0.58 ( -0.22 )</td>
<td>Galaxy PSF $e_2$</td>
</tr>
<tr>
<td>PSF Size</td>
<td>2.6 ( 5.6 )</td>
<td>-0.1 ( 0.42 )</td>
<td>Galaxy PSF size</td>
</tr>
</tbody>
</table>
Systematics of WL Measurement

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