Astron. Astrophys. 346, 1–6 (1999)

ASTRONOMY AND ASTROPHYSICS

Implications of SCUBA observations for the Planck Surveyor

Douglas Scott[1] **and Martin White**[2]

[1] Department of Physics and Astronomy, University of British Columbia, Vancouver, B.C. V6T 1Z1, Canada (dscott@astro.ubc.ca)
[2] Departments of Astronomy and Physics, University of Illinois at Urbana-Champaign, IL 61801, USA (white@physics.uiuc.edu)

Received 12 August 1998 / Accepted 7 December 1998

Abstract. We investigate the implications for the Planck Surveyor of the recent sub-millimetre number counts obtained using the SCUBA camera. Since it observes at the same frequency as one of the higher frequency science channels on Planck, SCUBA can provide constraints on the point-source contribution to the CMB angular power spectrum, which require no extrapolation in frequency. We have calculated the two-point function of these sub-millimetre sources, using a Poisson model normalized to the observed counts. While the current data are uncertain, under reasonable assumptions the point-source contribution to the anisotropy is comparable to the noise in the 353 GHz channel. The clustering of these sources is currently unknown, however if they cluster like the $z \sim 3$ Lyman-break galaxies their signal would be larger than the primary anisotropy signal on scales smaller than about 10 arcminutes. We expect the intensity of these sources to decrease for wavelengths longward of $850\,\mu$m. At the next lowest Planck frequency, 217 GHz, the contribution from both the clustered and Poisson terms are dramatically reduced. Hence we do not expect these sources to seriously affect Planck's main science goal, the determination of the primordial anisotropy power spectrum. Rather, the potential determination of the distribution of sub-mm sources is a further piece of cosmology that Planck may be able to tackle.

Key words: cosmology: cosmic microwave background – cosmology: observations – cosmology: theory – infrared: galaxies – submillimeter

1. Introduction

The study of the anisotropy in the Cosmic Microwave Background (CMB) has the potential to teach us a great deal about the background cosmology in which we live, about the formation of structure and about the early universe. Because of this promise, ESA selected the Planck Surveyor[1] as the third Medium sized mission of its Horizon 2000 Scientific Program. With its wide range of frequencies, superb angular resolution, and high sensitivity, Planck has been hailed as the definitive CMB anisotropy experiment.

While much of the cosmological information is expected to come from the angular power spectrum of *primary* anisotropies, the sky contains more than this simple imprint of the inhomogeneities at last scattering. In particular the brightness fluctuations should be dominated on the smallest scales by point sources. One of the collateral science goals of Planck is to produce an all sky catalogue of such sources over a wide range of frequencies. Recent observations suggest that there may be many more bright sub-millimetre sources than previously expected, and it is the purpose of this paper to explore the impact of these findings on the Planck mission. While several authors (see below) have looked at the one-point statistics of these sub-mm galaxies, little has been done on the two-point function (or power spectrum) of these sources. It is this statistic which is most familiar to the CMB community, and which we concentrate on here.

The most exciting recent observations in the sub-mm waveband have come from the new Submillimeter Common-User Bolometer Array (SCUBA; Holland et al. 1999) on the James Clerk Maxwell Telescope. A combination of the properties of the sky and the galaxies themselves make the SCUBA 850 μm filter the optimal one for cosmology. This waveband corresponds closely with the 353 GHz channel of the High Frequency Instrument (HFI) of Planck. The central frequencies are almost identical, although the Planck bandwidth will be considerably larger ($\Delta\nu/\nu = 0.25$ rather than the $\simeq 0.1$ of the SCUBA 850 μm filter). SCUBA has now been used to make several deep integrations which have detected distant sources at 850 μm (Barger et al. 1998, Eales et al. 1998, Holland et al. 1998, Hughes et al. 1998, Smail et al. 1997), and this has radically altered our expectations for the importance of dusty galaxies at high redshift.

A summary of the source count observations is provided in Table 1. These new data thus provide us with direct measurements of the number density of bright sources (albeit currently only over small patches of the sky, and a limited range of flux) at a frequency directly relevant to the Planck science channels. We shall work primarily at 353 GHz, though we shall also extrapolate these counts to nearby frequencies using models of the spectral energy distribution of the sources.

