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An upper limit to polarized submillimetre emission in Arp 220

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ABSTRACT

We report the results of pointed observations of the prototypical ultraluminous infrared galaxy (ULIRG) Arp 220 at 850 μm using the polarimeter on the Submillimetre Common User Bolometer Array instrument on the James Clerk Maxwell Telescope. We find a Bayesian 99 per cent confidence upper limit on the polarized emission for Arp 220 of 1.54 per cent, averaged over the 15-arcsec beam-size. Arp 220 can serve as a proxy for other, more distant such galaxies. This upper limit constrains the magnetic field geometry in Arp 220 and also provides evidence that polarized ULIRGs will not be a major contaminant for next-generation cosmic microwave background polarization measurements.

Key words: galaxies: individual: Arp 220 – galaxies: magnetic fields – cosmic microwave background.

1 INTRODUCTION

The new generation of cosmic microwave background (CMB) experiments, such as NASA's *Wilkinson Microwave Anisotropy Probe* (*WMAP*) and a number of balloon-borne and ground-based instruments, are revolutionizing cosmology by providing precision estimates of a number of fundamental cosmological parameters (e.g. Bennett et al. 2003; Tegmark et al. 2004; MacTavish et al. 2006; Spergel et al. 2006). The upcoming launch of ESA's *Planck* mission (The Planck Collaboration 2005) will provide an opportunity for even more precise parameter estimates.

In addition to the temperature anisotropy, the CMB is expected to be partially polarized due to Thomson scattering of the anisotropic radiation field near the surface of last scattering. The first definitive detections of CMB polarization have recently been made (Kovac et al. 2002; Kogut et al. 2003; Readhead et al. 2004; Barkats et al. 2005; Montroy et al. 2006; Page et al. 2006). The angular power spectrum of polarized fluctuations can provide a wealth of additional cosmological information (see e.g. Hu & White 1997). Perhaps the most tantalizing prospect is that primordial gravitational waves from the epoch of inflation will leave a distinct divergence-free (or '*B*-mode') signature in the CMB polarization that may be detectable by future experiments and cleanly separated from the curl-free (or '*E*-mode') dominant polarization signal (Kamionkowski, Kosowsky & Stebbins 1997; Zaldarriaga & Seljak 1997).

To realize this potential, careful control of systematic effects, including foreground emission, is essential. A number of studies have characterized the potential of extragalactic sources to contaminate CMB anisotropy measurements (e.g. Toffolatti et al. 1998; Tegmark et al. 2000; Tucci et al. 2004; Toffolatti et al. 2005). In general, these authors conclude that extragalactic contamination is most important at small angular scales (high multipole moments), that current estimates are not precisely constrained by available measurements, and that these sources are unlikely to pose a major difficulty to future CMB measurements.

Scott & White (1999) analysed the data from early Submillimetre Common User Bolometer Array (SCUBA) surveys at 850 μm (e.g. Smail, Ivison & Blain 1997; Barger et al. 1998; Hughes et al. 1998; Eales et al. 1999) and concluded that the *Planck* mission may be confusion limited at frequencies of 350 GHz and higher, and that clustering of faint sources may be a measurable signal.

Borys, Chapman & Scott (1999) provided the first limit of the contribution of SCUBA point sources to the CMB. Several studies (e.g. Haiman & Knox 2000; González-Nuevo, Toffolatti & Argüeso 2005) have modelled how clustering of such sources may be manifest in the background over a wide range of wavelengths.

The potential of polarized extragalactic sources to contaminate polarized CMB anisotropies has been much less well studied, particularly in the submm region (de Zotti et al. 1999; Tucci et al. 2004). In this paper, we address this concern by investigating polarized submm emission from one particular object.

Arp 220 is a prototypical member of the class of ultraluminous infrared galaxies (ULIRGs), with a far-IR luminosity of approximately 1.6×10^{12} L$_{\odot}$ (Soifer et al. 1984; Lisenfeld, Isaak & Hills 2000). At roughly 70 Mpc ($H_0 = 70$ km s^{-1} Mpc^{-1}) distance, it is the closest member of this class and one of the brightest galaxies in

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the local Universe. It is therefore well suited for studies that would be much more difficult for other, more distant ULIRGs.

