TENTATIVE DETECTION OF QUASAR FEEDBACK FROM WMAP AND SDSS CROSS-CORRELATION

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ABSTRACT

We perform a cross-correlation analysis of microwave data from the Wilkinson Microwave Anisotropy Probe and photometric quasars from the Sloan Digital Sky Survey, testing for the Sunyaev–Zeldovich (SZ) effect from quasars. A statistically significant (2.5σ) temperature decrement exists in the 41 GHz microwave band. A two-component fit to the cross-correlation spectrum incorporating both dust emission and SZ yields a best-fit y parameter of (7.0±3.4)×10⁻⁷. A similar cross-correlation analysis with the luminous red galaxy sample from Sloan gives a best-fit y parameter of (5.3±2.5)×10⁻⁷. We discuss the possible physical origin of these signals, which is likely a combination of SZ effects from quasars and galaxy clusters. Both the Planck Surveyor satellite and the current ground-based arcminute-resolution microwave experiments will detect this signal with a higher statistical significance.

Key words: cosmic background radiation – galaxies: active – submillimeter: general

Online-only material: color figure

1. INTRODUCTION

Secondary anisotropies in the cosmic microwave background (CMB) provide a number of opportunities for probing the growth of structure in the universe. Numerous recent and current experiments aim to detect these effects. The thermal Sunyaev–Zeldovich (TSZ) effect (Sunyaev & Zeldovich 1972), which is the inverse Compton scattering of CMB photons due to hot electrons, creates a spectral distortion in the CMB and is the dominant secondary effect contributing to arcminute-scale anisotropies. The TSZ effect arises from the random thermal motion of the electrons. If there is a finite velocity of the cluster in the CMB frame there will be an additional Doppler term. This Doppler anisotropy is called the kinetic SZ (KSZ) distortion. The TSZ effect serves as a powerful tool for probing accumulations of hot gas (see Carlstrom et al. 2002 for a review). Most of the TSZ signal comes from galaxy clusters, which contain the majority of the thermal energy of the universe. State-of-the-art SZ surveys like the Atacama Cosmology Telescope (ACT5; Hincks et al. 2009) and the South Pole Telescope (SPT6; Staniszewski et al. 2009) aim to detect large numbers of clusters in blind surveys via their SZ signatures.

A number of other astrophysical processes will also create both TSZ and KSZ distortions. These include KSZ distortions from peculiar velocities during reionization (McQuinn et al. 2005; Iliev et al. 2006), both thermal and kinetic distortions from supernova (SN)-driven galactic winds (White et al. 2002; Majumdar et al. 2001), thermal effect from black hole-seeded protogalaxies (Aghanim et al. 2000; de Zotti et al. 2004; Rosa-González et al. 2004; Massardi et al. 2008), KSZ from Lyman break galaxy outflows (Babich & Loeb 2007), and TSZ effect from SNe from the first generation of stars (Oh et al. 2003). Here, we consider another generic signal: the TSZ distortion from hot gas surrounding active galactic nuclei (AGNs; e.g., Natarajan & Sigurdsson 1999; Yamada et al. 1999; Lapi et al. 2003; Platania et al. 2002; Roychowdhury et al. 2005; Chatterjee & Kosowsky 2007; Scannapieco et al. 2008; Chatterjee et al. 2008). The SZ effect from these sources provides a new observational tool to study the role of baryonic physics in structure formation.

