INTERFEROMETRIC OBSERVATIONS OF CMB TEMPERATURE AND POLARIZATION WITH DASI

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ABSTRACT

The Degree Angular Scale Interferometer (DASI) has been in continuous service since its deployment at the South Pole in December 1999. In its first season of operation (2000) DASI observed CMB temperature anisotropies in 32 fields, measuring the temperature power spectrum across angular scales that revealed the first three harmonic peaks. In its second season (2001) DASI observed mainly in polarization mode, integrating to very high sensitivity on 2 of the original 32 fields. We discuss the state of results from data that has been taken so far in both modes, as well as current observations and future plans.

INTRODUCTION

The Degree Angular Scale Interferometer (DASI) is a compact centimeter-wavelength array designed to measure anisotropies in the temperature and polarization of the Cosmic Microwave Background (CMB) at degree and sub-degree angular scales. It was deployed at the Amundsen-Scott South Pole Station during the 1999-2000 austral summer, and has been operating successfully since that time, returning data that can be used to directly constrain the temperature and polarization power spectra of the CMB over the angular wavenumber range $\ell = 100$–900. Results from the first season of observations (2000) have previously been reported [1,2], measuring the temperature power spectrum and finding strong evidence for three harmonic peaks within these angular scales. These temperature power spectrum measurements have been powerful tools for constraining cosmological parameters [3].

DASI's second season of operation (2001) was mainly dedicated to polarization observations. The polarization of the CMB is predicted to contain a wealth of cosmological information that can be used both to complement and strengthen parameter constraints obtainable from temperature power spectrum measurements and to probe phenomena that cannot be accessed in the temperature anisotropies alone (see, e.g., [4]). The polarization signal is expected to quite small, and the best observational efforts to date are still only able to place upper limits on its amplitude, e.g. [5]. The DASI experiment has high enough sensitivity that, in a full season of polarization observations, it should be capable of detecting polarization anisotropies at the amplitudes predicted in the CMB under a wide range of models. Furthermore, DASI's polarization response is such that it is capable of making simultaneous, largely independent measurements of polarization anisotropies of the two distinct possible types ($E-$ and $B-$modes) at angular scales in the range $\ell = 100$–900 over which it has sensitivity.

THE DASI TELESCOPE

DASI is a 13-element interferometer operating at 26-36 GHz. The antenna elements are arranged in a 3-fold symmetric pattern on a common mount which is fully steerable in azimuth and elevation. The configuration

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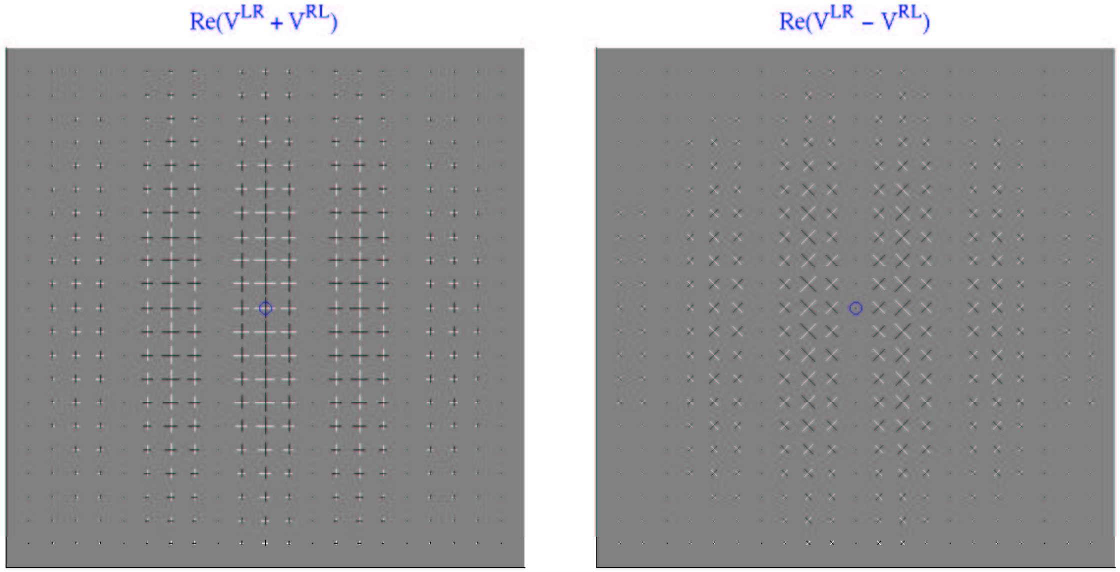