Although our initial motivation for investigating the submm polarization of Arp 220 was as a means to estimate CMB contamination, such measurements of polarization are interesting in their own right. Studying regions of polarized dust emission is important as a means of probing the magnetic field geometry responsible for aligning the dust grains (Lazarian & Finkbeiner 2003). Related issues include understanding the source of submm emission, galactic superwinds, internal dynamics and dust physics.

2 OBSERVATIONS

We observed Arp 220 with the SCUBA (Holland et al. 1999) at the James Clerk Maxwell Telescope (JCMT), Mauna Kea on 2000 August 23 and again on 2001 March 16. Conditions in the 2000 run were favourable, with an 850-μm opacity of $\sim$0.3 ($\tau_{\rm CSO} \sim 0.07$). The sky was much less opaque in the 2001 run, where we enjoyed roughly a factor of 2 lower opacity. Observations were conducted using the SCUBA polarimeter (Greaves et al. 2003) which consists of a rotating quartz half waveplate in front of a fixed wire grid analyser, mounted externally on the SCUBA dewar.

We chose to perform the polarization observations in ‘photometry’ mode as opposed to the more common imaging mode, in order to achieve higher on-source efficiency. The angular size of Arp 220’s infrared luminous core is smaller than the resolution of SCUBA at even its highest frequency channel, and thus we are not missing any flux by performing a photometry-mode observation. Because SCUBA employs a dichroic beam splitter, data are collected simultaneously for the 450- and 850-μm arrays. Although we are mainly interested in the central array bolometers (denoted ‘C14’ and ‘H7’, for the short and long wavelength arrays, respectively), data from the remaining array bolometers were also gathered and used as a monitor of the atmospheric emission.

The observations required several levels of signal modulation. The array was chopped in azimuth at 7.8125 Hz in order to remove common mode atmospheric signal in the source and reference positions. The chop throw was 90 arcsec for the 2000 observations and 40 arcsec for the 2001 observations. After four, 1-s integrations, the telescope was ‘nodded’ in azimuth to match the fast azimuth chop and another set of four, 1-s integrations were taken. The difference between the chopped signal in both nods removes instrumental effects which are dependent on the secondary mirror position (Zemcov, Halpern & Pierpaoli 2005).

After these integrations, the polarimeter half waveplate was moved to the next in a sequence of 16 rotational positions. A full set of rotational positions was thus obtained, consisting of 128 s of observations, with an elapsed time of 280 s, including overheads. Arp 220 was observed at elevation angles ranging from approximately 30° to 85° above the horizon. From the two runs, the total on-source observing time was approximately 3.4 h, consisting of 95 full waveplate cycles. As we explain later, however, some data were not included in the analysis.

In the 2000 observing run, several levels of systematic controls were performed. Two different sequences of waveplate positions were used: the first sequence was the standard one, with 16 22°.5 rotational steps, one after another; in the second method, the angular sequence was 0°–315° in steps of 45°, and then 22°.5–337°.5 using the same step. Observations with the two sequences were interleaved. The different waveplate strategies were performed in an attempt to detect or limit the contribution of atmospheric fluctuations to the polarization signal. Additional observations were performed in a similar manner using a different 850-μm bolometer (‘G15’) centred on Arp 220. After reducing these data and not finding any significant difference between the different approaches, we decided that for the second run the more straightforward approach of using the default waveplate position order and H7 as the primary bolometer was better suited for observations of Arp 220.

A polarization ‘standard’, DR 21 was also observed for 15 total waveplate cycles. This galactic star-forming region has previously been observed to be bright and polarized. Greaves et al. (1999) found 2.34 ± 0.27 per cent polarization at 800 μm with a position angle of 20° ± 3°. Minchin & Murray (1994) report 1.8 ± 0.3 per cent polarization at a position angle of 17° ± 4°, also at 800 μm. DR21’s relatively high flux and likely lack of variability make this source convenient for cross-checking polarization measurements.

