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An Overview of the SPTpol Experiment

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Abstract In 2012 the South Pole Telescope (SPT) will begin a 625 deg^2 survey to measure the polarization anisotropy of the cosmic microwave background (CMB).

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Observations of the CMB B-mode angular power spectrum will be used to search for the large angular scale signal induced by inflationary gravitational waves. Additionally, the B-mode spectrum will enable a measurement of the neutrino mass through the gravitational lensing of the CMB. The new 780 pixel polarization-sensitive camera is composed of two different detector architectures and will map the sky at two frequencies. At 150 GHz, the camera consists of arrays of corrugated feedhorn-coupled TES polarimeters fabricated at the National Institute of Standards and Technology (NIST). At 90 GHz, we use individually packaged dual-polarization absorber-coupled polarimeters developed at Argonne National Laboratory. Each 90 GHz pixel couples to the telescope through machined contoured feedhorns. The entire focal plane is read out using a digital frequency-domain multiplexer system. We discuss the design and goals of this experiment and provide a description of the detectors.

Keywords Polarimetry · Transition-edge sensors · Bolometers · Cosmic microwave background · Cosmology

1 Introduction

Imprinted in the polarization of the Cosmic Microwave Background (CMB) is a wealth of information concerning both fundamental physics and cosmology. In an analogy with electromagnetism, polarization maps can be decomposed into two scalar fields—a grad-like E-mode and a curl-like B-mode. Density perturbations in the early universe are the primary source of E-mode polarization. B-mode polarization can be sourced by lensing of the E-mode by large-scale structure and by gravitational waves generated during inflation. These primordial gravitational waves,

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predicted by some inflationary models, leave their signature at large angular scales. Detection of this polarization would provide a unique probe of physics at energy scales of 10^{16} GeV [1]. Conversely, the B-mode sourced by lensing from large scale structure produces a significant signal at smaller angular scales. The lensing B-mode spectrum provides sensitivity to the sum of the neutrino masses through their impact on the growth of structure [2].

The E-mode polarization has been measured by a number of experiments (for example [3–6]), but the B-mode polarization has yet to be observed. Ongoing advances in detector and electronics technology have greatly increased the sensitivity of upcoming experiments, which now have the potential to measure this polarization. We describe in this paper SPTpol, one such polarization experiment that will begin observations in January 2012. We begin with an overview of the SPTpol instrument, describe detector characteristics and conclude with sensitivity projections for the experiment.

2 The South Pole Telescope

SPTpol will consist of a new polarization-sensitive bolometric focal plane deployed on the South Pole Telescope (SPT). The SPT [7] is a 10-m diameter telescope located at the Amundsen-Scott South Pole station in Antarctica, one of the premier sites for mm-wave observations. The telescope, optimized for observations of the CMB with arcminute resolution, is designed to scan quickly (2°/s) to help suppress low frequency atmospheric noise contributions. The SPT recently completed a deep three band (90, 150, 220 GHz) survey of 2500 deg^2 of the southern extragalactic sky. The SPT-SZ survey, in addition to its primary science goals of constraining cosmology through the detection of massive galaxy clusters via the Sunyaev-Zel'dovich Effect [8, 9] and studies of the low and high-ℓ CMB power spectrum [10, 11], has allowed extensive characterization of the performance of the telescope in preparation for SPTpol. With SPT-SZ, we measured the side-lobe response of the telescope optics. From this data, we were able to build shielding to reduce these side-lobes so their expected contribution to our polarization systematics is negligible.

3 Focal Plane Configuration and Detector Design

The SPTpol focal plane will consist of a central core of 588 150 GHz pixels (1176 total detectors) fabricated in arrays at the National Institute of Standards and Technology (NIST), surrounded by a ring of 192 individually packaged 90 GHz pixels (384 detectors) fabricated at Argonne National Laboratory (ANL). Figure 1 shows the layout of the SPTpol focal plane.

The overall scheme of each detector technology is identical: light from the telescope is coupled through a feed horn and single-modes wave guide onto a lithographically fabricated detector. A transition edge sensor (TES) is connected to a SQUID amplifier which is used to read out the change in optical power on an absorber for each detector. The upper and lower band edges are defined by a free space filter [12]

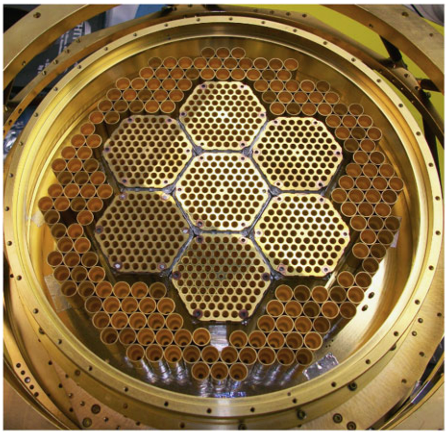

Fig. 1 (Color online) The SPTpol focal plane. Seven arrays of 150 GHz detectors are surrounded by a ring of individually packaged 90 GHz detectors. The diameter of the focal plane is approximately 225 mm

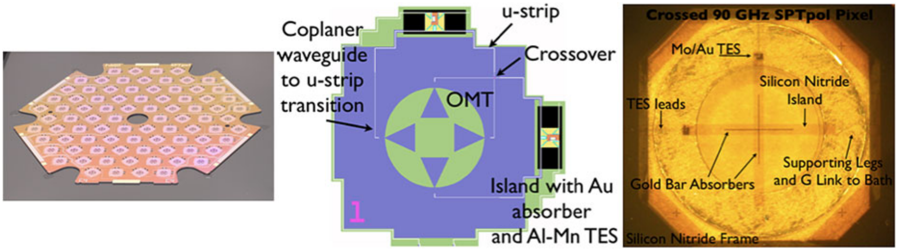

Fig. 2 Layout for detectors that will be used for SPTpol. The images on the *left* show a 150 GHz array and a schematic of a 150 GHz array pixel being fabricated at NIST. On the *right* is an image of a crossed 90 GHz pixel fabricated at Argonne National Laboratory

and the horn waveguide cutoff respectively. All detectors are readout using a digital frequency domain multiplexer (dFMUX) [13]. The expected knee of $1/f$-noise from the detectors and readout is less than 50 mHz and therefore sub-dominant to the atmospheric noise contribution.