X-ray and optical studies of the effect of AGN feedback on structure formation at different scales has been shown by several groups (e.g., McNamara et al. 2005; Voit & Donahue 2005; Sanderson et al. 2006; Weinmann et al. 2006; Schawinski et al. 2007). At the same time, studies of radio jets have illuminated the morphology and outburst history of AGNs (e.g., Birzan et al. 2004; Dunn et al. 2005; Dunn & Fabian 2006). Although effects of AGN feedback have been successfully detected on different scales, the challenge lies in quantifying the amount of feedback energy and its particular effects on structure formation. Adding SZ (thermal from now on) measurements to X-ray data will provide stronger constraints on feedback effects than X-ray data alone (e.g., Scannapieco et al. 2008; Chatterjee et al. 2008; Moodley et al. 2009). But the AGN signal is tiny, and direct detection through pointed observations with, for example, the Atacama Large Millimeter Array (ALMA7; Lapi et al. 2003; Chatterjee & Kosowsky 2007) will be challenging. In this work, we instead cross-correlate CMB maps with optical quasar catalogs (Chatterjee & Kosowsky 2007; Scannapieco et al. 2008) to enhance the detectability of the SZ signal.

The cross-correlation function and its Fourier transform, the cross-power spectrum (Peebles 1980), have been powerful techniques in cosmology to probe small signals. The cross-correlation of CMB data sets with galaxy surveys has proven useful for measuring secondary anisotropies in the CMB (e.g., Peiris & Spergel 2000; Refregier et al. 2000; Fosalba et al. 2003; Afshordi et al. 2004; Padmanabhan et al. 2005; Ho et al. 2008; Giannantonio et al. 2008; Hirata et al. 2004; Smith et al. 2007; Diego et al. 2003; Cheng et al. 2004; Croft et al. 2006; Myers et al. 2004; Kashlinsky et al. 2009; Diego & Partridge 2010; Hernandez-Monteagudo et al. 2006; Ho et al. 2009). Here, we investigate the SZ distortion from AGN feedback by

5 http://www.physics.princeton.edu/act/
6 http://pole.uchicago.edu
7 http://science.nrao.edu/alma/index.shtml
cross-correlating the WMAP CMB maps with a photometric quasar catalog selected from the Sloan Digital Sky Survey (SDSS).

Our paper is organized as follows. In Section 2, we give a brief description of the data sets used in this work. Section 3 discusses our methodology for estimating the amplitude of the SZ-quasar cross-correlation. Our results are discussed in Section 4. Finally, in Section 5, we give a brief summary of our results and discuss the prospects of detecting quasar-SZ cross-correlations with future experiments.

2. DATA SETS

The analysis presented here uses four data sets: the Wilkinson Microwave Anisotropy Probe (WMAP) CMB temperature maps, the SDSS quasar and luminous red galaxy (LRG) catalogs, and the NRAO VLA Sky Survey (NVSS) radio catalog. Table 1 summarizes the sky areas, objects, and redshift ranges for these surveys. Figure 1 displays the sky regions covered by the SDSS and NVSS catalogs, as well as the masks used in the analysis.

2.1. WMAP Temperature Maps

The WMAP satellite has mapped the microwave sky in five frequency bands (Bennett et al. 2003) with an angular resolution ranging from 0.88 to 0.22 (corresponding to multipole moments ranging from $l = 250$ to $l = 900$). We have used the WMAP 5 yr foreground-reduced CMB temperature maps for $Q$ (41 GHz), $V$ (61 GHz), and $W$ (94 GHz) bands (Gold et al. 2009). The temperature $T_i$ assigned to pixel $i$ is the temperature difference from the mean map temperature after dipole and foreground removal. These maps use the HEALPix scheme developed by Gorski et al. (2005). We have used the HEALPix resolution 9 maps for our analysis. This corresponds to a total of 3,145,728 pixels with each pixel being 47.2 arcmin$^2$ in area. For each frequency band, we use a weighted average of the maps from the individual differencing assemblies (Bennett et al. 2003).