Send offprint requests to: Douglas Scott
Correspondence to: Douglas Scott

[1] http://astro.estec.esa.nl/Planck/

There have been several estimates of how many sub-mm sources Planck might be able to detect (e.g. Bersanelli et al. 1996), as well as estimates of other one-point statistics, often referred to as 'confusion noise' (Condon 1974, Blain et al. 1998). As far as the fluctuations are concerned, several studies have already been carried out on the implications of point sources for the measurement of CMB anisotropies. Much of this work dealt more specifically with radio galaxy contributions at low frequency (e.g. Tegmark & Efstathiou 1996), or dealt with far-IR sources, but concentrated on the uniform background contribution and the correlation function (e.g. Franceschini et al. 1991, Bond et al. 1991, Wang 1991, Gawiser & Smoot 1997, Blain et al. 1998). Very similar studies have also been carried out for the X-ray background (see Yamamoto & Sugiyama 1998, and references therein), the optical background (see Vogeley 1998, and references therein), and more exotic backgrounds (e.g. Scott 1993). The most relevant work are the recent papers by Toffolatti et al. (1998) and Guiderdoni et al. (1996) which contain many useful results, and estimates of confusion noise, although they were written before the new series of SCUBA measurements. Our approach here also differs from theirs in that our predictions are based on straightforward extrapolations from observable properties. We deliberately avoid any modelling of the complex galaxy evolution process.

To calculate the impact of these new data on Planck it will be necessary to model the number density of sources as a function of flux, $N(>S)$. We shall take care to ensure that our model does not overproduce, when integrated, the far-infrared background (FIB) light detected by (Puget et al. 1996, Fixsen et al. 1998). At 353 GHz the background is approximately $0.14 \pm 0.04\,\mathrm{MJy\,sr^{-1}}$, although this is not a directly measured quantity, so the real error bar at 353 GHz may be larger. We construct our fiducial model so that the integrated light from the sources contribute essentially all of this background.

2. Counts and the far infrared background

Guided by models of galaxy formation (e.g. Toffolatti et al. 1998, Guiderdoni et al. 1998, Blain et al. 1998), we model $N(>S_{\rm cut})$ as a double-power-law,

$$N(>S_{\rm cut}) = N_0 \left(\frac{S}{S_0}\right)^{-\alpha} \left(1 + \frac{S}{S_0}\right)^{-\beta} \qquad (1)$$

(see also Borys et al. 1998), where for convenience we take $S_0 = 10$ mJy. Such a parameterization will certainly not be valid for all values of S, but it will be adequate for our purposes. Matching to the general behaviour of successful models, and normalizing specifically to the Hubble Deep Field (HDF) counts, we obtain 'fiducial' values for these parameters of $N_0 = 4.05 \times 10^6\,\mathrm{sr^{-1}}$, $\alpha = 0.8$ and $\beta = 1.8$. This fit, plus the data of Table 1, are shown in Fig. 1. Some models show the counts to steepen even more at the bright end, but this has little effect on any results, since it is already steep enough that any upper flux cut is not very important. We also show in Fig. 1 an estimate for the number of pixels over the whole sky at 353GHz, to indicate where we expect one source per pixel.

Table 1. SCUBA point source observations at 850 μm (353 GHz). We list the flux level to which each field was searched (generally 3 times the rms level), the number of sources found, the Bayesian 95% confidence level on the mean counts coming from Poisson statistics, the area covered, the number density of sources (with $\pm 1\sigma$ errors also from Poisson statistics). These numbers were taken from Hughes et al. (1998), Barger et al. (1998), Eales et al. (1998), Smail et al. (1997), Chapman et al. (in preparation), and Holland et al. (1998), respectively.

$S_{\rm cut}$ (mJy)	N	95% CL	Area (Sq. Deg.)	Density 10^3/(Sq. Deg.)
2.0	5	(1.8,10.9)	1.6×10^{-3}	$3.2^{+1.7}_{-1.2}$
3.0	2	(0.3, 6.4)	2.5×10^{-3}	$0.8^{+0.7}_{-0.4}$
2.8	12	(6.4,20.2)	6.8×10^{-3}	$1.8^{+0.6}_{-0.5}$
4.0	6	(2.3,12.3)	2.4×10^{-3}	$2.5^{+1.2}_{-0.9}$
5.0	5	(1.8,10.9)	6.0×10^{-3}	$0.8^{+0.4}_{-0.3}$
8.0	4	(1.2, 9.4)	4.0×10^{-3}	$1.0^{+0.6}_{-0.4}$

