New Results from the Dark Energy Survey and the South Pole Telescope

Eric Baxter, University of Pennsylvania
with the South Pole Telescope and Dark Energy Survey collaborations
The standard cosmological model

Credit: WMAP
Important unanswered questions and close connections to particle and nuclear physics.

- Is dark energy a cosmological constant?
- What powered inflation?
- Quantum Fluctuations
- Afterglow Light Pattern 380,000 yrs.
- Dark Ages
- Development of Galaxies, Planets, etc.
- Particle nature of dark matter
- 1st Stars about 400 million yrs.

Credit: WMAP

Big Bang Expansion
13.7 billion years
Important unanswered questions and close connections to particle and nuclear physics

- What powered inflation?
- Afterglow Light Pattern 380,000 yrs.
- Quantum Fluctuations
- Baryon asymmetry
- Dark Ages
- Development of Galaxies, Planets, etc.
- Dark Energy Accelerated Expansion
- Is dark energy a cosmological constant?
- Particle nature of dark matter
- Sum of neutrino masses
- 1st Stars about 400 million yrs.

Credit: WMAP
Two main tools of cosmology

- Cosmic microwave background (CMB)
- Large scale structure (LSS)

Key events:
- Inflation
- Afterglow Light Pattern 380,000 yrs.
- Dark Ages
- Development of Galaxies, Planets, etc.
- 1st Stars about 400 million yrs.
- Big Bang Expansion 13.7 billion years
- Dark Energy Accelerated Expansion
How do we learn from the CMB?

Primary Anisotropies

Primary anisotropies in temperature and polarization imprinted at time of recombination

Provide snapshot of the Universe at \( z \approx 1100 \) (age \( \approx 400,000 \) years)

Sensitive to geometry, matter content, extra light degrees of freedom, inflation, …
How do we learn from the CMB?
Secondary Anisotropies

Secondary anisotropies are imprinted after recombination:
Gravitational lensing
Sunyaev Zel’dovich effect
Integrated Sachs Wolfe effect

Sensitive to expansion history, growth of structure, thermal history...
How do we learn from large scale structure?

Like the CMB, galaxies and gravitational lensing probe underlying matter fluctuations

Many more modes than CMB (3D vs. 2D)

But nonlinear!

credit: Millennium simulation, Springel et al. 2005
Cross-correlations between the CMB and LSS

Secondary anisotropies induce correlation between CMB and LSS

Cross-correlation between tracers of large scale structure and CMB can be used to isolate contributions to secondary anisotropy as a function of redshift
Cross-correlations between the CMB and LSS

Secondary anisotropies *induce correlation* between CMB and LSS

Cross-correlation between tracers of large scale structure and CMB can be used to isolate contributions to secondary anisotropy as a function of redshift.
Outline

1. The South Pole Telescope and the Dark Energy Survey

2. Overview of recent results from both experiments

3. Future data from SPT and DES
The South Pole Telescope (SPT)

10-meter sub-mm wavelength
Roughly 1 arcmin resolution

2007: SPT-SZ
960 detectors
100, 150, 220 GHz

2012: SPTpol
1600 detectors
100, 150 GHz
+Polarization

2016: SPT-3G
~15,200 detectors
100, 150, 220 GHz
+Polarization

Credit: Brad Benson
Planck
143 GHz
50 deg²
Science with SPT

High angular resolution and low noise

Secondary anisotropies
• Gravitational lensing
• Galaxy clusters

Polarization
• Lower foregrounds at high ell
• Inflationary B-modes

George et al. 2014
The Dark Energy Survey

5.5 year survey of southern sky in optical wavelengths (year 1 results recently released)

4 m mirror telescope

Dark energy camera (DECam)
wide field of view, 62 CCDs, optimized for high redshift
Galaxy image from the Sloan Digital Sky Survey (DR7)

H. Dominguez Sanchez et al. 2018
Same galaxy with DES (Year 1)

H. Dominguez Sanchez et al. 2018
Science with DES

DES strengths:
• Wide area (5000 sq. deg.)
• Sensitivity to high redshifts
• Weak lensing quality imaging

Multicomponent cosmology strategy:
  - Gravitational lensing
  - Galaxy clustering
  - Galaxy cluster counts
  - Supernovae

\( w_0 \) and \( w_a \) describe equation of state of dark energy
Recent results from SPT
Recent results from SPT: Are SPT and Planck consistent?