2.2. SDSS Quasar Catalog

SDSS has performed five-band ($ugriz$) photometry (Fukugita et al. 1996) over roughly 10,000 deg$^2$ of sky area. We use the quasar catalog developed by Ho et al. (2008). The quasars are selected photometrically. A quasar candidate catalog of UV-excess objects $(u-g < 1.0)$ with observed $g$ magnitudes fainter than 14.5, extinction-corrected $g$ magnitudes brighter than 21.0, and $u$-band error less than 0.5 mag are generated (Ho et al. 2008). A catalog of DR3-UV-excess objects is also constructed. The candidate quasar catalog is then matched in color space with the DR3-QSO catalog (Richards et al. 2006) and the DR3-UV-excess catalog to generate the current QSO catalog. Three additional maps were used to clean the data set from stellar contamination and mask out regions affected by poor seeing: (1) a point-spread function (PSF) map, (2) a stellar density map ($18.0 < r < 18.5$ stars smoothed with a 2$^\circ$ FWHM), and (3) a stellar surface density map using red stars with $(g-r) > 1.4$. These maps are described in detail in Ho et al. (2008). The data set here uses SDSS PSF magnitudes for all quasars.

2.3. SDSS Luminous Red Galaxy Catalog

LRGs are useful mass tracers in the universe. The LRGs tend to have an old stellar population with a uniform spectral energy distribution. The characteristic 4000 Å break makes LRGs ideal objects for photo-$z$ algorithms with redshift accuracies $\sigma_z \approx 0.03$ (Padmanabhan et al. 2005). The selection criterion, color, and magnitude cuts for the LRG sample employed here are described in Padmanabhan et al. (2005). The LRGs are chosen to be galaxies that have colors consistent with an old stellar population and absolute magnitudes above a certain threshold (Padmanabhan et al. 2005). The magnitude cuts are given as $r_{\text{petro}} < (13.6 + 2.3(g-r) + 4(r-i-0.18))$, $i < (18.3 + 2(r-i) - 0.25(g-r))$, and $i < 20$, where $r_{\text{petro}}$ is the SDSS $r$-band Petrosian magnitude (Padmanabhan et al. 2005). The LRG catalog used for the current work is drawn from the SDSS sample prepared by Ho et al. (2008). The magnitudes we use for the LRGs are model magnitudes (as opposed to the PSF magnitudes used for quasars).

2.4. NVSS Catalog

NVSS is a 1.4 GHz continuum sky survey with the Very Large Array (VLA; Condon et al. 1998). It covers the sky region that lies north of $\delta = -40^\circ$. The entire survey area is about 82% of the celestial sphere. The survey catalog includes about $2 \times 10^8$ discrete objects with an FWHM of 45$''$ and a nearly uniform sensitivity. The error in right ascension (R.A.) and declination (Decl.) varies from $<1''$ for sources with fluxes above 15 mJy to about 7$''$ for sources at the survey flux limit of 2 mJy (Condon et al. 1998). The median redshift for the NVSS objects is around $z = 1$.

3. THE CROSS-CORRELATION AND SYSTEMATICS

We have cross-correlated the SDSS QSO catalog with the WMAP sky maps to estimate the average amplitude of the SZ distortion associated with a known QSO. The estimated amplitude of the quasar signal in a given WMAP band is simply

$$\Delta T = \left( \sum_i N_i T_i \right) \left( \sum_i N_i \right)^{-1}, \quad (1)$$

where $N_i$ is the number of quasars in the $i$th WMAP pixel and $T_i$ is the effective thermodynamic temperature of the pixel in the chosen frequency band. This expression just gives the average temperature distortion associated with each individual QSO. The theoretical SZ signal from a single QSO is expected to be about $1-10 \mu$K for an arcminute beam depending on the mass of the black hole (Scannapieco et al. 2008; Chatterjee et al. 2008). This, when translated to WMAP beams, gives a signal of roughly 10–100 $\mu$Jy at WMAP frequencies (Refriger et al. 2000). At WMAP frequencies, the SZ effect reduces the temperature in a pixel, so the average temperature in Equation (1) will be negative if dominated by the SZ effect. Galactic foregrounds and other systematic emission (described later) will positively bias the signal and lead to an underestimate of the SZ temperature decrement. For comparison, we also cross-correlate the SDSS LRG catalog with the WMAP sky maps, which serves as a rough

| Catalog      | Redshift | Area (deg$^2$) | Objects |
|--------------|----------|----------------|---------|
| QSO catalog  | 0.08–2.82| 6039           | 586435  |
| LRG catalog  | 0.4–0.6  | 6641           | 911686  |
| NVSS catalog | 0–3.0    | 27361          | 1104983 |
measure of the galaxy cluster SZ signal to the extent that the LRG sample predominantly traces clusters.