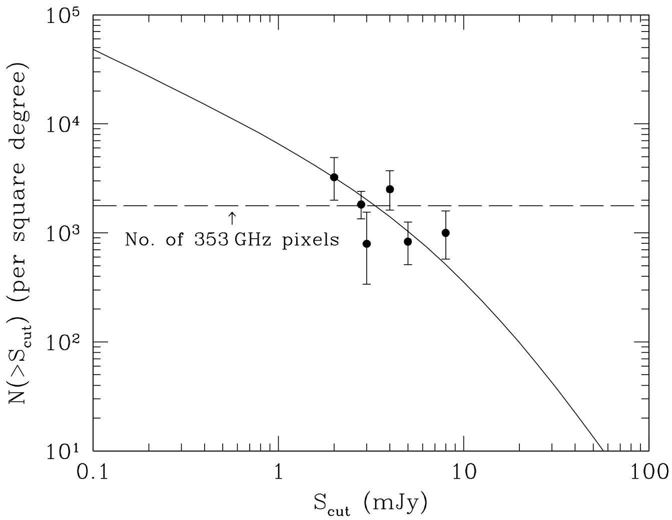

Fig. 1. The number of objects brighter than flux $S_{\rm cut}$ as a function of $S_{\rm cut}$. The curve is Eq. (1) with our fiducial parameters. The data are taken from Table 1, with the second and third points offset for clarity. The error bars are $\pm 1\sigma$ (68% Bayesian confidence region) errors based on Poisson statistics. The horizontal dashed line is an estimate of the number of pixels on the whole sky for the Planck 353 GHz channel, assuming 10 pixels per $4.5'$ beam.

We have assumed an oversampling by a factor of 10 pixels per beam as an illustrative number. With our adopted source counts model, Planck will then have about one 20 mJy source per beam (which then sets the basic level of 'confusion noise').

In practice Planck will only be able to detect individual sources with at best a flux cut of $S \gtrsim 100$ mJy using data from the 353 GHz channel alone. With extra information from the higher frequency channels (as well as information from other instruments, at least in some regions of the sky), it should be possible to remove all sources down to a few $\times\,10$ mJy. The SCUBA counts constrain the model at somewhat lower flux levels than these, however in our model the counts at the SCUBA flux lev-

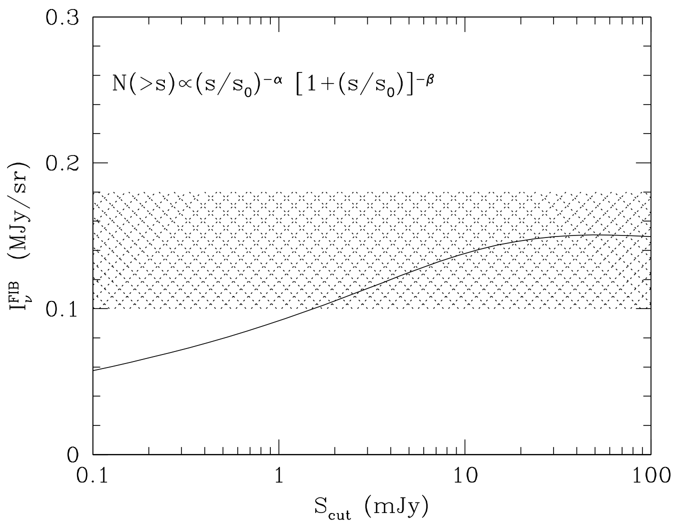

Fig. 2. The integrated flux as a function of the upper flux cut, with $S_0 = 10\,$mJy, $\alpha = 0.8$, $\beta = 1.8$, and normalized to the HDF counts. The hatched region is the FIB detection of Fixsen et al. (1998). Note that in our fiducial model much of the integrated flux comes from sources near the flux levels detected by SCUBA.

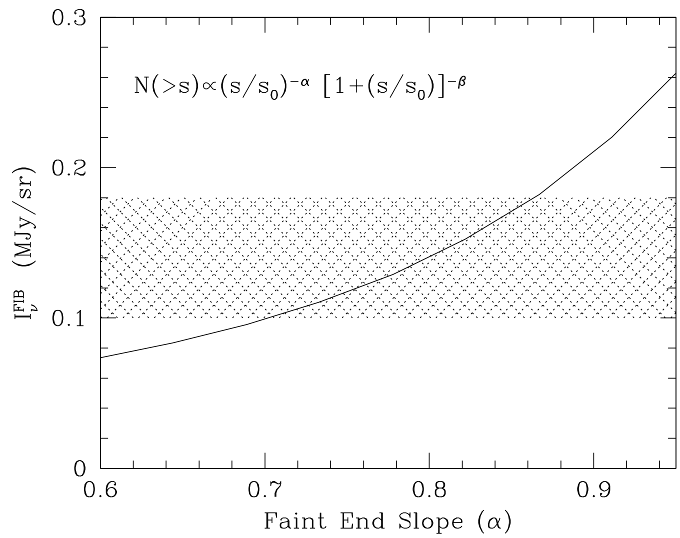

Fig. 3. The total integrated flux as a function of the faint end slope, α of Eq. (1), with the other parameters fixed at their fiducial values. The hatched region is the FIB detection of Fixsen et al. (1998).

