Extragalactic source contributions to arcminute-scale Cosmic Microwave Background anisotropies

Luigi Toffolatti¹, Mattia Negrello², Joaquín González-Nuevo¹, Gianfranco De Zotti²-³, Laura Silva⁴, Gian Luigi Granato²-³, and Francisco Argüeso⁵

1 Departamento de Física, Universidad de Oviedo, c. Calvo Sotelo s/n, 33007 Oviedo, Spain
2 International School for Advanced Studies, SISSA/ISAS, Via Beirut 2-4, I-34014 Trieste, Italy
3 INAF–Osservatorio Astronomico di Padova, Vicolo dell’Osservatorio 5, I-35122 Padova, Italy
4 INAF–Osservatorio Astronomico di Trieste, Via Tiepolo 11, I-34131 Trieste, Italy
5 Departamento de Matemáticas, Universidad de Oviedo, c. Calvo Sotelo s/n, 33007 Oviedo, Spain

Received / Accepted

Abstract. The possible contributions of the various classes of extragalactic sources (including, in addition to the canonical radio sources, GHz Peaked Spectrum sources, advection-dominated sources, starburst galaxies, high-redshift proto-spheroidal galaxies) to the arcminute scale fluctuations measured by the CBI, BIMA, and ACBAR experiments are discussed. At 30 GHz, fluctuations due to radio sources undetected by ancillary low-frequency surveys may be higher than estimated by the CBI and BIMA groups. High-redshift dusty galaxies, whose fluctuations may be strongly enhanced by the effect of clustering, could contribute to the BIMA excess signal, and dominate at 150 GHz (the ACBAR frequency). Moreover, in the present data situation, the dust emission of these high-redshift sources set an unavoidable limit to the detection of primordial CMB anisotropies at high multipoles, even at frequencies as low as ≃ 30 GHz. It is concluded that the possibility that the excess power at high multipoles is dominated by unsubtracted extragalactic sources cannot be ruled out. On the other hand, there is room for a contribution from the Sunyaev-Zeldovich effect within clusters of galaxies, with a density fluctuation amplitude parameter σ₈ consistent with the values preferred by current data.

Key words. Cosmic microwave background — Galaxies: general — radio continuum: galaxies

1. Introduction

In the past few years different experiments (BIMA: Dawson et al. 2002; CBI: Mason et al. 2003, Readhead et al. 2004, and ACBAR: Kuo et al. 2004), aimed at measuring the anisotropies of the cosmic microwave background (CMB) on arcminute angular scales, have detected signals at multipoles ℓ > 2000 in excess of the expected primordial CMB anisotropies. The origin of this excess signal, in the range 16 ≤ ΔT ≤ 26 µK, is not well understood yet, although several possibilities have been discussed in the literature.

All experimental groups argue that it cannot be due to point-source contamination. If so, the most likely candidate is the thermal Sunyaev-Zeldovich (SZ) effect, which is expected to dominate CMB anisotropies on angular scales of a few arcminutes (Gnedin & Jaffe 2001). However, an interpretation on terms of SZ effects from clusters of galaxies (Bond et al. 2005; Komatsu & Seljak 2002) or to the inhomogeneous plasma distribution during the formation of large scale structure (Zhang et al. 2002) requires values of σ₈ (the rms density fluctuation on a scale of 8h⁻¹ Mpc) significantly higher than indicated by current data. SZ effects associated with the formation and the early evolutionary phases of massive spheroidal galaxies could account for the BIMA signal, although some parameters need to be stretched to their boundary values (De Zotti et al. 2004). Alternative interpretations advocate non-standard inflationary models (Cooray & Melchiorri 2002; Griffiths et al. 2003).

In this paper we revisit the contributions of extragalactic point sources to the power spectrum on arcminute scales at the relevant frequencies, including the possible role of faint sources, with flux densities too weak to be
filtered out, and the effect of clustering. The outline of
the paper is as follows. In Section 2 we describe the dif-
f ferent source populations which give the dominant con-
tributions to number counts at cm and mm wavelengths.
In Section 3 we present our estimates of arcminute-scale
CMB anisotropies due to extragalactic sources, while in
Section 4 we summarize our main conclusions.

A flat $\Lambda$CDM cosmology with $\Omega_{\Lambda}=0.7$ has been used
throughout the paper.