Signals contributing to the sum in Equation (1) are affected by a number of possible systematic effects, which we attempt to minimize. Sky regions with higher dust extinction will lead to selection biases in the QSO and LRG samples. Also, dust emission in these bands will contaminate the WMAP signal. We employ the dust prescription described in Ho et al. (2008). Using the Schlegel et al. (1998) extinction map, we construct $E(B-V)$ masks excluding pixels with $E(B-V)$ above some threshold value (see Section 4 for the dust mask thresholds). We apply the $E(B-V)$ mask to both our SDSS and NVSS samples. Figure 1 shows the SDSS and NVSS sample spaces after applying the dust masks.

Another source of contamination in the signal will come from radio emission from radio-loud quasars. The spectral index of these radio-loud sources is commonly around $0.7$ (Carlstrom et al. 2002), so radio contamination at low frequencies is an important issue. We have matched the objects in the SDSS quasar catalog with the NVSS radio catalogs to find radio counterparts of the Sloan quasars. This was accomplished (note that WMAP sky pixels are 7 arcmin) by choosing radio sources which are within an angular distance of 45 arcsec, the beam size of the radio survey (although the pointing error is substantially less). We then mask WMAP pixels that contain selected radio sources with fluxes above 2 mJy at 1.5 GHz. The right column of Figure 1 shows the Mollweide projections of our data sets after applying the dust mask and the radio mask (for the SDSS samples only).

We also want to minimize the noise arising from random associations of QSO positions with temperature distortions in the primary CMB anisotropies. Following the WMAP team’s spatial Weiner filter analysis when obtaining point source amplitudes from the temperature maps (Hinshaw et al. 2007), we use a similar high-pass spatial filter to cut off power at large angular scales where primary CMB fluctuations dominate the signal. Microwave temperature maps are conventionally expressed as spherical harmonic coefficients, $T(\theta, \phi) = \sum_{lm} a_{lm} Y_{lm}(\theta, \phi)$. A filtered map is reconstructed from the coefficients $a_{lm} = \mathcal{F}_l a_{lm}$, with the Wiener filter (Tegmark & de Oliveira-Costa 1998; also see Chatterjee 2009 for detailed implementation of the filter)

$$\mathcal{F}_l = \left( \frac{4\pi W_l}{c_l W_l^2 + n_l} \right) \left( \sum_l \frac{(2l+1)W_l^2}{c_l W_l^2 + n_l} \right)^{-1},$$

where $c_l$ are the multipole moments for the primary CMB power spectrum, $W_l$ are the moments of the angular WMAP beam profile, and $n_l$ give the detector noise at each multipole moment. We computed the $c_l$ values from the best-fit WMAP cosmological model using the CAMB code (Lewis et al. 2000; although the filter is relatively insensitive to the precise set of multipole moments used), the detector noise $n_l$ from the noise-per-differencing-assembly values for WMAP (WMAP explanatory supplement; Limon et al. 2009), and the WMAP beam moments from Page et al. (2003). The maximum $l$ values that we have used for constructing the filters for different frequencies depend on the angular resolutions of the corresponding bands: $l = 1000$ ($Q$ band), $l = 1500$ ($V$ band), and $l = 2000$ ($W$ band). The filter suppresses power at scales that are dominated by the primary CMB temperature fluctuations or detector noise; the precise form of the filter in Equation (2) gives a better signal-to-noise estimate of the amplitude of a point source superimposed on the primary CMB fluctuations and observed with the WMAP beam and detector noise. At WMAP angular resolutions, the SZ signal from an individual QSO or galaxy cluster can be treated as a point source.

