New results from the Dark Energy Survey

Eric Baxter, University of Pennsylvania with the Dark Energy Survey collaboration
The Success of LCDM

LCDM model explains many observations amazingly well

Mantz et al. 2014
The beginning of tension?

$\sigma_8$: lensing (+clusters) vs. CMB

Douspis et al.
The beginning of tension?

$H_0$: local vs. CMB (+BAO)

Freedman, 2017
What do you when model tension is at the 2-4σ level?
What do you when model tension is at the 2-4σ level?

Collect more data!
The Dark Energy Survey

5.5 year survey of 5000 sq. deg. of southern sky in optical wavelengths

4 meter mirror

Dark energy camera (DECam)
Wide field of view, 62 CCDs, red optimized

Year 5 data already collected

Many probes: weak lensing, galaxy clustering, clusters, supernovae
The Dark Energy Survey

5.5 year survey of 5000 sq. deg. of southern sky in optical

Many probes: weak lensing, galaxy clustering, clusters, supernovae
Outline

1. Year one two-point function analysis
2. DES + BAO constraint on Hubble constant
3. Going to small scales: splashback
DES year one joint two-point correlation function analysis a.k.a. 3x2pt
Two-point correlations between galaxies and lensing

Correlations between galaxies and gravitational lensing are sensitive to cosmology.

For a Gaussian random field, two-point functions contain all information.*

*But...large scale structure is non-Gaussian.
The three 2pt functions

Joint measurement of three two-point functions:
• $<\text{galaxies} \times \text{galaxies}>$
• $<\text{galaxies} \times \text{lensing}>$
• $<\text{lensing} \times \text{lensing}>$

Multiple probes make 3x2pt very robust to systematics

Main measurement ingredients are galaxy positions, redshifts, and shapes
Measuring galaxy redshifts

Galaxy redshift estimates are needed for modeling 3x2pt

For source galaxies, use standard template fitting approach
• Use other techniques to constrain potential systematics

For lens galaxies, use redMaGiC (Rozo et al. 2016)
• Only include galaxies that are good match to a template

Credit: http://www.stsci.edu/~dcoe/BPZ
Measuring galaxy lensing

DES uses images of galaxy shapes to infer gravitational lensing.

DES Y1 approach: metacal (Sheldon & Huff 2017)

- Calibrate response of a shear estimator by applying artificial shear to actual image.
Modeling 3x2pt

DES year one philosophy: keep it “simple”

The model:
- Constant linear galaxy bias in each redshift bin
- Ignore baryonic effects
- Basic intrinsic alignment model
- One parameter photo-z and shear systematic models

Cut out scales that we don’t know how to model
- Unfortunately, this means throwing out lots of signal!

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Cosmology</th>
<th>Prior</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Omega_m$</td>
<td>flat (0.1, 0.9)</td>
<td></td>
</tr>
<tr>
<td>$A_s$</td>
<td>flat (5 x 10^{-10}, 5 x 10^{-9})</td>
<td></td>
</tr>
<tr>
<td>$n_s$</td>
<td>flat (0.87, 1.07)</td>
<td></td>
</tr>
<tr>
<td>$\Omega_b$</td>
<td>flat (0.03, 0.07)</td>
<td></td>
</tr>
<tr>
<td>$h$</td>
<td>flat (0.55, 0.91)</td>
<td></td>
</tr>
<tr>
<td>$\Omega_{\nu} h^2$</td>
<td>flat(5 x 10^{-4}, 10^{-2})</td>
<td></td>
</tr>
<tr>
<td>$w$</td>
<td>flat (-2, -0.33)</td>
<td></td>
</tr>
</tbody>
</table>

| Lens Galaxy Bias | $b_i(i = 1, 5)$ | flat (0.8, 3.0) |
| Intrinsic Alignment | $A_{1A}(z) = A_{1A}[(1 + z)/1.62]^{0.1A}$ | $A_{1A}$ flat (-5, 5) |
|                    | $\eta_{1A}$ | flat (-5, 5) |