els contribute significantly to the IR background and hence the CMB fluctuations if the sources are clustered (see below). In any case the precise flux cut for Planck is not currently easy to estimate, and so we have erred on the side of conservatism; if the flux cut ends up being higher than we are assuming here, then the fluctuations will only be larger.

By describing the counts in this phenomenological way we avoid any direct modelling of galaxy formation, evolution and spectral synthesis. Currently there are too many free parameters in these 'semi-analytic' models to yield a great deal of insight. Instead we prefer to use simple model fits to observables on the sky, which are motivated by the current data. Because of this we are considering only the two-dimensional distribution of objects on the sky, with no requirement on the radial distribution.

The contribution of these sources to the FIB is just the total flux per unit solid angle, or

$$I_\nu^{\rm FIB} = \int_0^{S_{\rm cut}} S_\nu\, \frac{{\rm d}N}{{\rm d}S_\nu}\, dS_\nu, \qquad (2)$$

which can be integrated by parts to yield

$$\int_0^{S_{\rm cut}} N\, dS_\nu - N(S_{\rm cut})\, S_{\rm cut} \qquad (3)$$

(a little care has to be taken with minus signs, since conventionally $N \equiv N(S{>}S_{\rm cut})$). The faint end limit for constant slope is just $\alpha(1-\alpha)^{-1}N(>S_{\rm cut})S_{\rm cut}$. We show in Fig. 2 the contribution to the integrated background light as a function of $S_{\rm cut}$. Notice that the sources at the flux levels probed by SCUBA contribute significantly to the background. As we will see below, it is those clustered sources which contribute most to the background that may be of greatest interest to us here. In Fig. 3 we show the contribution to the FIB, integrating to $S_{\rm cut} = \infty$, i.e. the total background, as a function of the faint-end slope α. The FIB was first detected by Puget et al. (1996), and has recently been measured by Fixsen et al. (1998). Their value is shown in Figs. 2, 3 as the hatched region. In our fiducial model the sub-mm sources account for *all* of the FIB.

Let us acknowledge that the real situation may be more complicated. The counts may come from a number of separate populations, and so of course there could be features in the actual curve. In addition there is the possibility that some more diffuse emission contributes to the FIB, and is not accounted for in these counts. Indeed there are some early indications (Hughes et al. 1998, Borys et al. 1998) that the counts may be flatter at the faint end than the form we have adopted. Again we have been conservative here; lower faint-end slopes would require higher overall normalization in order to match the background, implying stronger fluctuations.

3. Power spectrum for sources

We shall quote our results in 'temperature' units as is usual in CMB anisotropy studies. For fluctuations about a mean, the conversion factor from temperature to intensity (or flux) is

$$\begin{aligned}\frac{\partial B_\nu}{\partial T} &= \frac{2k}{c^2}\left(\frac{kT_{\rm CMB}}{h}\right)^2 \frac{x^4{\rm e}^x}{({\rm e}^x-1)^2} \\ &= \left(\frac{99.27\,{\rm Jy\ sr}^{-1}}{\mu{\rm K}}\right)\frac{x^4{\rm e}^x}{({\rm e}^x-1)^2}, \qquad (4)\end{aligned}$$

where B_ν is the Planck function, k is Boltzmann's constant, $x \equiv h\nu/k_BT_{\rm CMB} = \nu/56.84\,$GHz is the 'dimensionless frequency' and $1\,{\rm Jy} = 10^{-26}\,{\rm W\,m^{-2}Hz^{-1}}$.