Absolute flux calibration and determination of the instrumental polarization (IP) were provided by observations of Uranus (13 waveplate cycles) and Mars (12 waveplate cycles). The Uranus observations were conducted with the same variety of systematic checks as the Arp 220 observations. Pointing was checked roughly once per hour using the blazar 1611+343. Pointing corrections were typically a few arcseconds, except near transit – because the JCMT is an Altaz Telescope, it has difficulty tracking sources such as Arp 220 that transit near the zenith. Arp 220 reaches an elevation of $\sim$85° at the latitude of the JCMT.

3 DATA ANALYSIS AND RESULTS

The raw data were reduced with a combination of routines from the SCUBA User Reduction Facility (SURF, Jenness & Lightfoot 1998) and our own software. SURF was used to provide data free from atmospheric signal, while our own code was devoted to estimating the polarization strength. The roles of the codes are described below.

3.1 Preliminary processing

Using SURF, the data from the two nod positions were subtracted, flat-fielded and then corrected for extinction. We used the polynomial fits to the CSO 225-GHz opacity from the JCMT web page.[1] The opacity at 225 GHz was then converted to the 450- and 850-μm bands using the relations in Archibald et al. (2002). The residual sky background was subtracted (Jenness, Lightfoot & Holland 1998), as estimated from the median of the 12 lowest noise bolometers on ring 3 of the array, and additionally a few anomalous 5σ or greater spikes were removed.

Since we expect that the polarization will be weak, particular care was taken to ensure the quality of the data that went into the analysis. In Fig. 1, we plot the time-streams of the central bolometer in each array for both runs.

3.2 Systematic error control

Among the many sources of potential systematic error for polarization measurements, atmospheric transmission fluctuations, pointing errors or drifts, and spurious pick-up from the telescope environment are perhaps the most important (Hildebrand et al. 2000).

Contaminating pick-up was evaluated by processing the data from an off-source bolometer through the entire analysis pipeline. We have done this for the ‘H9’ bolometer. The polarized signal from this bolometer was consistent with zero, at the 1σ level, and had a

[1] See http://www.jach.hawaii.edu for more information.

