SPT-POL  A polarimeter for the South Pole Telescope

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for the SPT Collaboration
# Experiment Summary

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequencies</td>
<td>95/150 GHz</td>
</tr>
<tr>
<td>Angular resolutions</td>
<td>1/1.6 arcmin</td>
</tr>
<tr>
<td>Field centers and sizes</td>
<td>Southern hole, 600 sq. deg</td>
</tr>
<tr>
<td>Telescope type</td>
<td>Off-axis Gregorian</td>
</tr>
<tr>
<td>Polarization Modulations</td>
<td>Up to 4 deg/s az scan, HWP (?)</td>
</tr>
<tr>
<td>Detector type</td>
<td>Bolometer</td>
</tr>
<tr>
<td>Location</td>
<td>South Pole</td>
</tr>
<tr>
<td>Instrument NET per pixel</td>
<td>450/400 μK_{CMB} s^{1/2}</td>
</tr>
<tr>
<td>Observation start date</td>
<td>Early 2012</td>
</tr>
<tr>
<td>Planned observing time</td>
<td>3 years</td>
</tr>
<tr>
<td>Projected limit on $r$</td>
<td>$\sigma_r = 0.004^*$</td>
</tr>
</tbody>
</table>

- Includes effects of 1/f noise, foregrounds and foreground removal, and lensing B-mode removal
SPT-POL Science Goals

- Measure neutrino mass through gravitational lensing
- Constrain Inflationary B-modes
- Precision tests of the cosmological standard model

<table>
<thead>
<tr>
<th>Datasets</th>
<th>$\Omega_{DE}$</th>
<th>Improve</th>
<th>$\Omega_b h^2$</th>
<th>Improve</th>
<th>$\Omega_m h^2$</th>
<th>Improve</th>
<th>$\Sigma m_{\nu}$</th>
<th>Improve</th>
<th>$n_s$</th>
<th>Improve</th>
<th>$r \equiv T/S$</th>
<th>Improve</th>
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</thead>
<tbody>
<tr>
<td>WMAP3</td>
<td>0.16</td>
<td>1</td>
<td>0.0012</td>
<td>1</td>
<td>0.011</td>
<td>1</td>
<td>1.3</td>
<td>1</td>
<td>0.027</td>
<td>1</td>
<td>*</td>
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<tr>
<td>+SPT</td>
<td>0.061</td>
<td>2.6</td>
<td>0.00035</td>
<td>3.4</td>
<td>0.0037</td>
<td>3.0</td>
<td>0.49</td>
<td>2.7</td>
<td>0.0099</td>
<td>2.8</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>+SPT-POL</td>
<td>0.039</td>
<td>4.1</td>
<td>0.00023</td>
<td>5.2</td>
<td>0.0028</td>
<td>3.9</td>
<td>0.23</td>
<td>5.7</td>
<td>0.0073</td>
<td>3.7</td>
<td>*</td>
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<td>Planck</td>
<td>0.032</td>
<td>5.0</td>
<td>0.00016</td>
<td>7.5</td>
<td>0.0012</td>
<td>9.2</td>
<td>0.22</td>
<td>5.9</td>
<td>0.0041</td>
<td>6.6</td>
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<tr>
<td>+SPT-POL</td>
<td>0.028</td>
<td>5.7</td>
<td>0.00014</td>
<td>8.6</td>
<td>0.0012</td>
<td>9.2</td>
<td>0.11</td>
<td>12</td>
<td>0.0037</td>
<td>7.3</td>
<td>*</td>
<td></td>
</tr>
</tbody>
</table>

* Parameter held fixed.
SPT Experimental Approach

- **Control of Instrument Systematics**
  - Off-axis telescope design
  - Multiple layers of shielding
  - No chopping optical elements
    - Entire telescope scans sky

- **Sensitivity for a Large Survey**
  - ~1000 element focal plane array
  - Photon noise limited detectors
  - 1 square deg field of view
  - South Pole site provides low water vapor, smooth atmosphere
  - 1 arcmin beam (10-m primary)
    - Efficiently couples to galaxy cluster size
    - Relaxes tolerances on beam systematics for CMB polarization

- **Signal Discrimination**
  - Multi-frequency focal plane
  - 95/150/220 GHz bands for SZ camera
  - 95/150 GHz bands for polarimeter
Deployment: Nov 2007 - Feb 2008
First Galaxy Clusters Discovered with the SZ Effect by SPT

Staniszewski et al, arXiv:0810.1578
SPT Current Status

- SPT is online and is conducting a large area, multiband SZ cluster survey of the southern sky at 1’ resolution.
- SPT now has many SZ detections of previously unknown galaxy clusters.
  - SZ clusters surveys work!
- Aggressive follow-up observations underway.
- More results on the way, including observations of known clusters, an intriguing population of mm-wave selected dusty galaxies, and measurements of the high-l CMB power spectrum.
Precision Large-Aperture Telescope Platform

- 10 meter submillimeter telescope
- 1’ FWHM beam at 150 GHz
- Off-axis Gregorian optics design
- 20 microns RMS surface accuracy
- 1 arc-second pointing
- Fast scanning (up to 4 deg/sec in azimuth)