No evidence for inconsistency between SPT and Planck over same patch of sky and same modes, 650 < ell < 2000 (Aylor et al. 2017, Hou et al. 2018)

PTEs Between Planck full-sky and SPT

<table>
<thead>
<tr>
<th>$\ell_{\text{max}}$</th>
<th>1800</th>
<th>2000</th>
<th>2500</th>
<th>3000</th>
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<tbody>
<tr>
<td>$D_b^{150 \times 150}$</td>
<td>0.21</td>
<td>0.24</td>
<td>0.094</td>
<td>0.032</td>
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<tr>
<td>$D_b^{150 \times 143}$</td>
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</tr>
<tr>
<td>$D_b^{143 \times 143}$</td>
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</tbody>
</table>

Mild tension (pte = 0.03) between SPT cosmology constraints over 650 < ell < 3000 and Planck full sky
- Tension requires both high ell SPT data and Planck data not in SPT patch
Recent results from SPT: SPTpol 500 sq. deg.

Most sensitive measurements to date of EE and TE power spectra at high ell

For ell < 1000, consistent with Planck cosmological constraints
For ell > 1000, prefers slightly higher $H_0$ and lower $\sigma_8$
Full dataset in mild tension (2.1$\sigma$) with LambdaCDM
Recent results from SPT:
Gravitational lensing

Can use observed pattern of anisotropies to map gravitational lensing strength

Better constraints from combination of Planck (large scale) and SPT (small scale) data

Simard et al. 2018
Omori et al. 2017
Recent results from SPT: Galaxy clusters

SPT detects galaxy clusters via Sunyaev-Zel’dovich effect

Abundance of galaxy clusters is a sensitive cosmological probe

Can use CMB lensing to measure cluster masses
  First detection of gravitational lensing of CMB by SZ-selected galaxy clusters (Baxter et al. 2015)
Recent results from DES
Recent results from DES:
Cosmological constraints from 2pt functions

Two-point correlations between galaxy positions and gravitational lensing are sensitive to cosmology:
Recent results from DES: Cosmological constraints from 2pt functions

Two-point correlations between galaxy positions and gravitational lensing are sensitive to cosmology.

DES Y1 joint two-point analysis (3x2pt)
Tightest cosmological constraints from a single galaxy survey!

Shear = gravitational lensing alone
$w + \gamma_T = \text{clustering and galaxy lensing}$

DES Y1, Abbot et al. 2017
Recent results from DES: Cosmological constraints from 2pt functions

DES prefers slightly lower value of $S_8$
- Same as earlier lensing results
- But **not** statistically significant
Recent results from SPT x DES

Significant overlap between SPT and DES surveys makes cross-correlation analyses possible.
Recent results from SPT x DES: Joint 2pt function measurements

Two-point correlations between DES galaxies and shears with SPT measurement of CMB lensing

- Provides consistency test
- Breaks parameter degeneracies
- Adds signal-to-noise

Baxter et al. 2018a
Recent results from SPT x DES: Using the CMB to measure masses of DES galaxy clusters

SPT CMB lensing measurements place competitive constraints on masses of DES galaxy clusters!

Baxter et al. 2018b
Future: SPT-3G

**SPT-3G**
- Order of magnitude more detectors than SPTpol
- 20x mapping speed

~10,000 galaxy clusters
- Masses calibrated to ~3% with CMB lensing

~150σ measurement of CMB lensing power spectrum

First light on Jan. 30th 2017

### Projections (w/ Planck priors)

<table>
<thead>
<tr>
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<th>SPT-3G (2019)</th>
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<tbody>
<tr>
<td>σ(r)</td>
<td>0.011</td>
</tr>
<tr>
<td>σ((N_{eff}))</td>
<td>0.058</td>
</tr>
<tr>
<td>σ(Σm(\nu))</td>
<td>0.061 eV*</td>
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* Includes BOSS prior

Benson et al. 2014
Future: DES Year 5.5

Year 5 data already collected, currently being processed
• Deeper imaging, more area
• Improved shear estimates
• Expanded galaxy catalogs
• Analysis improvements
Future: cross-correlation science

Future DES and SPT data

- More overlap
- Better CMB lensing maps

DES x Atacama Cosmology Telescope
AdvancedACT has low noise and large overlap with DES

Highlights of cross-correlation science

- Improved cosmological constraints with CMB lensing cross-correlations
- Improved cosmological constraints from multi-wavelength galaxy cluster observations
- Constraints on gas physics in dark matter halos from measurement of thermal and kinematic Sunyaev-Zel’dovich effects
Summary

Many different probes from two fundamentally different experiments are broadly consistent with same cosmological model (with possible hints of tensions)

High level of synergy between SPT and DES experiments
  • Overlap enables exciting cross-correlation science

Stay tuned for new results!
Thank you!