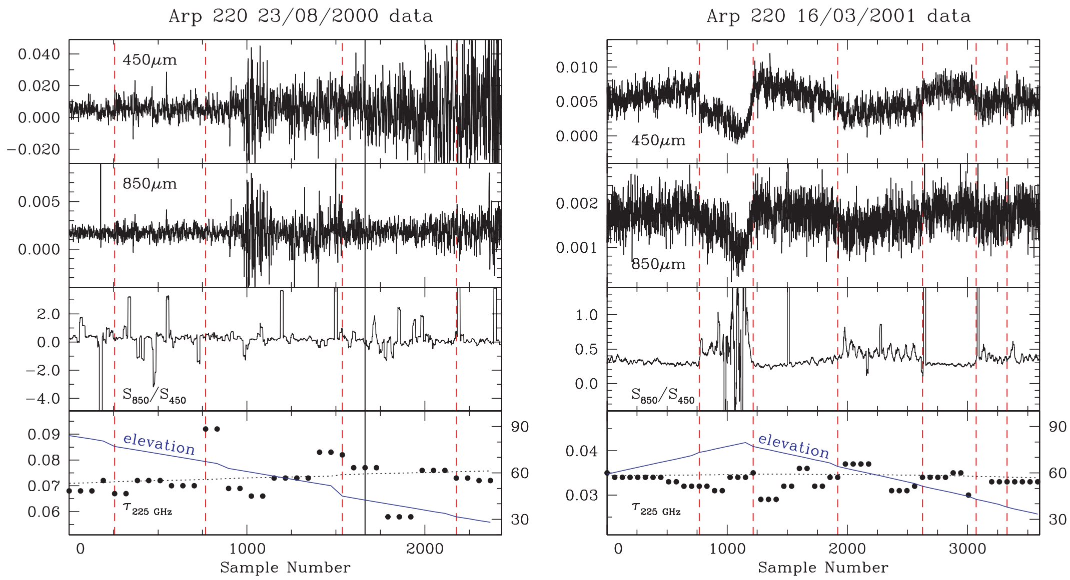

Figure 1. Time streams for the extinction-corrected, sky-subtracted on-source bolometer from the two runs. The top two panels show the 450- and 850-μm signal (in volts). The third panel shows the ratio of the two signals, and should be constant under ideal conditions. The bottom plot shows the measured 225-GHz CSO τ (black circles) and the polynomial fit (dotted line), together with the elevation angle of the observation (solid line). Vertical dashed lines indicate where pointing checks were performed. Left-hand panel: the 2000 data are shown, with a solid black vertical line at sample 1664, denoting the transition from observations taken with H7 as the on-source bolometer to using bolometer G15. Right-hand panel: the 2001 data highlight the problems associated with observing the target near the zenith. In particular, the data between samples $\sim$750 and $\sim$1250 demonstrate that the source probably drifted away from the bolometer centre around transit. These data were not included in the analysis. The opacity was much lower in the 2001 observations, and one can actually see the instrumental polarization in the 450-μm data.

similar noise level to the on-source bolometer analysis. We therefore conclude that polarized contamination from the ground or from atmospheric emission (which we would expect to contaminate the on- and off-source bolometers at a similar level) does not contribute significantly to our on-source observations.

We have examined the time series data for evidence of atmospheric transmission fluctuations. These would affect an observation of a bright point source differently than an off-source pixel, and may be expected to add noise to the measurement. If such fluctuations were significant and had somewhat shorter time-scale than the waveplate rotation period, they would introduce a spurious signal that could be confused with intrinsic source polarization. One may also expect that a decrease in atmospheric transmission would be correlated with an increase in atmospheric emission (if due to a short time-scale fluctuation in opacity). In examining the time series data for the on- and off-source bolometers for our observations, we have found no evidence for such an effect. We are only sensitive to the spatial gradients in off-source emission, however, because only the differenced data after the fast chop are available from SCUBA.

By examining the full time-series of both the 450- and 850-μm data, we have concluded that some observations were drifting somewhat off-source. A key signature of such a drift is a significant decrease in the amplitude of the observed signal, and a greater change at 450 μm than at 850 μm due to the differences in beam-size. Such a decrease is evident near sample number 1000 in the right-hand panel of Fig. 1. We have excluded from our final analysis the seven full waveplate cycles of data between pointing checks near where this pointing drift occurred. We note that the telescope was pointed at very high elevation angle during this period, where tracking is most difficult. A comparison with and without these data included shows that our final polarization result changes by less than 1σ. Very small pointing drifts that may exist in the remaining data are not expected to affect the final result, since each waveplate cycle has a gradient removed from the fit to Q and U.

A period of increased noise near sample number 1000 in the left-hand panel of Fig. 1 is evident. A comparison of data before and after sky subtraction shows that this is due to a period of increased sky noise. Excluding this section of data make less than a 0.3σ change in the Arp 220 polarization fraction, and this section of data has been retained in our final result. In order to test the robustness of our results we have experimented with removing additional short sections of data. Aside from the seven waveplate cycles mentioned above, we have not found the results to be sensitive to the removal of other sections, beyond the expected increase in overall noise.

Our observations of DR21 formally detect 850-μm polarization at approximately the 4σ level and are consistent (at the 1σ level) with those reported by Minchin & Murray (1994). It is not clear to us, however, that our off-source chop or sky subtraction is always in an emission-free region, so our claim for DR21 is one of broad consistency with previous measurements, rather than of precise determination.

3.3 Polarization analysis

Using our own software, the average signal and estimated error for the four integrations at each waveplate position for a full waveplate cycle were fit (using singular value decomposition) to provide an estimate of the total flux and the degree and direction of polarization. A linear gradient in flux was removed from each waveplate cycle in an attempt to decrease the effect of residual pointing drifts. The results for all the waveplate cycles were then combined after discarding several waveplate cycles due to pointing drift as described above. This fitting procedure essentially mirrors that of the observatory's available software, but allowed us to pipeline the analysis and rapidly compare a number of alternative reduction schemes before concluding that the processing described here was sufficient. Among the alternatives investigated (and eventually passed over) were fits to partial and multiple waveplate rotations, discarding waveplate rotation cycles based on a goodness-of-fit criterion, discarding waveplate rotations that produced outliers in Q and U, and an attempt at regressing fluctuations as measured with the 450-μm data. An overall IP that is contributed mostly by the JCMT wind screen must also be subtracted before arriving at the final source polarization estimate. We removed the IP estimated from previous observations of Mars and Uranus (assumed to be unpolarized) of 1.06 per cent at a position angle of 161° given by Greaves et al. (2003). Through our observations of Mars, we derive our own estimate of the IP of 0.89 ± 0.23 per cent at $154° \pm 7°$, which is consistent with the Greaves et al. (2003) value. Our final results are relatively insensitive to the precise value of the IP, because of the range of elevation angles during which the Arp 220 measurements were made. Switching between the two estimates of IP above gives less than a 1σ change in the final results for Stokes q and u. We use the values from Greaves et al. (2003) for our final results.