If we assume that the number of sources of a given flux is independent of the number at a different flux, and if the angular

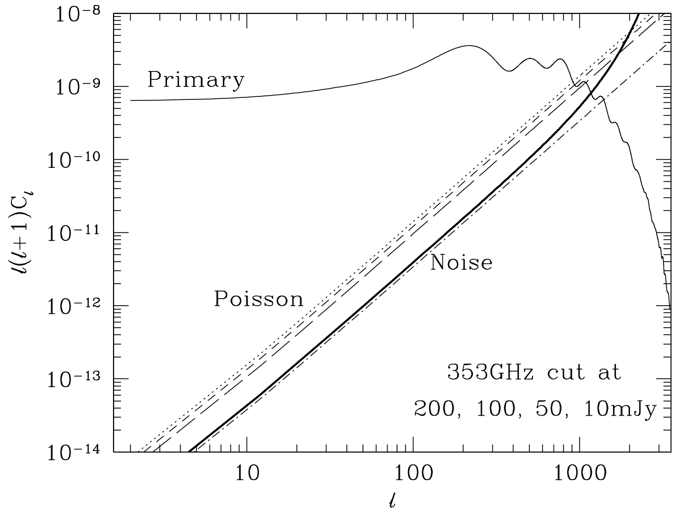

Fig. 4. The Poisson component of the angular power spectrum of the point sources, in dimensionless units, for a range of flux cuts (i.e. removing all sources brighter than $S_{\rm cut}$). Higher flux cuts give larger fluctuation levels. To compare with the level of primary anisotropy expected, the prediction for a standard CDM spectrum is also shown, normalized to COBE. The thick solid line is the expected contribution to the power spectrum from noise in the 353 GHz channel of the Planck HFI.

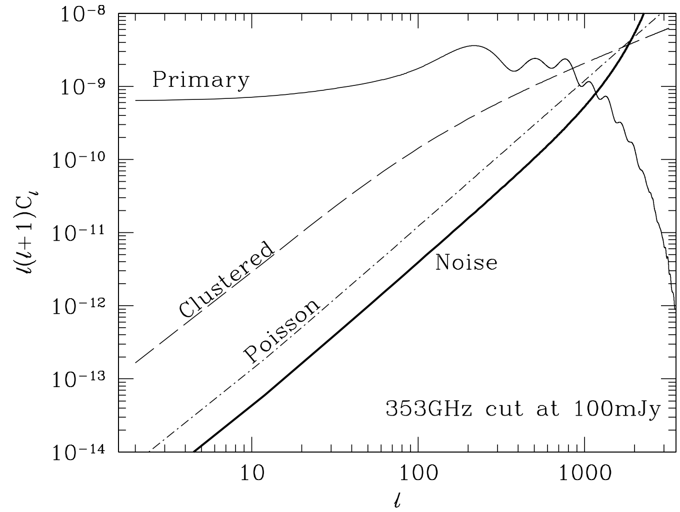

Fig. 5. As in Fig. 4, showing a flux cut of 100 mJy only, and including the component due to clustering. We have modelled the clustering using Eq. (10).

two-point function of the point-sources is $w(\theta)$, then the angular power spectrum, C_ℓ, contributed by these sources is

$$C_\ell(\nu) = \int_0^{S_{\rm cut}} S_\nu^2 \, \frac{{\rm d}N}{{\rm d}S_\nu} \, dS_\nu + w_\ell \left(I_\nu^{\rm FIB}\right)^2, \qquad (5)$$

assuming that all sources with $S{>}S_{\rm cut}$ are removed. Here, $I_\nu^{\rm FIB} = \int S \, {\rm d}N/{\rm d}S \, dS$ is the background contributed by sources below $S_{\rm cut}$ as before. Following the conventional notation (essentially introduced by Peebles 1973), C_ℓ is the Legendre transform of the correlation function $C(\theta)$ produced by the sources and w_ℓ is the Legendre transform of $w(\theta)$:

$$C(\theta) = \frac{1}{4\pi} \sum_\ell (2\ell+1) C_\ell P_\ell(\cos\theta) \qquad (6)$$

$$w(\theta) = \frac{1}{4\pi} \sum_\ell (2\ell+1) w_\ell P_\ell(\cos\theta), \qquad (7)$$

with $P_\ell(\cos\theta)$ the Legendre polynomial of order ℓ. The first term in Eq. (5) is the usual Poisson shot-noise term (see Peebles 1980 Sect. 46, or Tegmark & Efstathiou 1996), the second is due to clustering, assuming that the clustering is independent of flux.

Integrating by parts the Poisson term can be rewritten

$$C_\ell(\nu) = 2 \int_0^{S_{\rm cut}} N \, S_\nu \, dS_\nu - N(S_{\rm cut}) \, S_{\rm cut}^2. \qquad (8)$$

At low flux it becomes $\alpha(2-\alpha)^{-1} N({>}S_{\rm cut}) S_{\rm cut}^2$, if the counts have slope α at the faint end.