2. Extragalactic sources at cm and mm
wavelengths

The estimated contributions of the various populations
of extragalactic sources to the counts at 30 GHz (the fre-
quency of BIMA and CBI experiments) and at 150 GHz
(ACBAR experiment), obtained from the model of De
Zotti et al. (2005), which updates the model by Toffolatti
et al. (1998), are shown in Fig. 1. In addition to the cano-
nical flat- and steep-spectrum radio sources, the model
takes into account star-forming galaxies with their com-
p lex spectra including both radio (synchrotron plus free-
free) and dust emission, and the source populations char-
acterized by spectra peaking at high radio frequencies,
such as extreme GHz Peaked Spectrum (GPS) sources
and accretion flows on almost inactive supermassive black-
holes in early type galaxies (ADAF/ADIOS sources).

Because of their inverted low-frequency spectrum, GPS
and ADAF/ADIOS sources are potentially worrisome.
However, GPS sources are rare and the analysis made by
De Zotti et al. (2000) implies that they likely have very flat
counts and therefore are minor contributors to small scale
fluctuations. Furthermore, the repeated multifrequency
measurements by Tinti et al. (2005) have demonstrated
that most GPS candidates identified with quasars in the
sample of Dallacasa et al. (2000) are in fact flaring blazars,
so that the surface densities of bona-fide GPS sources is
probably substantially lower than estimated by De Zotti
et al. (2000), a conclusion further supported by an ex-
amination, carried out by De Zotti et al. (2005), of GPS
candidates in the WMAP sample (Bennett et al. 2003).

ADAF/ADIOS sources are far more numerous, but
have a low radio power. The estimate by De Zotti et al.
(2005) of their counts is well below that by Perna & Di
Matteo (2000), whose results are probably affected by a
numerical error, and implies that also these sources do
not contribute significantly to the fluctuations measured
by the BIMA and CBI experiments. On the other hand,
Pierpaoli & Perna (2004; model A) pointed out that if the
standard ADAF model (Narayan & Yi 1994) is used, these
sources could make up to 40–50% of the BIMA and CBI
excesses. We note, however, that the standard ADAF sce-
nario faces a number of serious difficulties, some of which
are summarized in Sect. 4.3 of De Zotti et al. (2005), sug-
gesting that the radio emission is suppressed by massive
outflows. It is therefore likely that the results of model A
by Pierpaoli & Perna (2004) should be regarded as, prob-
ably generous, upper limits.

As for starburst galaxies, the slope of their differen-
tial counts can exceed 3, if these objects have to account
for the very steep ISOCAM 15µm counts below a few
mJy, as implied by recent analyses (Gruppioni et al. 2003;
Franceschini et al. 2003; Pozzi et al. 2004; Silva et al.
2005). In this case, their main contribution to small scale
fluctuations comes from weak sources, at µJy levels, far
fainter than those removed from CBI and BIMA maps.
On the other hand, the counts of such sources are tightly
constrained by µJy counts at 1.4 GHz (Richards 2000), 5
GHz (Fomalont et al. 1991), and 8.4 GHz (Fomalont et al.
2002). Taking such constraints into account and applying
an average spectral index $\alpha=0.8$, appropriate for this
class of sources, we find that they can only provide a mi-
nor contribution to the excess power detected by BIMA
and CBI: $\sim 4.3\mu K$ at $\ell \simeq 6880$, by using the nominal $6\sigma$
detection limit, $S_d=150\mu Jy$, for BIMA and $\sim 5.0\mu K$
at $\ell \simeq 2500$ ($S_d=3.4\ mJy$) for CBI, respectively. Their
contribution is negligible at the ACBAR frequency.

An additional contribution is expected from dusty
proto-spheroidal galaxies, which may account for galax-
ies selected by SCUBA and MAMBO surveys (Granato
et al. 2001, 2004), whose counts at 850µm and 12mm
appear to fall down very rapidly at flux densities above
several mJy (Scott et al. 2002; Borys et al. 2003; Greve
et al. 2004). The spectral energy distribution of nearby dusty
galaxies is dominated by synchrotron plus free-free emis-
sion at $\lambda > 2$–3 mm (Bressan et al. 2002), while at shorter
wavelengths dust emission, rapidly raising with frequency
($S_\nu \propto \nu^4$), takes over. Since these sources are at typi-
cal redshifts $> 2$ (Chapman et al. 2003), dust emission
can significantly contribute to the counts even at 30 GHz.
When dust emission comes in, the counts, already steep
because of the effect of the strong cosmological evolution,
are boosted by the large negative K-correction.