The data reduction process was run on all the planetary observations to produce an estimate of the system calibration. We adopt a value of 425 Jy V^{-1} for the results presented here. There is a systematic uncertainty in this value from atmospheric and pointing effects, which we estimate to be approximately ±5 per cent based on the distribution of the calibration data. An overall change in the calibration, however, will not affect the polarization estimate.

The results from the first and second observing runs are consistent, with most of the statistical weight coming from the second run. Our formal statistical result for Arp 220 at 850 μm is

$$\begin{aligned} I &= 751 \pm 38 \text{ mJy} \\ q &= 0.00582 \pm 0.00350 \\ u &= 0.00426 \pm 0.00448, \end{aligned}$$

where q and u are the normalized Stokes parameters, and I is the Stokes intensity. Our intensity measurement is consistent with the values measured by Lisenfeld et al. (2000) and Dunne et al. (2000). A naive estimate for the polarization amplitude and orientation can be produced from these measurements, using $p^2 = q^2 + u^2$ and $\tan(2\theta) = q/u$. This yields a polarization fraction of $p = 0.72 \pm 0.39$ per cent at a position angle of $18\overset{\circ}{.}1 \pm 15\overset{\circ}{.}4$. This value, however, considerably overestimates the true level of polarization due to the biasing effect of noise (see Rice 1947; Serkowski 1958; Wardle & Kronberg 1974; Simmons & Stewart 1985; Hildebrand et al. 2000). To counter the effect of noise bias, we can produce an estimate of the posterior probability distribution using a Bayesian framework and an assumed uniform prior on the degree of polarization and the position angle. This procedure yields no firm polarization detection and gives our final result for the 99 per cent confidence upper limit on the polarization of Arp 220: 1.54 per cent.

We note that pointing control is a likely systematic limitation to these or similar measurements. A systematic wander of 2.5 arcsec during the 12 min it takes to complete a waveplate rotation is sufficient to induce a 1 per cent polarized signal. These concerns are more serious for the 450-μm measurements, which have a smaller beam-size. We therefore do not report a polarization result for the 450-μm Arp 220 measurements. The coming SCUBA-2 upgrade (Holland et al. 2003, 2006) will minimize the effects of pointing drift and atmospheric fluctuations with a filled detector array and a much faster waveplate rotation speed.

4 DISCUSSION

The lack of submm polarization signal in Arp 220 is intriguing, but perhaps not very surprising. In our own Galaxy, polarized dust emission has been observed in a variety of molecular clouds (e.g. Fiege & Pudritz 2000; Matthews & Wilson 2002; Houde et al. 2004) and also in pre-stellar cores (Ward-Thompson et al. 2000). Magnetic fields in these environments can result in aligned dust grains which emit radiation with an E-field preferentially aligned. The expected level of polarization is typically a few per cent (Hildebrand & Dragovan 1995). For extragalactic sources Greaves et al. (2000) have reported a detection of polarized 850-μm emission from M82, via resolved imaging observations with SCUBA. Because of the dust grain alignment mechanism, submm-polarized emission traces the magnetic field geometry averaged over the beam-size. Arp 220's small angular size means that the magnetic field would have to be aligned over a significant fraction of the source in order to produce detectable polarization, otherwise the random orientations from a variety of distinct regions sampled by the JCMT beam would tend to cancel out. Note that the average polarization over the entire M82 SCUBA mapping of M82 carried out by Greaves et al. (2000) corresponds to only about 0.4 per cent. For Arp 220, high-resolution interferometric maps in CO (1–0) and dust continuum (Scoville et al. 1991) show that the emission is extremely concentrated in a dense core. Perhaps we can therefore conclude that there does not exist a simple aligned magnetic field geometry in the core of Arp 220. The extreme dust environment in Arp 220's core, however, makes it dangerous to draw conclusions based on dust properties in more benign environments like that in our own Galaxy or even M82.