The shot-noise component of the angular power spectrum of our fiducial model is shown in Fig. 4, along with the primary CMB signal and the projected noise in the Planck 353 GHz channel. The Poisson fluctuations are calculated using our fiducial model and assuming that we cut out all sources brighter than $S_{\rm cut} = 200, 100, 50, 10$ mJy. Note that much of the fluctuation power comes from sources fainter than 50 mJy. The uncertainty in the normalization of these curves is directly proportional to our uncertainty in the counts, N_0, which we have normalized to the data of Table 1. Clearly N_0 is uncertain to at least a factor of 2. However, increasing the normalization by this amount would overproduce the FIB unless the faint end slope is also modified.

As an aside we mention that though the noise and Poisson component of the sources appear to have similar power spectra, they are nonetheless quite different entities. The sources are on the sky, and thus contribute to the flux in every observation of that pixel, whereas the noise varies from observation to observation and by assumption is uncorrelated with the signal in the pixel observed. Given many observations of a given direction on the sky (as expected for Planck), the noise properties can be separated from the sky signal, *even if* they have the same power spectra. The estimated instrumental noise can be subtracted from the measured power spectrum, with any point source contribution being evident as an extra $C_\ell = {\rm constant}$ component. We therefore expect that analysis of the Planck data set will include fitting for an excess white noise component, which would be most likely due to unclustered point sources.

We now turn to the other contribution to Eq. (5). Unfortunately there is essentially no information about the clustering of the SCUBA sources at present. Hence the most conservative assumption would be no clustering at all, but that is obviously unreasonable. Hence, although we tried to be as conservative as possible when discussing the shot-noise power spectrum, for clustering we will just make some simple guess. If we approximate $w(\theta) \propto \theta^{-\beta}$ then $w_\ell \propto \ell^{\beta-2}$. Assuming either that the sources cluster like galaxies today or as Lyman-break galaxies (Giavalisco et al. 1998) at $z \sim 3$, we would expect $\beta \simeq 0.8$–0.9.

As an illustrative example we can assume that the sources which make up much of the FIB cluster like these Lyman-break galaxies at $z \sim 3$. We suspect that this may in fact be close to reality, since it is equivalent to assuming that the population is a highly biased one, collapsing early. On the other hand the SCUBA sources will span a wider redshift range than galaxies selected by the UV-dropout technique, thereby washing out the angular correlations to some extent. But, certainly the SCUBA-type sources are likely to be more highly clustered than IRAS galaxies at low redshift. Our example can be probably considered an optimistic one in terms of clustered power. If the objects are less biased than the Lyman-break galaxies (LBGs) by a factor of b^{-1} then one reduces w_ℓ, and hence the clustered contribution to C_ℓ, by b^{-2}.

With our assumption $w(\theta) \simeq (\theta/2'')^{-0.9}$ and

$$w_\ell^{\rm LBG} \simeq 10^{-6} \left(\frac{\ell}{100}\right)^{-1.1} . \quad (9)$$

On large angles $w(\theta)$ is expected to drop below the power-law behaviour assumed in Eq. (9). The scale of non-linearity approximately marks this transition. If we assume the power spectrum is a power-law with index n then $w_\ell \propto \ell^n$. Thus we expect that on larger angular scales w_ℓ will flatten and gradually turn over to $w_\ell \propto \ell$. To take this into account we cause w_ℓ to become constant[2] for $\ell \lesssim 100$, where we have chosen this multipole because it is a round number, and not because we think it has any physical significance. Explicitly we approximate using

$$\frac{1}{w_\ell} = \frac{1}{w_{100}^{\rm LBG}} + \frac{1}{w_\ell^{\rm LBG}} . \quad (10)$$

We show the amplitude of the clustering signal in Fig. 5. Note that the contribution due to source clustering dominates over the Poisson term on the range of angular scales relevant to CMB anisotropies. In fact if the clustering proves to be this strong then Planck may be able to measure the power spectrum of the IR sources over a range of angular scales. We imagine that such a component will be included as one of the foreground templates to be fitted for in a full Planck analysis – the template would include frequency dependence, as well as a power spectrum which is white noise with perhaps one or two additional parameters to describe the clustering part. Exactly how to model this component may change as we learn more from SCUBA and other instruments. Further understanding of the clustering of these sources is clearly an important direction for future research.