The poor knowledge of the millimeter emission of these
sources, however, makes estimates of their contributions to
the 30 GHz counts quite uncertain. The two short-dashed
lines in Fig. 1 show the counts we obtain using the physical
evolutionary model by Granato et al. (2004) but with two
choices for the spectral energy distribution (SED). The
lower (thicker) line refers to the SED produced by the
code GRASIL (originally described by Silva et al. 1998).
An excess emission by a factor $\sim 2$ at $\lambda \geq 1$ mm was
however detected in several Galactic clouds, combining
Archeops with WMAP and DIRBE data (Bernard et al.
2003; Dupac et al. 2003), and in NGC1569 (Galliano
et al. 2003). The origin of the excess is still not understood.
Possibilities discussed in the literature are that the grain
sizes or composition change in dense environments or that
there is an intrinsic dependence of the dust emissivity in-
dex on temperature (Dupac et al. 2004). If the excess is
due to very cold grains (Reach et al. 1995; Galliano et al.
2003) it cannot be present in the high-z proto-spheroids.
But if it is a general property of the SED of dusty galaxies,
the predicted counts of dusty proto-spheroids are given by
the upper (thin) short-dashed curve.
Fig. 1. Differential counts, $dN/d\log S$, of different source populations at 30 and 150 GHz, based on the De Zotti et al. (2005) evolution model. Solid lines: canonical flat–plus steep-spectrum sources; dot-dashed lines: starburst galaxies; short-dashed lines: dusty proto-spheroidal galaxies with (upper curve) and without the mm excess (see text). In the left-hand panel only the estimated counts of GPS sources (dotted line) and of ADAF/ADIOS sources (long-dashed line) are also shown.

3. Contributions of extragalactic sources to arcminute scale anisotropies

3.1. Observations with the Cosmic Background Imager (CBI)

The strategy of the CBI group (Mason et al. 2003; Readhead et al. 2004) to remove the point source contamination comprises pointed 31 GHz observations with the OVRO 40m telescope of all NVSS sources with 1.4 GHz flux density $\geq 6$ mJy, and direct counts at 31 GHz using the CBI deep and mosaic maps. Although the 4$\sigma$ threshold of OVRO observations is 6 mJy, the survey is 99% complete only at $S_{31\mathrm{GHz}} > 21$ mJy. The limiting flux density ranges from 6 to 12 mJy in the deep CBI maps, and from 18 to 25 mJy in the mosaic maps. Subtraction of OVRO detected sources removes two-thirds of the observed power level.

Furthermore, they have adopted the constraint matrix approach to remove from their dataset all NVSS sources with flux densities greater than 3.4 mJy at 1.4 GHz (Readhead et al. 2004), and have estimated the contribution to fluctuations due to sources below the NVSS cutoff using the observed OVRO-NVSS distribution of spectral indices and adopting a rather shallow power-law slope for the counts ($N(>S) \propto S^{-0.875}$); for comparison, Richards (2000) finds $N(>S) \propto S^{-1.43^{+0.1}_{-0.3}}$ for $40\mu Jy < S_{1.4} < 1$ mJy (see also Windhorst et al. 1993).

At the flux-density levels relevant for the CBI experiment, apart from SZ effects (see Sect. 1), the dominant contribution to fluctuations due to extragalactic sources is expected to come from the classical steep- and flat–spectrum radio sources. However, an accurate determination of the 30 GHz fluctuations due to sources with $S_{1.4} \leq 3.4$ mJy is very difficult because of the effect of sources with inverted spectra (in fact, Readhead et al. 2004 report the detection of a source, NGC 1068, at $S_{30\mathrm{GHz}} \approx 400$ mJy, not removed by the constraint matrix), and of variability. The difficulty is illustrated by the results of high-frequency surveys. Ricci et al. (2004) found that the 18 GHz flux densities of extragalactic sources detected by the ATCA pilot survey are not significantly correlated with the SUMSS flux densities at 0.84 GHz (i.e. at a frequency not far from that of the NVSS survey). Waldram et al. (2003) also reported a large spread (about a factor of 10) of the 15 to 1.4 GHz flux density ratios of sources detected in their 9C survey at 15 GHz, although the flux densities at the two frequencies are correlated. They also noted that pointed 15 GHz observations of the NVSS sources with $S_{1.4} \geq 25$ mJy in the area covered by their survey would have detected 434 sources above the 9C survey limit of 25 mJy but would have missed 31 sources having $S_{15} \geq 25$ mJy but $S_{1.4} < 25$ mJy. The distribution of spectral indices has a systematic drift towards flatter values with decreasing low-frequency flux density down to $S_{1.4} \approx 1$ mJy (Windhorst et al. 1993), so that the fraction