4. RESULTS

Figure 2 shows the average radiation intensity difference per QSO in three frequency bands, obtained from Equation (1). For clarity across bands, the thermodynamic effective temperature in each band is converted to intensity. Figure 3 shows the same signal, except for the cross-correlation with LRGs instead of QSOs. The dashed lines shows the best-fit SZ distortion with the usual spectrum

$$\frac{\Delta I}{I_0} = \frac{x^4 e^x}{(e^x - 1)^2} [x \coth(x/2) - 4] y,$$
where \( x = h\nu/(K_B T_0) \). The solid lines are a two-component fit incorporating both SZ and dust emission with a spectrum \( I(x) = Ax^4 \), corresponding to an effective dust temperature power-law index of 2 (Gold et al. 2009). The best-fit \( y \) values for all cases are shown in Table 2. The fits were done using the MPFIT package (Markwardt 2009). The errors on the fit parameters are generated in the following way. We resimulate the data by drawing an error from a Gaussian distribution with rms values given by the standard errors in the estimated signal for each band calculated from the variance in \( \Delta T \) and number of pixels used for averaging. We then perform the fits on the mock data and determine the standard deviation of the fit parameters among all mock data sets. The value of this standard deviation is provided as the estimate of error on the parameter. The values for the reduced \( \chi^2 \) and the Bayesian Information Criterion (BIC = \( \chi^2 + k \log(n); k \): degrees of freedom; \( n \): number of data points; Liddle et al. 2006) for the various cases are also listed in Table 2. The information criterion tests whether the improvement in the fits is worth the extra parameters. The two-component fit gives a lower \( \chi^2 \) value; the improvement to the BIC indicates that the improvement from adding an additional parameter is enough to outweigh the extra model freedom from the additional parameter. This conclusion should perhaps be taken with a grain of salt since only three data points with large errors are being fit. Note also that the two-parameter fit gives different values of \( y \); the larger SZ component can better fit the suppressed point at 41 GHz, and the resulting lower SZ signal at 94 GHz can then be compensated by the increased dust contribution. The overall spectra for the two possibilities are significantly different, and measurements with smaller errors and data points at higher frequencies can distinguish between the two cases.

To investigate the significance of the observed anticorrelation, we randomize the positions of the quasars and recalculate the values of \( \Delta I \) for a thousand realizations. We find that in 0.1% (Q band), 1.3% (V band), and 6% (W band) of all realizations, the correlation amplitude is more negative than in the real sample. The \( E(B - V) \geq 0.05 \) mask has been used in this case. We are thus confident that we are observing a real average CMB temperature decrement associated with QSOs. We change the thresholds of the dust masks in calculating the correlation for the randomized case. The results do not change with the change in the thresholds of the dust masks.

To study the possible impact of foreground emission or absorption, we investigate the change in the cross-correlation amplitude when we change the thresholds used for each mask. Table 3 shows the effect on the cross-correlation amplitude of changing the threshold of our dust mask. The signal in the Q and V bands varies significantly with the thresholds of the dust mask; we note that the cross-correlation amplitude increases in these bands (that is, it becomes more negative) when we use more restrictive masks. The signal in the W band is always consistent with noise. The fact that the cross-correlation signal does not converge with increasingly stringent dust map masks indicates that the observed signal is due to a combination of SZ and dust components. We speculate that some of the actual SZ decrement is filled in by dust emission in regions with higher dust. Also, since dust will not be correlated with the quasar positions, the mean dust signal contributions to the QSO and LRG samples should be comparable. To check this, we examined the trend of the signal with the threshold of the dust mask using the randomized sample for both LRGs and QSOs. The results are shown in Table 4. The values for the LRG and QSOs are roughly consistent, and we also see the correlation value to be highly positive (compared to the other bands) in the W band. This likely means that the \( y \) parameters derived here for the two-component fit including dust are closer to the real \( y \) parameters. Our cross-correlation signals are unchanged when the radio mask threshold is changed from 2 to 4 mJy, so the signal likely has no significant radio contamination. This is further borne out because the signal is unchanged if we increase the coverage of the mask to include all WMAP pixels within 20 arcmin of any radio source.
One of the major possible contributors to the cross-correlation signal is an SZ distortion from galaxy clusters associated with the QSOs. A number of authors have previously reported evidence of SZ distortion in WMAP temperature maps (e.g., Bennett et al. 2003; Myers et al. 2004; Hernandez-Monteagudo et al. 2006; Spergel et al. 2007; Diego & Partridge 2010), most likely from unresolved galaxy clusters. To estimate the effect from galaxy clusters, we cross-correlate SDSS LRGs, which serve as a tracer of galaxy clusters, with the same filtered WMAP maps and the same masks used for the QSOs. Errors are also calculated in the same way; the signal has about the same statistical significance as the QSO signal. The cross-correlation spectrum is shown in Figure 3; the amplitude and shape of the distortion is very similar to the QSO case shown in Figure 2. The similarity in the cross-correlation spectrum suggests that both the signals might be coming from the same SZ source population.