Figure 1: Polarization response patterns typical of a short DASI baseline. A source with linear polarization aligned with white (black) "vectors" gives a positive (negative) response to the two data combinations illustrated (see text for detail). The 3.4° primary beam taper is apparent; neglecting this taper, the left and right patterns contain pure $E-$ and $B-$type polarization, respectively.

was chosen so that the 78 baselines that connect pairs of receivers have lengths distributed across the range 25-121 cm, providing dense coverage of the CMB angular power spectrum from $100 < \ell < 900$. The mount is also able to rotate the array about the line of sight axis to fill in u-v (Fourier plane) coverage or to provide consistency tests. The mount itself is fully enclosed and insulated, with all RF and IF components mounted on a rigid assembly in the easily accessed heated space immediately behind the receivers. This configuration has resulted in both exceptional phase stability and convenient serviceability in the harsh environment of South Pole winter observations.

The DASI receivers operate in Ka-band, using 4-stage InP HEMT amplifiers for first stage low-noise amplification of the 26-36 GHz RF signal. These amplifiers were built at the University of Chicago according to an NRAO design [6], and give typical minimum noise temperatures of 10-15 K. They are cooled by a closed cycle helium refrigerator to 10 K along with the other RF components, including the mixer which downconverts to a 2-12 GHz IF. This 10 GHz bandwidth IF is channelized, downconverted, and finally correlated in ten 1-2 GHz bands in a compact analog correlator mounted with the other components immediately behind the receivers.

THE DASI POLARIZERS

In the 2000-2001 austral summer the DASI receivers were upgraded with switchable achromatic circular polarizers, which allow each receiver to be set to admit either right- or left-circular polarization. The switching is accomplished by 90° mechanical rotation of the polarizer in a circular waveguide section, all of which is at 10 K. These polarizers use a novel "achromatic" design which enables them to achieve very low cross-mode leakage across the entire 26-36 GHz RF bandwidth. This is important for minimizing residual temperature response in cross-polarized baselines, which are used when operating DASI in its polarization observing mode. In this mode, the polarization states of individual receivers are switched in a Walsh-cycle sequence, so that each