Fig. 2. Angular power spectrum ($\delta T = \sqrt{\ell(\ell + 1)C_\ell / 2\pi}$) measured at 30 GHz by CBI (left-hand panel; data points from Readhead et al. 2004) and by BIMA (right-hand panel; data points from Dawson et al. 2002). In each panel, we have plotted the primordial CMB angular power spectrum (dot-dashed line), the estimated range of contributions of unsubtracted canonical radio sources (dotted lines; see text), and of Poisson distributed (short-dashed line) and clustered (long-dashed line) proto-spheroidal galaxies. In the BIMA case, the upper pair of long- and short-dashed lines refers to proto-spheroidal galaxies with the submillimeter excess mentioned in Sect. 2 (not shown in the other panel). The contributions of the latter sources are insensitive to the adopted flux limit because of the very steep counts. The shaded areas show the ranges spanned by the quadratic sum of the different contributions.
of sources with inverted spectra is expected to be higher at the fainter flux density levels of interest here.

High frequency surveys emphasize flat-spectrum sources. The dominant flat-spectrum population are blazars, that are highly variable on timescales of years and whose variability amplitude increases with frequency (Impey & Neugebauer 1988; Ciaramella et al. 2004). The monitoring campaigns at 22, 37 and 87 GHz by the Metsähovi group (Teräsranta et al. 1998) have shown that intensity variations by factors of several are common at these frequencies, so that a substantial fraction of such sources may have had, at the moment of the CBI observations, 30 GHz fluxes higher than 3.4 mJy, even by a considerable factor. Variability can indeed account, to a large extent, for the lack of a correlation between the ATCA 18 GHz and the SUMSS 0.84 GHz flux densities (Ricci et al. 2004) and for the large spread of the 15 to 1.4 GHz flux density ratios (Waldram et al. 2003).

To appraise residual fluctuations at 30 GHz due to unsubtracted sources we have adopted the analytical description of the counts below a few mJy by Richards (2000; $dN/dS_{1.4} = S_{1.4}^{-0.4} \cdot e^{-S_{1.4}/3}$) with $A = 8.3 \pm 0.4$ and $\gamma = 2.4 \pm 0.1$ and computed the Poisson fluctuations at 30 GHz of those sources with $S_{1.4} < 3.4$ mJy, assuming a Gaussian distribution of spectral indices with mean $\bar{\alpha} = 0.4$ (Fomalont et al. 1991; Windhorst et al. 1993) and two values of the dispersion ($\sigma = 0.3$ or 0.4), based on the width of the distribution of $\alpha_{1.4}$ of Waldram et al. (2003, their Fig. 9). A comparison with the 30 GHz counts yielded by the De Zotti et al. (2005) model, which takes into account the available information from high-frequency surveys, shows that, in the 30 GHz flux density range relevant to estimate fluctuations, the counts extrapolated using the upper values of $A$ and $\gamma$ are somewhat too high if $\sigma = 0.4$; more consistent counts (only slightly above the model predictions) are obtained with the central values $A = 8.3$, $\gamma = 2.4$. To bound the plausible range of residual fluctuations we have therefore considered the cases $A = 8.3$, $\gamma = 2.4$, $\sigma = 0.4$ (upper dotted line in the left-hand panel of Fig. 2) and $A = 7.9$, $\gamma = 2.3$, $\sigma = 0.3$ (lower dotted line).

