SPTpol

Clarence Chang
KICP/UChicago
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The South Pole Telescope: a mm-wave observatory

- Excellent site
- 1 arcmin resolution
- 1 deg² FOV

photo by Dana Hrubes
The South Pole Site

- Dry air for optimal atmospheric transmission
- Stable environment

![Image of South Pole Site]

**Its very dry.**

<table>
<thead>
<tr>
<th>Precipitable Water Vapor (mm of water)</th>
<th>South Pole</th>
<th>Atacama</th>
<th>Mauna Kea</th>
</tr>
</thead>
<tbody>
<tr>
<td>4/95-9/95</td>
<td>0.19</td>
<td>0.25</td>
<td>0.24</td>
</tr>
<tr>
<td>10/95-3/96</td>
<td>0.80</td>
<td>0.32</td>
<td>0.47</td>
</tr>
<tr>
<td>Jan-Jun</td>
<td>3.70</td>
<td>1.10</td>
<td>2.00</td>
</tr>
<tr>
<td>July-Dec</td>
<td>5.88</td>
<td>1.05</td>
<td>1.65</td>
</tr>
</tbody>
</table>

(A.P. Lane 1998)

From radiosonde
Computed from measured 225 GHz opacity

**SPT bands + 0.25 mm PWV**

![Graph showing transmission vs. frequency]
Small angular resolution

• 10-m dish at 150 GHz gives \(~1\) arcmin beam (PSF)

• \(~260\) panels aligned to 25 \(\mu\)m rms over 10-m surface gives 95% efficiency at 220 GHz
High sensitivity and large throughput

- FOV ~ 1 deg$^2$ ... large focal plane = lots of detectors
- 2500 deg$^2$ survey at 1,2, & 3 mm; now complete
Recent highlights

Fig. 2.— The WMAP7 and SPT bandpowers. The SPT bandpowers at $\ell \leq 2000$ are taken from K11 and are at $500\,\text{GHz}$ only. At $\ell \geq 2000$, we show the bandpowers at 95, 150, and 220 GHz measured with the SPT in this work. Below $\ell = 2000$, the primary CMB anisotropy is dominant at all frequencies. On smaller scales, the CIB, radio sources, and secondary CMB anisotropies contribute to the signal. With the SPT source masking, the CIB is the largest source of power on subarcminute scales at 95, 150, and 220 GHz. Due to the relative spectral behavior of the CIB and synchrotron emission, the 95 GHz bandpowers also have a significant contribution from radio sources.

The kSZ temperature anisotropy requires perturbations in the free electron density. This can be due to local perturbations in the baryon density, $\delta_b = \rho_b / \bar{\rho}_b - 1$, where $\bar{\rho}_b$ is the mean baryon density in the universe, or ionization fraction, $\delta_x = x_e / \bar{x}_e - 1$. Perturbations that are correlated with the large scale velocity field will produce an observable change in temperature of the CMB. The total contribution to the temperature anisotropy is given by the integral over conformal time:

$$\Delta T_{\text{kSZ}} = \int d\eta \left[ a^{-2} e^{-\tau(\eta)} (\bar{x}_e)^c \eta \hat{n} \cdot \mathbf{q} \right]$$

where $\sigma_T$ is the Thomson scattering cross-section, $a$ is the scale factor, $\tau(\eta)$ is the optical depth from the observer to conformal time $\eta$, $\bar{x}_e$ is the mean electron density of the universe at the present day, and $\hat{n}$ is the line of sight unit vector. Finally, $\mathbf{q}$ represents the peculiar velocity of free electrons at $\eta_i$.