One other issue is the variance in these power spectra estimates. Assuming that the point sources are a Poisson sample, it is straightforward to estimate the cosmic variance associated with this component of the angular power spectrum[3]. The variance is a sum of two terms, one due to the finite number of modes sampled by any given C_ℓ and the other from the Poisson nature of the process. So we have

$$C_\ell \;=\; \int S_\nu^2 \, \frac{{\rm d}N}{{\rm d}S_\nu} \, dS_\nu , \quad (11)$$

$$\text{and} \quad (\delta C_\ell)^2 \;=\; \frac{2}{2\ell+1} C_\ell^2 + \int S_\nu^4 \, \frac{{\rm d}N}{{\rm d}S_\nu} \, dS_\nu . \quad (12)$$

The first term of Eq. (12) is the usual result for Gaussian fluctuations, the second term is the extra variance associated with the Poisson sampling. If only a fraction $f_{\rm sky}$ of the sky is observed then the first term is increased by $f_{\rm sky}^{-1}$ while the Poisson term is unchanged. For now it seems safe to assume that the uncertainty in our modelling of the sources (i.e. the normalization and shape of ${\rm d}N/{\rm d}S$) is larger than the estimate of Eq. (12), so we can neglect the latter.

We expect the intensity of these sources to decrease for wavelengths longward of $850\,\mu$m. Assuming the flux decreases as $\nu^{2.5}$, similar to the slope of the FIB, we have calculated the contribution at the next lowest Planck frequency: 217 GHz. As expected the contribution is considerably lower, as shown in Fig. 6. If we use information on the spectra of individual galaxies which have been detected by SCUBA, (e.g. Ivison et al. 1998, Hughes et al. 1998), then the derived slope may be steeper still, leading to lower 217 GHz contributions. Obviously at even lower frequencies, the signal will be correspondingly reduced. At the next higher frequency channel, 545 GHz, the sources are obviously brighter. We find that the Poisson con-

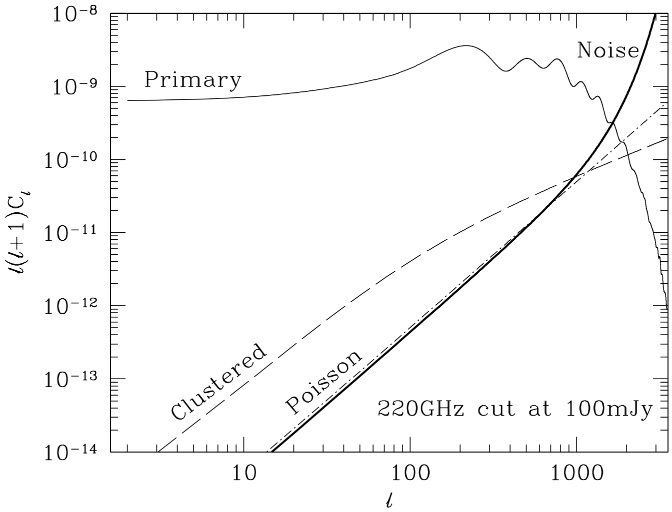

Fig. 6. As in Fig. 5, except at 217 GHz assuming the fluxes scale as $\nu^{2.5}$. We have kept the flux cut at 100 mJy to isolate the effect of changing frequency, however in principle the higher frequency channels could be used to isolate sources with 217 GHz flux substantially less than 100 mJy. This would lower the power spectra even further.

[2] Following our argument above there is no reason why w_ℓ might not drop to low-ℓ, rather than go constant, but for $\ell \lesssim 100$ the CMB signal dominates anyway, so our precise assumptions are not important. If we cause w_ℓ to approach ℓ immediately then the clustered signal is down from Fig. 5 by an order of magnitude at $\ell = 10$. Thus we caution the reader that this simple model may overestimate the clustered signal at low-ℓ. A more complete treatment would require knowledge of the redshift distribution and the evolution of the clustering of the sources.

[3] If the full power spectrum is a sum of uncorrelated terms, the variance of the total is just the sum of the variances.

tribution with a 100 mJy cut dominates the noise by more than 2 orders of magnitude over the range $2 \lesssim \ell \lesssim 10^3$, with the clustered contribution potentially larger still.