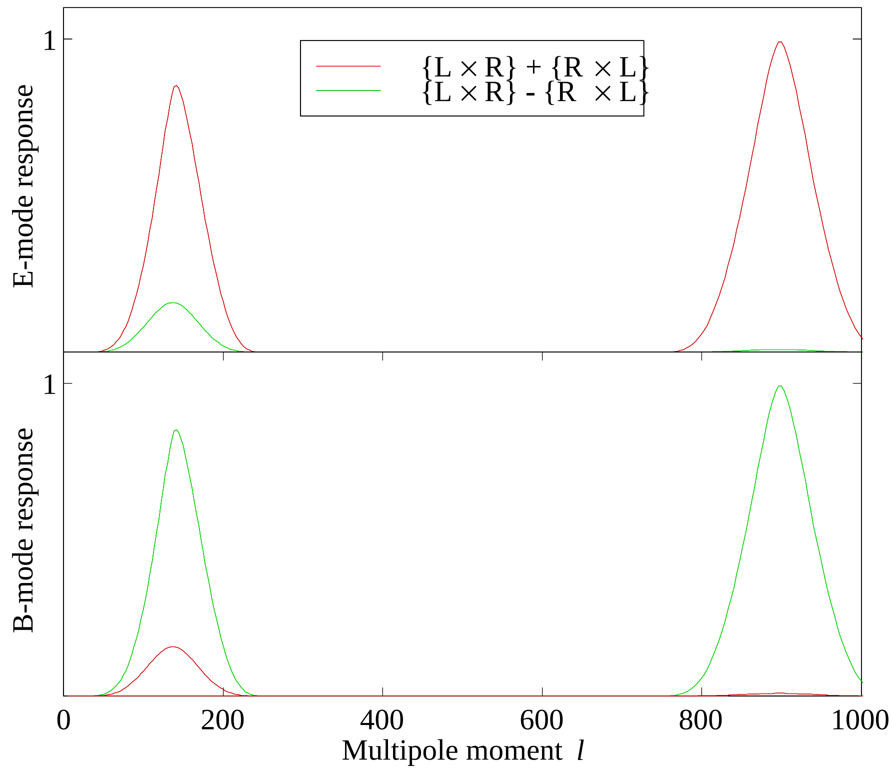

Figure 2: Relative amplitudes of the window functions to $E-$ and $B-$mode polarization power spectra are illustrated for two different data combinations which have response patterns similar to those illustrated in Fig. 1. These combinations may be formed for any of DASI's baselines; only the shortest and longest are shown here. Note that for the longest baselines, the separation of $E-$ and $B-$mode response in these combinations is nearly perfect.

baseline visits all four combinations (RR, LL, RL, LR) of states equally over a complete one-hour observation period.

POLARIZATION RESPONSE

The interferometric technique is particularly well suited to observations of CMB anisotropies, both in temperature and polarization. The instantaneous differencing and fast phase switching capability of an interferometer lead to excellent rejection of atmospheric and systematic effects over the long integration times necessary. Moreover, the quantities that are directly measured are Fourier components of the sky temperature and polarization fields; the amplitudes of these data elements are directly related to the power spectra of CMB anisotropies at angular scales corresponding to the baseline lengths.

In the case of the polarization anisotropies, observations for each baseline can be easily decomposed into combinations which are nearly pure $E-$ or $B-$type polarization modes, so that the physically distinct $E-$ and $B-$spectra can be separately constrained. The polarization response pattern on the sky for a single baseline is illustrated in Fig. 1. For a baseline vector that is aligned N-S, the illustrated response patterns result from considering the real part of the sum or the difference of the complex correlator outputs when the two receivers for this baseline are in LR and RL states. These response patterns are nearly pure $E-$ or $B-$type polarization "plane wave" patterns, differing from strictly pure modes only in the taper due to the 3.4° primary beam. For the longer DASI baselines, the scale of this beam taper is much greater than the scale of the "wavelength" of the polarization pattern, and as a result the separation of $E-$ and $B-$type polarization is nearly exact (see Fig. 2). We find that even at the largest angular scales, when data from different baselines are used in a power spectrum analysis, the constraints on $E-$ and the $B-$type polarization spectra are nearly independent, and of equal sensitivity.

CONCLUSION

In its first season of operation (2000) DASI observed CMB temperature anisotropies in 32 fields, each 3.4° across. The season yielded an average of 50 hours of integration on each of these fields, producing high signal-to-noise measurements of the temperature anisotropies at all angular scales in the range $\ell = 100$–900, allowing high-precision, mainly sample-variance limited estimates of the temperature power spectrum to be made across these angular scales.

In its second season (2001) DASI observed in polarization mode, integrating to very high sensitivity on two of these original 32 fields. The telescope performed extremely well, and the season yielded approximately 1500 hours of integration on each of these two fields. This amount of integration is adequate for DASI to achieve an instrumental sensitivity sufficient to detect polarization anisotropies at the amplitudes predicted to exist in the CMB under a wide range of models. Furthermore, we expect constraints on $E-$ and the $B-$type polarization spectra to be nearly independent, and of equal sensitivity. Analysis of this data is ongoing. DASI is currently beginning to take data in its third season of observations at the South Pole, operating both in temperature and polarization mode. We look forward to reporting to the General Assembly this August on the status of the analysis efforts and the continuing observations.

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