The kSZ power spectrum can be broken down loosely into two components. The first is the kSZ signal from the postreionization epoch, $z < z_{\text{end}}$, where we define $z_{\text{end}}$ as the redshift at which hydrogen reionization is complete. The second component comes from the epoch of reionization itself. Models of inhomogeneous reionization predict bubbles of free electrons around UV-emitting sources embedded in an otherwise neutral medium. Any large-scale bulk velocity of these bubbles will impart a temperature anisotropy onto the CMB. The kSZ signal from reionization is thus sensitive to fluctuations in both the gas density and ionization fraction. Note that in the case of instantaneous reionization, the postreionization signal is the only source of kSZ power.

We henceforth refer to the postreionization component as the 'homogeneous kSZ' signal and that from the reionization epoch as the 'patchy kSZ' signal. We now discuss our modeling of each in more detail.

5.3.1. Homogeneous Kinetic Sunyaev-Zel'dovich Anisotropy

For the homogeneous postreionization kSZ signal, we adopt the non-radiative ($c_{\text{NR}}$) and cooling plus star-formation ($c_{\text{CSF}}$) models presented by Shaw et al. These models are constructed by calibrating an analytic model for the homogeneous kSZ power spectrum with two hydrodynamical simulations. The first simulation was run in the non-radiative regime, while the second included metallicity-dependent radiative cooling and star-formation. Shaw et al. measured the power spectrum of gas density fluctuations in both simulations over a range of redshifts and used this to calculate the kSZ power spectrum for each case. They argue that these two cases are likely to bracket the true homogeneous kSZ power. For our fiducial cosmology (detailed in §), the NR template predicts $\mu_K^2 = \text{C. Reichardt et al. arXiv:1111.0932}$
Recent highlights

$\ell$ (\ell\ell + 1) $\ell_{\text{eff}}$ / 2$\pi$ (\muK$^2$)

- WMAP 7-year
- SPT - K11
- SPT 220 GHz
- SPT 150 GHz
- SPT 95 GHz

**DSFG emission**

**tSZ unresolved clusters**

**low-el sensitivity**

C. Reichardt et al. arXiv:1111.0932
Recent highlights

- Clear measurement of gravitational lensing of CMB temperature anisotropies
- High S/N allows reconstruction of the spectrum of the deflection field
CMB lensing cartoon
Lensing B-modes

- Lensing distorts CMB. Pure E gets mixed to some B
SPTpol: goals

- Cluster science from ultra-deep multi-band observations of 600 deg$^2$
SPTpol: technical challenges

- Optics
- Sensitivity
- Calibration
SPTpol: technical challenges

- Optics
- Sensitivity
- Calibration
Optics: small beams mitigate T -> P leakage

- cross polarization systematics appear as undesired beam patterns on the sky
- large primary places these effects at the sub-arcmin scale (no CMB power)
Optics: baffling eliminates undesired coupling
SPTpol: technical challenges

- Optics
- Sensitivity
- Calibration
Bolometer basics

- thermal measurement of power, not single photons
- fundamental noise
  - background photons
  - thermal fluctuations
- Non-zero photon load sets a lower limit to the noise
- Background limited means sensitivity can only be improved by more detectors
- Need lots of detectors and...
- Detectors must have background limited performance
SPTpol detectors at 90 GHz
SPTpol detectors at 150 GHz
Superconducting Orthomode Transducer (OMT) separates two linear polarizations onto superconducting microstrip
SPTpol focal plane
First light!
First light!
SPTpol: technical challenges

- Optics
- Sensitivity
- Calibration
Angle Calibration
Angle Calibration
Angle calibration

4 km away
The commute out
View of SPT from the source
Looking “North” away from SPT
Looking at yourself
Large/small collaborative effort

- ~50 scientists
  - Chicago
  - Berkeley
  - Case Western
  - McGill
  - Boulder
  - Harvard
  - Caltech
  - Munich
  - Michigan
  - Arizona
  - NIST
  - ANL
  - ...
Grand Challenge: austral winter 2012
Summary and outlook

• Successful SPTpol deployment

• ~750 polarization sensitive pixels at 2 & 3 mm

• Initial performance looks good

• 3 seasons observation of 600 deg$^2$