Chatterjee et al. (2008) show that the SZ signal from QSOs will be dependent on redshift due to the time evolution of quasar feedback. We perform this test by binning the quasars in two redshift slices (z \(\leq 1.5\) and z \(\geq 1.5\)). The results do not show any significant evolution with redshift.

### 5. Discussion and Prospects

The SZ effect serves as a viable probe for detecting hot gas in AGN environments, though the signal is small. We have presented a first step toward detecting this signal by cross-correlating optical quasar catalogs with microwave maps. At frequencies lower than the null frequency, the SZ signal is a decrement which makes it unique among other potential signals at those frequencies. However, oversubtraction of foregrounds can also lead to decrements. Wright et al. (2009), Hinshaw et al. (2007), and Chen & Wright (2008) report detection of negative fluxes associated with point sources in the WMAP 3 yr and 5 yr point source catalogs. In the present work, we find a deficit in microwave flux associated with both QSOs and LRGs from SDSS, which suggests SZ, but the fits to the observed spectrum are not sufficiently constraining to establish this conclusion definitively.

Any SZ signal is likely to be some combination of the signal associated with gas heated by QSOs and hot gas in galaxy clusters. The observed correlation of flux decrement with the LRGs is similar to that for QSOs. This suggests that the sources of the signals might be similar. LRGs are tracers of galaxy clusters, and hence the SZ effect that we observe could be originating from galaxy clusters associated with QSOs. Diego & Partridge (2010) have analyzed WMAP data by stacking regions around known X-ray clusters, finding an SZ signal from galaxy clusters in the range of 10–20 \(\mu K\), corresponding to tens of mJy. The mean fluxes we get are of the order of 1 mJy, while the theoretical mean SZ signal from quasars is in the range 10–100 mJy, depending on the mass of the black hole (Chatterjee & Kosowsky 2007; Scannapieco et al. 2008). Our signal is at least an order of magnitude higher than the signal that we expect from quasars and an order of magnitude less than what is expected from massive galaxy clusters.