The additional contribution to CMB fluctuations given by correlated positions in the sky of canonical steep- and flat-spectrum radio sources has been recently analyzed by González-Nuevo et al. (2005). Their outcomes indicate that the extra power due to the clustering of radio sources cannot, by itself, explain the excess signal detected by CBI and BIMA. Using the $w(\theta)$ estimated by Blake & Wall (2002) from sources in the NVSS survey down to $S \sim 10$ mJy - which can represent a realistic approximation to the clustering properties of faint undetected sources in the CBI fields - they found that clustered radio sources at $S_{30\, \text{GHz}} < 3.4$ mJy can give an extra power $\Delta T \sim 3-4 \mu$K, which has to be summed up - in quadrature - to the Poisson term, $\Delta T \sim 20-22 \mu$K. The dominance of Poisson over clustering fluctuations even at faint fluxes is due to the strong dilution of the clustering signal of extragalactic radio sources by the broadness of their luminosity function and of their redshift distribution (Dunlop & Peacock 1990; Toffolatti et al. 1998; Negrello et al. 2004).

### 3.2. Observations with the Berkeley-Illinois-Maryland Association Array (BIMA)

To remove the point source contamination, the BIMA group (Dawson et al. 2002) have carried out a VLA survey at 4.8 GHz of their fields. These observations reached a rms flux of $\sim 0.02$ mJy beam$^{-1}$ for a 6 arcmin$^2$ region with center coinciding with the center of the corresponding BIMA field. Sources with flux density $> 6\sigma_{\text{VLA}}$ within 8$^\prime$ of the pointing center were projected out. On the other hand, point sources with flux densities $S_{4.8} > 150$ mJy, lying at an angular distance $\theta$ from the BIMA field center, cannot be detected (and removed) by VLA observations if $S_{4.8} < S_{\text{lim}}(\theta) = 6\sigma/f(\theta)$, where $f(\theta)$ is the VLA response function, assumed Gaussian.

Therefore, we have estimated the fluctuations in the BIMA fields due to sources fainter than $150$ mJy/f(\theta), where $\theta$ is the angular distance from the pointing direction, by adopting the number counts at 4.8 GHz of Fomalont et al. (1991), $N(S) = (23.2 \pm 2.8)S_{4.8,\mu\text{Jy}}^{-0.15 \pm 0.09} \times \alpha^{-0.4}$, extrapolated to 30 GHz with mean spectral index $\alpha = 0.4$ ($S_{\nu} \propto \nu^{-\alpha}$), appropriate for the relevant flux-density range (Fomalont et al. 1991; Windhorst et al. 1993). The corresponding power spectrum is shown in Fig. 2 (right-hand panel), where the shaded area reflects the range of values corresponding to the uncertainties in the counts of Fomalont et al. (1991) and in the dust emission spectrum of high redshift spheroids (see below).

The fluctuations due to forming spheroidal galaxies, not represented in the 4.8 GHz counts, get comparable contributions from both the Poisson and the clustering term, while the latter term turns out to be small, compared to the former, for the other classes of sources relevant here. Adopting the standard expression for the two-point correlation function, $\xi(r) = (r/r_0)^{-1.8}$ with a constant comoving clustering length $r_0 = 8.3h^{-1}$ Mpc, $h$ being the Hubble constant in units of $100$ km s$^{-1}$ Mpc$^{-1}$ (see Negrello et al. 2004), we find, at $\ell_{\text{eff}} = 6864$, a Poisson contribution of $\approx 5\mu$K and a clustering contribution of $\approx 3\mu$K. Clearly these contributions, to be summed in quadrature to the contribution discussed above, have a minor effect. If, however, these sources show the mm excess mentioned in Sect. 2, their contribution to fluctuations would be approximately doubled (see Fig. 2), and, summed in quadrature to the above estimate of the contribution of radio sources, could account for the reported excess signal.

### 3.3. Observations with the Arcminute Cosmology Bolometer Array Receiver (ACBAR)

The ACBAR measurements in the 150 GHz band reported by Kuo et al. (2004) up to multipoles $\ell = 3000$ are consistent with the primordial CMB power spectrum predicted
In this case we adopted panel) the excess mm-wave emission discussed in the text. The contribution given by undetected Poisson distribution and clustered proto-spheroidal galaxies has been calculated without (left-hand panel) and with (right-hand panel) the excess mm-wave emission discussed in the text. In this case we adopted $S_{\text{lim}} \simeq 24$ mJy (left-hand panel) and $S_{\text{lim}} \simeq 43$ mJy (right-hand panel) for source detection. These limits correspond to the $5\sigma$ source detection threshold estimated as in Negrello et al. (2004) for a $5'$ FWHM.