4. Conclusions

We have investigated the implications of the recent SCUBA number counts for the Planck Surveyor. Since it observes at the same frequency as one of the main science channels on Planck, SCUBA can provide constraints on the point-source contribution to the CMB angular power spectrum which require no extrapolation in frequency. While previous authors have investigated mainly one-point statistics of several SCUBA fields, it is the two-point function which has the most impact on the CMB science which will be done with Planck. We have calculated the two-point function of point-sources, using a Poisson model normalized to the observed counts. While the current data are uncertain, under reasonable assumptions the point-source contribution to the anisotropy is comparable to the instrumental noise in the 353 GHz channel. We have emphasized that if the instrumental noise power spectrum can be accurately estimated (as is expected to be the case for Planck, since each pixel is observed multiple times), then even a white noise contribution from point sources could still be detected. The clustering of these sources is extremely uncertain, however if they cluster like the $z \sim 3$ Lyman-break galaxies their signal would be larger than the primary anisotropy signal on scales smaller than about 10 arcminutes. We expect the intensity of these sources to decrease for wavelengths longward of $850\,\mu$m. At the next lowest frequency channel, 217 GHz, the contribution from both the clustered and Poisson terms is dramatically reduced.

The bottom-line is that the sub-mm sources revealed by SCUBA will not have a strong impact on the most important goal of the Planck mission, that of precisely characterising the CMB anisotropy. For the entire Low Frequency Instrument, and the three lowest frequency channels of the HFI there will be no significant contribution. And certainly the signals in the higher frequency channels can be used to remove point sources and recover most of the CMB information even at 353 GHz. Moreover, the possibility of actually measuring the Poisson and clustering signals over most of the sky for these galaxies provides Planck with yet another way of tackling fundamental cosmological issues.

Acknowledgements. This work was supported by the Natural Sciences and Engineering Research Council of Canada and by the National Science Foundation of the USA.

References

Barger A.J., Cowie L.L., Sanders D.B., Taniguchi Y., 1998, Nat 394, 248 [astro-ph/9806317]
Bersanelli M., Bouchet F.R., Efstathion G., et al., 1996, COBRAS/SAMBA, SCI(96)3, ESA, Paris
Blain A.W., Ivison R.J., Smail I., 1998, MNRAS 296, L29 [astro-ph/9710003]
Blain A.W., Smail I., Ivison R.J., Kneib J.-P., 1998, MNRAS, in press [astro-ph/9806062]
Bond J.R., Carr B.J., Hogan C.J., 1991, ApJ 367, 420
Borys C., Chapman S.C., Scott D., 1998, MNRAS, submitted [astro-ph/9808031]
Condon J.J., 1974, ApJ 188, 279
Eales S., Lilly S., Gear W., et al., 1998, ApJ, submitted [astro-ph/9808040]
Fixsen D.J., Dwek E., Mather J.C., Bennett C.L., Shafer R.A., 1998, ApJ 508, 123 [astro-ph/9803021]
Franceschini A., Toffolatti L., Mazzei P., Danese L., De Zotti G., 1991, A&AS 89, 285
Gawiser E., Smoot G.F., 1997, ApJ 480, L1 [astro-ph/9603121]
Giavalisco M., Steidel C.C., Adelberger K.L., et al., 1998, ApJ 503, 543 [astro-ph/9802318]
Guiderdoni B., Hivon E., Bouchet F.R., Maffei B., Gispert R., 1996, In: Dwek E. (ed.) Unveiling the Cosmic Infrared Background. IAP conference proceedings 348, p. 202
Guiderdoni B., Hivon E., Bouchet F.R., Maffei B., 1998, MNRAS, in press [astro-ph/9710340]
Holland W.S., Greaves J.S., Zuckerman B., et al., 1998, Nat 392, 788
Holland W.S., Robson E.I., Gear W.K., et al., 1999, MNRAS 303, 659 [astro-ph/9809122]
Hughes D.H., Serjeant S., Dunlop J., et al., 1998, Nat 394, 241
Ivison R.J., Smail I., Le Borgne J.-F., et al., 1998, MNRAS 298, 583 [astro-ph/9712161]
Peebles P.J.E., 1973, ApJ 185, 413
Peebles P.J.E., 1980, The Large-Scale Structure of the University. Princeton University Press, Princeton
Puget J.-L., Abergel A., Bernard J.-P., et al., 1996, A&A 308, L5
Scott D., 1993, MNRAS 263, 903
Smail I., Ivison R.J., Blain A.W., 1997, ApJ 490, L5
Tegmark M., Efstathiou G., 1996, MNRAS 281, 1297
Toffolatti L., Argüeso Gómez F., De Zotti G., et al., 1998, MNRAS 297, 117 [astro-ph/9711085]
Vogeley M.S., 1998, ApJ, in press [astro-ph/9711209]
Wang B., 1991, ApJ 374, 465
Yamamoto K., Sugiyama N., 1998, PRD, submitted [astro-ph/9807225]