| Lens photo-z shift (red sequence) | $\Delta z_1^1$ Gauss (0.001, 0.008) |
|                                  | $\Delta z_2^1$ Gauss (0.002, 0.007) |
|                                  | $\Delta z_3^1$ Gauss (0.001, 0.007) |
|                                  | $\Delta z_4^1$ Gauss (0.003, 0.01) |
|                                  | $\Delta z_5^1$ Gauss (0.0, 0.01) |

| Source photo-z shift | $\Delta z_1^2$ Gauss (-0.001, 0.016) |
|                      | $\Delta z_2^2$ Gauss (-0.019, 0.013) |
|                      | $\Delta z_3^2$ Gauss (+0.009, 0.011) |
|                      | $\Delta z_4^2$ Gauss (-0.018, 0.022) |

| Shear calibration | $m_{\text{METACALIBRATION}}^{i}(i = 1, 4)$ Gauss (0.012, 0.023) |
|                   | $m_{\text{IM3SHAPE}}^{i}(i = 1, 4)$ Gauss (0.0, 0.035) |

Abbot et al. 2017
Scale cuts

Prat et al. 2017
3x2pt results

The different DES two-point functions are consistent with each other.

Tight cosmological constraints

DES Y1, Abbot et al. 2017
3x2pt results

The different DES two-point functions are consistent with each other.

Tight cosmological constraints.
3x2pt results vs. Planck

DES 3x2 prefers low $S_8$ and matter density relative to Planck (similar to other previous weak lensing measurements)

Statistically consistent with Planck
Using DES and baryon acoustic oscillations to constrain the Hubble constant
Baryon acoustic oscillations

Same photon-baryon oscillations that give rise to CMB power spectrum also lead to characteristic scales in galaxy distribution

Credit: D. Eisenstein
Predicting the BAO scale

Angular scale of BAO feature is $r_s/D_M$
- $r_s$ is sound horizon at photon-baryon decoupling
- $D_M$ is angular diameter distance to galaxies

In flat LCDM, $D_M$ is fixed by $H_0$ and $\Omega_m$
$r_s$ depends on $T_{CMB}$, $\Omega_m h^2$, $\Omega_b h^2$

Can get constraint on Hubble with:
- BAO measurement of $r_s/D_M$
- COBE measurement of $T_{CMB}$
- big bang nucleosynthesis constraints on $\Omega_b h^2$
- **DES measurement of** $\Omega_m$

Completely independent of CMB power spectrum and distance ladder measurements
Constraints on the Hubble constant

Abbot et al. 2017
Constraints on the Hubble constant

Many different measurements of $H_0$

Considering all measurements, evidence for tension only at the $\sim 2\sigma$ level
Small scales with DES
Going to small scales

Lots of interesting physics and signal-to-noise at smaller scales

However: small scales are more difficult to model
Self similar collapse models predict that accreted matter piles up at first apoapsis after collapse (e.g. Fillmore & Goldreich 1984)
Splashback

Splashback feature seen in N-body simulations, even after averaging over many halos (Diemer & Kravtsov 2014)

Can measure in data by correlating galaxy clusters with galaxies
• Use galaxies as tracers of mass

However, predictions for splashback radius do not agree with observations
• Modified gravity? Dark matter-baryonic interactions? (Adhikari, Jain, Sakstein, Dalal…)

\[
\Sigma_g(R) = \frac{M_{\text{vir}}}{4\pi R^2}
\]

\[
d\log \Sigma_g / d\log R
\]
For the first time we measure this feature using gravitational lensing

Find similar level of tension (several sigma) with simulations using galaxy distribution

Chang, Baxter et al. 2017
The future of DES

Data: ~4.5x more data to be analyzed

Measurements: new shape measurement algorithms, new galaxy catalogs

Analysis: improved modeling of small scales
Summary

With first year data, **DES has already yielded tightest cosmological constraints from a single galaxy survey**

**Weak lensing and galaxy clustering are now competitive with Planck**

Lots of science beyond two-point function cosmology

**Significant near term improvements due to more data and better analysis**

Hopeful that situation with various tensions will be clarified in near future