Fig. 3. Angular power spectrum ($\delta T = \sqrt{\ell(\ell + 1)C_{\ell}/2\pi}$ measured by ACBAR at 150 GHz (data points are from Kuo et al. 2004). The dotted, long- and short-dashed, and dot-dashed curves have the same meaning as in Fig. 2; the solid lines are the quadratic sum of all the contributions. The contribution given by undetected Poisson distributed and clustered proto-spheroidal galaxies has been calculated without (left-hand panel) and with (right-hand panel) the excess mm-wave emission discussed in the text. In this case we adopted $S_{\text{lim}} \simeq 24$ mJy (left-hand panel) and $S_{\text{lim}} \simeq 43$ mJy (right-hand panel) for source detection. These limits correspond to the $5\sigma$ source detection threshold estimated as in Negrello et al. (2004) for a $5'$ FWHM.

4. Conclusions

Contamination from extragalactic point sources appears to be a likely candidate to account for a large fraction, perhaps for most of the excess power on arcminute scales detected by the CBI and BIMA experiments. The fluctuations due to radio sources undetected by the ancillary low-frequency surveys may in fact be higher than estimated by the CBI and BIMA groups. On the other hand, we argue that extreme GHz Peaked Spectrum sources and advection dominated sources, potentially worrisome because of their spectra peaking at high microwave/mm-wave wavelengths, should provide only a minor contribution to the CBI and BIMA signals.

Although the very steep $15\mu$m counts of starburst galaxies below a few mJy imply a very strong cosmological evolution, the radio surveys down to $\mu$Jy levels constrain the contribution of their radio emission to fluctuations at 30 GHz to be relatively small. On the other hand, the dust emission at rest-frame mm wavelengths from star-forming galaxies at high-redshifts, such as those detected by SCUBA and MAMBO surveys, can be redshifted down to 30 GHz. Using the spectral energy distributions given by the Granato et al. (2004) model, we find that these sources yield fluctuations of a few to several $\mu$K on arc-minute scales. Their rest-frame spectral energy distribution at mm wavelengths, however, is poorly known, and may well be higher than implied by the adopted model.

Moreover, observational indications and the theoretical arguments converge in suggesting that they are highly clustered (see Negrello et al. 2004, and references therein), so that their fluctuations may be strongly super-Poissonian for multipoles $\ell \leq 3000$ (remember that the clustering-to-Poisson ratio increases with the angular scale, i.e. with decreasing multipole number, De Zotti et al. 1996). Clustering fluctuations of the high-$z$ galaxies detected by (sub)-mm SCUBA and MAMBO surveys may indeed dominate the contamination by extragalactic sources of the signal measured by the ACBAR experiment at 150 GHz.

Because the dust emission spectrum rises very steeply with frequency, lower frequency surveys cannot be used to remove their effect from 30 GHz maps. In the present data situation, they therefore set an unavoidable limit to the determination of the primordial CMB angular power spectrum at high multipoles, even at frequencies as low as $\sim 30$ GHz.

We stress that the present results are fully compatible with the estimated contributions of Sunyaev-Zeldovich effects in clusters of galaxies to the arcminute scale anisotropies. In fact, while an interpretation of the full CBI and BIMA signals in terms of SZ fluctuations would require a density fluctuation amplitude (measured by the parameter $\sigma_8$) at or above the limit allowed by current data (Bond et al. 2005), our analysis leaves room for an SZ contribution corresponding to the $\sigma_8$ values favoured by analyses of CMB, cosmic shear, and large scale struc-
ture data (Spergel et al. 2003; Pierpaoli et al. 2003; Van Waerbeke et al. 2005).

New interesting constraints on the CMB angular power spectrum up to $\ell \sim 2500$ at 34 GHz should be provided in the near future by the VSA experiment. The reduced noise level of the new configuration and an effective cleaning of deep fields down to $\sim 5$ mJy – by dedicated observations with the Ryle Telescope at 15 GHz – will shed new light on the nature of the excess at high multipole and on the point source populations mainly contributing to the number counts at $S_{\rm 34} \sim$ a few mJy. Moreover, Planck HFI data as well as the forthcoming surveys by the Herschel telescope – at frequencies where the emission due to cold dust grains is the dominant one – shall be unique in determining much better the cosmological evolution, the emission and the clustering properties of high-redshift dusty galaxies.