Advantages for measuring large-scale B-modes

- deconvolution of lensing B modes
- relaxed tolerances for beam contamination systematics
- small pointing errors
SPT-POL polarization leakage constraints

Temperature to Polarization Leakage Beams and Averaged Window Functions

J. McMahon
SPT-POL polarization leakage constraints

CMB Power Spectra and T→P Leakage for a 0.017° Beam

Power [μK²]

- Temperature
- E-mode
- Lensing B-modes
- GW B-modes
- Dipole (-17dB)
- Quadrupole (-7dB)
- Monopole (-30dB)
- Monopole (-25dB)

Multipole moment (ℓ)

J. McMahon
South Pole Site

- Stable thermal environment and atmosphere
  - Reduces polarization systematic effects by stabilizing optics physical temperatures and gain calibrations
  - Yields reproducible data sets that lend themselves to systematic error “jack-knife” tests
- Round-the-clock access to the cleanest 600 sq. deg low foreground region of the sky, “Southern Hole”
  - Constant elevation angle while tracking in azimuth
- Clean and cold horizon
- Excellent support from existing research station
Simple Well-shielded Optical Design
SPT Far Sidelobe Characterization

SPT Window Scattering In AZ-EL Coordinates

Scattering Simulation

Diffraction Simulation

Measurement
different color scale

EL (deg)

AZ (deg)

-150  -100  -50   0    50   100  150

J. McMahon
J. Mehl
Foregrounds

C. Pryke, J. Kovac

FDS Dust T @ 150GHz x 0.05

Color range 0 to 4μK

WMAP K-band P @ 150GHz (assuming index -3.0)

Color range 0 to 4μK

Temperature
E modes
G-W B modes, 0.01 ≤ rs ≤ 0.1
Lensing B modes
IR sources
Radio sources
Diffuse synch

Tom Crawford
SPT Polarimeter

- Focal plane cooled to 250 mK using a closed cycle helium pulse tube cooler and 3-stage He sorption fridge
- No liquid cryogens
- Cold cycle hold time 1-2 days
- Entire assembly weighs ~380 lbs
Digital Frequency Multiplexed Readout

- New backend for frequency mux-ed readout developed at McGill.
  - Makes use of new generation of FPGAs, moving signal processing to firmware.
- Electronics supports MUX factors up to 16x
- 10x smaller, 10x lower power
- 1/f noise << 100 mHz
- Hardware is modulatorized “per squid comb”, not “per bolometer channel”.
- Each board has embedded linux processor for fully parallel operation.
- Flew June 2009 on EBEX.
Optimizing Corrugated Horn Size for Mapping Speed

- Optimal horn size for fixed FOV is $D = 1.5 +/− 0.4 \ f \lambda$
- Total number of pixels limited by readout and wafer layout
SPT-POL Focal Plane Layout

150 GHz
637 pixels
7 wafer arrays
1.5 \( f \lambda \) (4 mm) horns
Fabricated at NIST

90 GHz Pixels
198 pixels
Individually packaged
1.7 \( f \lambda \) (6.8 mm) horns
Fabricated at Argonne
- Two crossed absorbers
- Couple to only single mode in waveguide
- Beam defined by feedhorn
- Mo/Au bilayer with various Tc targets
Argonne 90 GHz Detector
Optical Characterization

~60% optical efficiency

Optical Time Constant

Pol. Eff > 98.5%
150 GHz Prototype Detector

CPW-to-microstrip transition

Dark TES

Band-defining stub filter & stepped-impedance LPFs

Simple cross-over (no need for matching cross-overs on opposite arms)

1.3 mm sq. waveguide OMT

TES (Tc~0.5K) Heater

Lossy Au meander
150 GHz Prototype Polarimeter Testing

![Graph showing frequency response vs. temperature for different polarization states.]

- **Response (arb. units)** vs. **Frequency (GHz)**
  - TES A
  - TES B
  - Simulation

- **CMB4 Tc vs. wafer position**
  - Temperature range: 500 - 540 mK
  - TESs layout: B, D, A

- **CMR108**
  - Efficiency vs. CL Temp (K)

- **Low-G Time constants**
  - Types 1 and 2
  - Col A at 0.5, 0.6, 0.7 V
  - Col D at 0.5 V

- **Time constant**: 2.5 ms
SPT-POL Calibration

- Absolute calibration from CMB T cross-calibration with WMAP & Planck
- Gain stability monitored with chopped IR source viewed through small hole in secondary mirror
- Array relative gains measured by elevation nods
- Unpolarized beam response from planet observations
- Polarization orientation angle
  - High-G bolometer measurements of moon
  - Transferred to low-G bolometers using tower-mounted polarized source
- Polarized beam response from tower-mounted source
Summary

- SPT successfully fielded in 2007
  - SZ data pouring in
  - Rich science, cluster counts/physics, high-l CMB power spectrum, point source population studies, etc
- We have a well-functioning large aperture precision telescope platform
  - Well suited for high-l CMB polarization measurements
- SPT-POL receiver currently under development
  - Receiver cryostats under construction
  - Detectors under development
  - First light in 2012