At 150 GHz, the detectors couple to polarized radiation via a planar ortho-mode transducer (OMT). The OMT is connected by superconducting Nb microstrip to a lossy Au absorber on a thermally isolated island containing the Al-Mn alloy TES [14]. The 150 GHz feedhorns are corrugated, and are constructed as a gold-plated platelet array micro-machined from silicon [15]. There will be seven such horn arrays, one for each of the 150 GHz pixel arrays. Each 90 GHz pixel utilizes a stacked pair of 1/2-wavelength lossy absorbers over a 1/4-wavelength backshort to terminate each linear polarization. Each absorber is housed with a Mo/Au bilayer TES on a suspended low-stress silicon nitride island. Radiation is coupled to the absorber by contoured feedhorns individually machined from aluminum [16, 17]. An example of a crossed 90 GHz pixel and a schematic showing a 150 GHz pixel as well as a prototype array designed for SPTpol are shown in Fig. 2. More information on each of the detector technologies can be found in Hubmayr et al. [18] for the NIST detectors and Chang et al. [19] for the detectors fabricated at ANL.

Table 1 Summary statistics for the SPTpol experiment

Frequency	90 (150) GHz
Number of Pixels	192 (588)
Angular Resolution	1.6 (1.0) arcminute
Detector NEP	50 (53.5) aW/$\sqrt{\text{Hz}}$
Optical Efficiency	85% (∼85%)
Bandwidth	36 (43) GHz
Observation Start Date	January 2012
Planned Observation Time	3 years
Field Size	625 sq. deg
Multipole Coverage	50–10,000

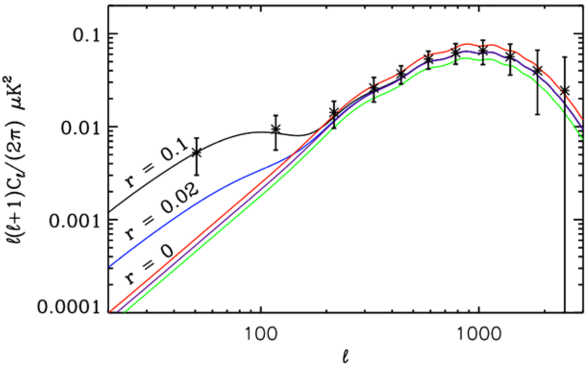

Fig. 3 (Color online) Projected 3-year SPTpol CMB BB polarization power spectra from Monte-Carlo simulations of a 625 deg^2 field including $1/f$ noise, foreground removal and E/B separation. Plotted: $r = 0.1$, $\sum m\nu = 0.5$ eV (*black line*); $r = 0.02$, $\sum m\nu = 0.5$ eV (*blue line*); $r = 0$, $\sum m\nu = 0$ eV (*red line*); $r = 0$, $\sum m\nu = 0.5$ eV (*purple line*); $r = 0$, $\sum m\nu = 1.0$ eV (*green line*)

In order to detect B-mode polarization the detectors must have low noise and high sensitivity. Table 1 provides summary statistics for each detector architecture. As explained in McMahon et al. [20] these specifications are driven by an optimization process that balances mapping speed against practical concerns such as the finite focal plane area and limitations on the size of the 90 GHz pixel modules. Targeted noise equivalent powers (NEPs) are comparable to the expected photon noise. The optical efficiencies of both detector architectures were measured using an internal cold load as described in Chang et al. [19]. The 90 GHz detectors have NEPs of 50 aW/$\sqrt{\text{Hz}}$ and 85% optical efficiency. Measurements of 150 GHz arrays demonstrate noise consistent with our target value of 53.5 aW/$\sqrt{\text{Hz}}$. We have tested witness pixels from these arrays and measure ∼85% optical coupling. Previous generations of NIST devices have shown significant power bypassing the microstrip and coupling directly to the TES island [21]. Initial tests show this unwanted power is greatly reduced (<5% total loading) relative to previous generations, as would be expected by the addition of the free-space filter.

4 Projections

We estimate SPTpol constraints on the CMB power spectrum through Monte-Carlo simulations of a 625 deg^2 field. We assume the described detector characteristics,

$1/f$ noise with a 50 mHz knee frequency, foregrounds similar to Chiang et al. [5], the effects of E–B mixing, and a 50% observing duty cycle during the Austral winter for the three years of observations. Additionally, we perform ray-tracing simulations of the telescope optics to model the effects of side-lobes and beam distortions on these observations. The projected sensitivity of SPTpol to various cosmological models is shown in Fig. 3. Simulations of the 3 year data forecast the one sigma uncertainty on the sum of the neutrino masses $\sigma(\sum m_v) = 0.17$ eV and a constraint on the tensor to scalar ratio, r, of 0.03 at 95% confidence.

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