Jones & Klebe (1989) detect weak near-infrared polarization in Arp 220, which they interpret as due to a simple screen of aligned dust in front of a bright nucleus. The reported value is 0.54 ± 0.18 per cent polarization at K-band, with a position angle of $58° \pm 11°$. Siebenmorgen & Efstathiou (2001) report a mid-infrared detection of polarization due to absorption of 3.1 ± 0.9 per cent at 14.3 μm with a position angle of $62° \pm 9°$. Both of these studies also conclude that the dust grain alignment must be inefficient, otherwise the high optical depth would lead to a much higher degree of polarization. It is unclear, however, if Arp 220's relatively low level of polarization is typical, since Siebenmorgen & Efstathiou (2001) report mid-IR polarization levels as high as 8 per cent in other ULIRGs.

At different wavelengths one might expect the core polarization to reflect the geometry of the nuclear disc, the separation of the double nucleus and the orientation of outflows. The gas disc of Arp 220 is at approximate position angle (PA) = 45° (e.g. Scoville, Yun & Bryant 1997), while models of the core radio, mm and submm emission suggest two components separated by $\sim$1 arcsec, with PA $\simeq$ 80–100° (e.g. Baan & Haschick 1995; Scoville, Yun & Bryant 1997; Eckart & Downes 2001; Mundell, Ferruit & Pedlarroy 2001). Obviously our upper limit sheds little light on whether the magnetic field structure is related to any of these features – this will await more stable measurements, as well as higher resolution studies.

A naive estimate for the level of polarized fluctuations from extragalactic sources is the product of the level of fluctuations in flux and the average percentage polarization (de Zotti et al. 1999). A more detailed calculation can be done using the source counts for submillimetre galaxies. The shot noise from these sources results in a flat contribution to the CMB temperature or Stokes I C_ℓs:

$$C_\ell^I = \int_0^{S_{\rm cut}} S^2 \left(\frac{\mathrm{d}N}{\mathrm{d}S}\right) \mathrm{d}S, \qquad (1)$$

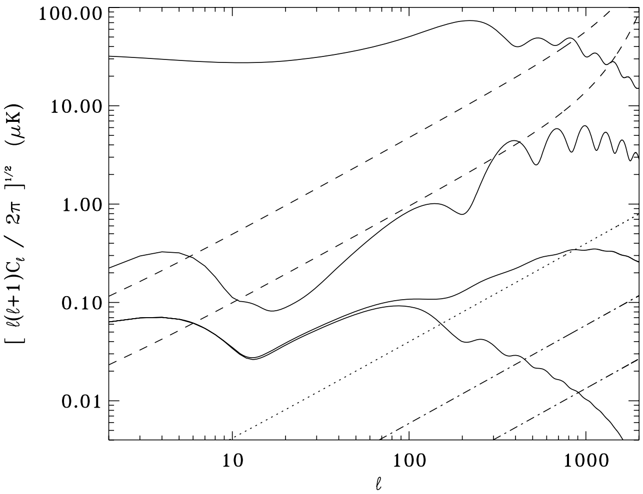

Figure 2. Theoretical CMB angular power spectra with potential contributions from polarized dusty galaxies and with noise estimates from *Planck*. The solid lines show the expected CMB power spectrum from (top to bottom) temperature fluctuations, *E*-mode polarization, *B*-mode polarization with lensing and *B*-mode without lensing. A standard cosmological model constrained by *WMAP* three-year data has been assumed, along with a tensor-to-scalar ratio of 0.1. Also shown are the pixel-polarized noise estimates from *Planck* at 353 GHz (upper dashed line) and 143 GHz (lower dashed line). The dotted line shows an estimate of the contribution of polarized dusty galaxies at 350 GHz assuming all the sources are 1.5 per cent polarized with random orientation angles, the sources are not clustered and that sources above 100 mJy have been removed. The two dot–dashed curves show two estimates from de Zotti et al. (1999) of the contribution of dusty polarized galaxies at 143 GHz, assuming 2 per cent galaxy polarization.