Acknowledgements. We are grateful to K. Dawson and to G. Holder for very stimulating comments and clarifications on the point source subtraction for the BIMA experiment, and to the referee whose comments greatly helped improving the paper. LT, JGN and FA thank the Spanish MEC (Ministerio de Educació n y Ciencia) for partial financial support (project ESP2004-07067-C03-01). JGN acknowledges a FPU fellowship and an “Ayuda” for Short Research Periods of the Spanish Ministry of Education (MEC). JGN also thanks the SISSA-ISAS, International School for Advanced Studies (Trieste, Italy), where his share of this work was completed, for the warm hospitality.

References

Bennett, C.L., Hill, R.S., Hinshaw, G., et al. 2003, ApJS, 148, 97
Bernard, J.-P., Meny, C., Dupac, X., et al. 2003, paper presented at the Planck WG7 meeting, Jodrell Bank
Blain, A.W., Ivison, R.J., & Smail, I. 1998, MNRAS, 296, L29
Blake, C., & Wall, J.V. 2002, MNRAS, 329, L37
Bond, J.R., Contaldi, C.R., Pen, U.L., et al. 2005, ApJ, in press (astro-ph/0203586)
Borys, C., Chapman, S., Halpern, M., & Scott D. 2003, MNRAS, 344, 385
Bressan, A., Silva, L., & Granato, G.L. 2002, A&A, 392, 377
Chapman, S.C., Blain, A.W., Ivison, R.J., & Smail, I.R. 2003, Nature, 422, 695
Ciaramella, A., Bongardo, C., Aller, H.D., et al. 2004, A&A, 419, 485
Cooray, A., & Melchiorri, A. 2002, PhRvD, 66, 083001
Dallacasa, D., Stanghellini, C., Centonza, M., & Fanti, R. 2000, A&A, 363, 887
Dawson, K.S., Holzapfel, W.L., Carlstrom, J.E., Joy, M., LaRoque, S.J., Miller, A.D., & Nagai, D. 2002, ApJ, 581, 86
De Zotti, G., Burigana, C., Cavaliere, A., Danese, L., Granato, G.L., Lapi, A., Platania, P., Silva, L. 2004, in proc. int. symp. “Plasmas in the Laboratory and in the Universe: new insights and new challenges”, eds. G. Bertin, D. Farina & R. Pozzoli, AIP conf. proc., 703, 375
De Zotti, G., Franceschini, A., Toffolatti, L., Mazzei, P., Danese, L. 1996, Astrophys. Lett. Comm., 35, 289
De Zotti, G., Granato, G.L., Silva, L., Maino, D., & Danese, L. 2000, A&A, 354, 467
De Zotti, G., Ricci, R., Mesa, D., Silva, L., Mazzotta, P., Toffolatti, L., & González-Nuevo, J. 2005, A&A, 431, 893
Dunlop, J.S., & Peacock, J.A. 1990, MNRAS, 247, 19
Dupac, X., Bernard, J.-P., Boudet, N., et al. 2003, A&A, 404, L11
Dupac, X., Bernard, J.-P., Boudet, N., Giard, M., Lamarre, J.M., Mény, C., Pajot, F., & Ristorcelli, I. 2004, in “The Dense Interstellar Medium in Galaxies”, Proc. 4th Cologne-Bonn-Zermatt Symp., S. Pfalzner, C. Kramer, C. Staubmeier, & A. Heithausen eds., Springer proceedings in physics, 91, 419
Fomalont, E.B., Kellermann, K.I., Partridge, R.B., Windhorst, R.A., & Richards, E.A. 2002, AJ, 123, 2402
Fomalont, E.B., Windhorst, R.A., Kristian, J.A., & Kellermann, K.I. 1991, AJ, 102, 1258
Franceschini, A., Berta, S., Rigopoulou, D., et al. 2003, A&A, 403, 501
Galliano, F., Madden, S.C., Jones, A.P., Wilson, C.D., Bernard, J.-P., & Le Peintre, F. 2003, A&A, 407, 159