The median redshift of the quasars in our sample is (1.3–1.4); quasars at these redshifts tend to reside in halos with masses around a few \(10^{12} M_\odot\) (e.g., Coil et al. 2007) and not in cluster mass halos. However, since the cluster SZ signal is so much larger than the QSO SZ signal, our results can be explained if only a small fraction of QSOs reside in galaxy clusters. If 10% of QSOs reside in clusters with \(10^{13}\) to \(10^{15} M_\odot\) halos, they would provide the observed cross-correlation signal. We made an estimate of the cluster signal from a typical halo mass for QSOs \(10^{12} M_\odot\) and a typical cluster mass \(10^{14} M_\odot\) by estimating the angular cross-correlation function \(\kappa_{qso,cluster}(\theta)\), which will be equal to bias (QSOs) \(\times\) bias (\(10^{14}\) solar mass halos) \(\times\) mean dark matter angular correlation function at \(z \approx 1\). To get an estimate of the SZ contribution of the cluster signal, we need to integrate the correlation function over the beam size which in Jy \(\text{sr}^{-1}\) will be \((\pi \theta_{\text{beam}}^2)^{-1} \theta_{\text{beam}}^2 d\Omega (qso,\theta) \times (\text{angular cluster SZ decrement}) \times (\text{angular number density of clusters})\). Assuming a beam size of 20 arcmin for WMAP, \(b_{\text{QSO}} = 2.31\) (Shen et al. 2009), \(b_{\text{cluster}} = 3.3\) (Estrada et al. 2009), a cluster density of \(10^{-2}\) deg\(^2\) (Carlstrom et al. 2002), the angular correlation function estimate at redshift 1.0 (Abell et al. 2009), and a typical SZ signal from a cluster to be \(\sim 20\) mJy, we get an estimate of the cross-correlation to be \(\sim 65\) Jy \(\text{sr}^{-1}\). This number is roughly comparable to our estimates of the cross-correlation. However, this estimate is slightly lower than our detected signal which might imply that some of the power in the signal could still be related to backgrounds. An alternate possibility is that the SZ signal from quasar feedback is higher (Natarajan & Sigurdsson 1999) than those obtained from current simulations (Chatterjee et al. 2008; Scannapieco et al. 2008).

Higher-resolution CMB maps can distinguish between QSO and galaxy cluster SZ signals by simply resolving the cluster signals (to all redshifts) and removing these pixels from any cross-correlation. Experiments which may improve on the current cross-correlation analysis include the Planck satellite, with angular resolution down to a few arcminutes in its higher frequency bands, and the ground-based arcminute resolution experiments like ACT, SPT, and APEX. The SZ effect is subdominant at angular scales probed by WMAP (e.g., Komatsu & Seljak 2002; Bennett et al. 2003), which will not be the case at higher resolution. The mean QSO SZ amplitude is predicted to be on the order of 1 \(\mu K\) at 150 GHz for an arcminute size beam (Scannapieco et al. 2008), with substantial modeling uncertainty. Data from SDSS reveal around 30 photometrically detected quasars per square degree. 400 deg\(^2\) of sky coverage can provide cross-correlation with around 10,000 QSOs. If a ground-based experiment can attain a noise of 10 \(\mu K\) pixel\(^{-1}\) over this sky area, this will give roughly a 10\(\sigma\) detection of the QSO cross-correlation signal and a clear separation of the cluster and QSO SZ signals. Planck will have 7 arcmin
resolution at 143 GHz; this implies a mean QSO SZ decrement of around 40 nK pixel$^{-1}$. The noise per pixel after 14 months is projected to be around 6 μK. With around $5 \times 10^5$ quasars over the full sky, the signal to noise of the cross-correlation will be $5\sigma$. Note that both of these estimates are for single frequency bands at the maximum decrement. Planck and ACT in particular are both mapping at frequencies above the null with higher angular resolution, giving stronger statistical constraints but more difficult systematic errors due to possible confusion between the SZ increment and foreground emission. Planck’s many frequency bands may allow efficient separation of SZ from foreground through spectrum information.

We have demonstrated a statistically significant correlation of a temperature decrement in WMAP sky pixels with the number density of both quasars and LRGs drawn from the SDSS. The inferred QSO $\gamma$-distortion for a two-component fit including both dust and SZ gives $\gamma = (7.0 \pm 3.4) \times 10^{-7}$. The signal appears to be partly correlated with local dust emission. Higher signal-to-noise measurements are required to separate the dust and SZ contributions, while higher spatial resolution will separate QSO and galaxy cluster SZ signals. Both prospects are likely in the near term with the Planck satellite and dedicated ground-based SZ measurements. We anticipate that SZ measurements will soon make a valuable contribution to characterizing the energy feedback from quasars to complement current data from the X-ray and radio bands.

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