where $\mathrm{d}N/\mathrm{d}S$ are the differential source counts and C_ℓ is the angular power spectrum. The contribution to the *E*- and *B*-mode power spectra are equal and given by

$$C_\ell^E = C_\ell^B = p^2 \frac{C_\ell^I}{2}, \tag{2}$$

for sources having fractional polarization p (see Tucci et al. 2004, and references therein). Assuming $p = 1.5$ per cent and following the counts estimate of Scott & White (1999) we show in Fig. 2 the level expected if individual sources can be removed at the 100-mJy level. We also show two estimates from de Zotti et al. (1999) at 143 GHz, assuming each galaxy is 2 per cent polarized.

In producing CMB angular power spectrum estimates, one can remove or marginalize over pixels in the map with clearly detected point sources. The contamination of concern is then generally due to the brightest sources immediately below the detection threshold. The 100-mJy flux cut corresponds to the 4σ detection limit for the *Planck* 353-GHz channel all sky survey (The *Planck* Collaboration 2005). The *Planck* point-source detection limits, however, can differ depending on the assumptions about the foregrounds, the specific method adopted, and whether data at multiple frequencies are used (e.g. Vielva et al. 2001, 2003). We note that raising the flux cut level to 200 mJy would result in roughly a 10 per cent increase in the contribution to the angular power spectrum.

Also shown is an overall view of the level of expected CMB temperature and polarization fluctuations using a standard cosmological model constrained by the *WMAP* results, constructed using CMBFAST (Seljak & Zaldarriaga 1996). The *B*-mode fluctuation curve (the potential contribution from primordial gravitational waves) was constructed assuming a tensor-to-scalar ratio of 0.1.

The *Planck* 143- and 353-GHz pixel noise contribution to the polarized angular power spectrum sensitivity levels are also shown in Fig. 2. The standard error per ℓ-mode is derived from the *Planck* instrument sensitivity (The Planck Collaboration 2005) using

$$\sigma_\ell^{\mathrm{P}} = \sqrt{\frac{2}{f_{\mathrm{sky}}(2\ell+1)}}\left(C_\ell^{\mathrm{P}} + N_\ell^{\mathrm{P}}\right), \tag{3}$$

where σ_ℓ^{P} is the standard error per mode in the polarization power spectrum, f_{sky} is the fraction of sky observed and C_ℓ^{P} is the angular power spectrum of the CMB polarization signal (see e.g. Knox 1995; Kesden, Corray & Kamionkowski 2002). N_ℓ^{P} is the pixel noise contribution given by

$$N_\ell^{\mathrm{P}} = f_{\mathrm{sky}} \frac{4\pi s^2}{\tau} \mathrm{e}^{\ell^2 {\sigma_{\mathrm{b}}}^2}, \tag{4}$$

where s is the effective sensitivity, τ is the total integration time and σ_{b} is the instrument beam Gaussian width. The noise estimates here are simple ones and do not account for the effects of non-uniform sky coverage, galactic cuts, detector $1/f$ noise, etc. Nevertheless, the *Planck* noise levels are more than an order of magnitude above the polarized dusty galaxy level and we therefore conclude that such galaxies are unlikely to contaminate CMB polarization measurements with *Planck* even in the higher CMB frequency bands.

Contamination in the 350-GHz range may be an issue, however, for future CMB polarization measurements that attempt to reach the 0.01 tensor-to-scalar ratio level, particularly at the higher multipoles. Experiments designed to measure the lensing contribution to *B*-mode polarization may also need to carefully consider the potential impact of polarized extragalactic sources.

Our current state of knowledge, however, is still incomplete. The above analysis relies on a number of extrapolations and simplifying assumptions which may not be correct, including: the unknown source counts at the $\sim$100 mJy level; precisely at what level individual sources can be removed; the real distribution in the degree of polarization of such objects; and whether clustering, potentially involving partial alignments of polarization axes, might be significant. Determining whether Arp 220's level of submm polarization is actually typical will await measurements of more objects and greater control of systematic effects, which will be possible with the new SCUBA-2 instrument.

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