Gnedin, N.Y., & Jaffe, A.H. 2001, ApJ, 551, 3
González-Nuevo, J., Toffolatti, L., & Argüeso, F. 2005, ApJ, 621, 1
Granato, G.L., Silva, L., Monaco, P., Panuzzo, P., Salucci, P., De Zotti, G., & Danese, L. 2001, MNRAS, 324, 757
Granato, G.L., De Zotti, G., Silva, L., Bressan, A., & Danese, L. 2004, ApJ, 600, 580
Greve, T.R., Ivison, R.J., Bertoldi, F., Stevens, J.A., Dunlop, J.S., Lutz, D., & Carilli, C.L. 2004, MNRAS, 354, 779
Griffiths, L.M., Kunz, M., & Silk, J. 2003, MNRAS, 339, 680
Gruppioni, C., Pozzi, F., Zamorani, G., Ciliegi, P., Lari, C., Calabrese, E., La Franca, F., & Mateu I. 2003, MNRAS, 341, L1
Haiman, Z., & Knox, L. 2000, ApJ, 530, 124
Impey, C.D., & Neugebauer, G. 1988, AJ, 95, 307
Komatsu, E., & Seljak, U. 2002, MNRAS, 336, 1256
Kuo, C.L., Ade, P.A.R., Bock, J.J., et al., 2004, ApJ, 600, 32
Loan, A.J., Wall, J.V., & Lahav, O 1997, MNRAS, 286, 994
Magliocchetti, M., Moscardini, L., Panuzzo, P., Granato, G.L., De Zotti, G., & Danese, L. 2001, MNRAS, 325, 1553
Mason, B.S., Pearson, T.J., Readhead, A.C.S., et al. 2003, ApJ, 591, 540
Myers, S.T., Contaldi, C.R., Bond, J.R., et al. 2003, ApJ, 591, 575
Narayanan, R., & Yi, I. 1994, ApJ, 428, L13
Negrello, M., Magliocchetti, M., Moscardini, L., De Zotti, G., Granato, G. L., Silva, L. 2004, MNRAS, 352, 493
Perna, R., & Di Matteo, T. 2000, ApJ, 542, 68
Perrotta, F., Magliocchetti, M., Baccigalupi, C., Bartelmann, M., De Zotti, G., Granato, G.L., Silva, L., & Danese, L. 2003, MNRAS, 338, 623
Pierpaoli E., Borgani S., Scott D., White M., 2003, MNRAS, 342, 163
Pierpaoli, E., & Perna, R. 2004, MNRAS, 354, 1005
Pozzi, F., Gruppioni, C., Oliver, S., et al. 2004, ApJ, 609, 122
Reach, W.T., Dwek, E., Fixsen, D.J., et al. 1995, ApJ, 451, 188
Readhead, A.C.S., Mason, B.S., Contaldi, C.R., et al. 2004, ApJ, 609, 498
Ricci, R., Sadler, E.M., Ekers, R.D., Staveley-Smith, L., Wilson, W.E., Kesteven, M.J., Subrahmanyan, R., Walker, M.A., Jackson, C.A., & De Zotti, G. 2004, MNRAS, 354, 305
Richards, E.A. 2000, ApJ, 533, 611
Scott, S.E., Fox, M.J., Dunlop, J.S., et al. 2002, MNRAS, 331, 817
Scott, D., & White, M. 1999, A&A, 346, 1
Silva, L., De Zotti, G., Granato, G.L., Maiolino, R., & Danese, L., 2005, MNRAS, 357, 1295
Silva, L., Granato, G.L., Bressan, A., & Danese, L. 1998, ApJ, 509, 103
Spergel, D.N., Verde, L., Peiris, H.V., et al., 2003, ApJS, 148, 175
Teräsranta, H., Tornikoski, M., Mujunen, A., et al. 1998, A&AS, 91, 121
Tinti, S., Dallacasa, D., De Zotti, G., Celotti, A., & Stanghellini, C. 2005, A&A, 432, 31
Toffolatti, L., Argueso Gomez, F., de Zotti, G., Mazzei, P., Franceschini, A., Danese, L., & Burigana, C. 1998, MNRAS, 297, 117
Van Waerbeke, L., Mellier, Y., & Hoekstra, H. 2005, A&A, 429, 75
Waldram, E.M., Pooley, G.G., Grainge, K.J.B., Jones, M.E., Saunders, R.D.E., Scott, P.F., & Taylor, A.C. 2003, MNRAS, 342, 915
Windhorst, R.A., Fomalont, E.B., Partridge, R.B., & Lowenthal, J.D. 1993, ApJ, 405, 498
Zhang P., Pen U., Wang B., 2002, ApJ, 577, 555