Correcting the analysis of "IR ANISOTROPIES IN SPITZER GOODS IMAGES..." by Cooray et al (2006)

A. Kashlinsky\textsuperscript{1,2}

ABSTRACT

We point out that in their analysis of the deep Spitzer images, Cooray et al (2006) perform Fourier transform on maps which have very few pixels left (only 20 to 30 percent). For such deeply cut maps one cannot reliably compute large-scale map properties using Fourier transforms. Instead the maps must be analyzed via the correlation function, $C(\theta)$, which is immune to mask effects. We find, when computing $C(\theta)$ for their maps, that removing ACS/HST galaxies does not lead to appreciable change in the correlation properties of the remaining diffuse emission. We then demonstrate with simulations that the power spectrum of CIB fluctuations prior to removal of the ACS galaxies reproduces $C(\theta)$ in the maps from which the ACS galaxies have been removed. This implies that these galaxies cannot be responsible for the CIB fluctuations detected in Kashlinsky et al (2005, 2007), contrary to the claims of Cooray et al (2006).

Subject headings: cosmology: observations - diffuse radiation - early Universe

Cosmic infrared background (CIB) anisotropies from early epochs should contain also the contribution from the first stars and galaxies (see Kashlinsky 2005 for review). In several attempts to uncover this component, we have analyzed deep Spitzer exposures identifying CIB fluctuations remaining after removal of galaxies to fairly faint levels (Kashlinsky, Arendt, Mather & Moseley 2005, 2007a,b). The initial findings were recently confirmed by our analysis of the newly available Spitzer GOODS data (Kashlinsky, Arendt, Mather & Moseley 2007b), where we could remove intervening galaxies to still fainter levels than in the earlier study. The analyzed fields were clipped of sources so that a reasonable fraction of pixels remained to allow a robust Fourier analysis. This fraction must in practice be fairly high; e.g. even when $\gtrsim 60\%$ of the original pixels are kept and the power spectrum has a simple power-law behaviour, computations of the power spectrum from Fourier transform may be

\textsuperscript{1}Observational Cosmology Laboratory, Code 665, Goddard Space Flight Center, Greenbelt MD 20771 and SSAI

\textsuperscript{2}e–mail: kashlinsky@milkyway.gsfc.nasa.gov
misleading (Gorski 1994). Thus, for maps where fewer than \( \sim 60\% \) of the pixels remained, Kashlinsky et al (2005) instead computed the diffuse light correlation function, showing that its value decreases little as the maps are clipped progressively deeper. Also note that the CIB fluctuations signal was found to be present at all four IRAC wavelengths with fairly high signal-to-noise measurements at 3.6 and 4.5 micron, so that any interpretation of the origin of that signal must explain all the wavelengths simultaneously (Kashlinsky, Arendt, Mather & Moseley 2007a) - not just results derived from the 3.6 micron data.

Recently, Cooray et al (2006) have presented their own analysis of the GOODS data at only 3.6 micron. In it they removed galaxies identified at shorter wavelengths from the HST ACS observations and claimed that the CIB fluctuations signal, whose power spectrum was evaluated via Fourier transforming the maps, is significantly diminished when this is done. Note that in their Fourier analysis they were left with only 30\% (their map C) to 20\% (their map D) of the map pixels. As is commonly known applying Fourier analysis to such deeply cut maps would lead to spurious results.

Indeed, Fourier analysis, which is meaningful only when the masking effects leave the basis functions at least approximately orthogonal, can lead to wrong results for the power spectrum, \( P(q) \), computed using it in such deeply cut maps. For such deeply cut maps, one must use a complementary to \( P(q) \) statistic, the correlation function \( C(\theta) = \langle \delta F(\vec{x}) \cdot \delta F(\vec{x} + \vec{\theta}) \rangle \) (e.g. Kashlinsky & Odenwald 2000, Matsumoto et al 2005) which is immune to masking effects. This is why we presented this quantity in the Supplementary Information to Kashlinsky et al (2005) for maps cut at deeper levels leaving fewer than \( \sim 65\% \) of the map pixels (see Fig. SI-4).

This quantity, \( C(\theta) \), and not the Fourier transformed maps, should also have been used by Cooray et al (2006) when analyzing their maps in which fewer than 30\% of the pixels have remained. Note that in this representation, the contributions of any white noise (such as shot noise and/or instrument noise) component to \( C(\theta) \) drop off very rapidly outside the beam (e.g. Smoot et al 1992) and for the IRAC 3.6 \( \mu \text{m} \) channel contribute negligibly to the correlation function at \( \theta > \) a few arcsec. Thus \( C(\theta) \) at these scales would reflect the clustering component.

To see if the final maps of Cooray et al, when analyzed correctly, indeed show less large scale CIB fluctuations, we have downloaded their maps C and D from www.cooray.org where they are advertised as publicly available. The CDF-S field does not have map C available there and so we could not compare the large scale correlations of the C and D maps. But we did that for the HDF-N field. Fig. 1 shows the resultant \( C(\theta) \) for their maps C (when ACS galaxies are not removed) and D (when ACS galaxies are removed). It shows that there is little difference between the two maps in terms of the large-scale correlations and that, in
fact, map D has higher amplitude correlations (it also has a larger variance than C).

For comparison, we also show the correlation function from Fig. SI-4 of Kashlinsky et al (2005), which is essentially the same as in the Cooray et al GOODS maps. This would suggest that the ACS detected galaxies are not major contributors to the CIB fluctuations contrary to the suggestions by Cooray et al (2006).

Indeed, one can verify with simulations that the correlation function values in Fig.1 are consistent with the amount of large scale power detected in KAMM1,2. In order to do this, we have constructed ten realizations (computation of $C(\theta)$ is a very CPU intensive procedure) of the CIB field with the power spectrum corresponding to Map C (which includes the ACS galaxies) from Fig. 2 of Cooray et al., which as they note are consistent with the measurements of KAMM1. We selected their central values; allowing for the errors on power will make our conclusions stronger. Of the ten computed $C(\theta)$, we show in Fig. 2 the realization with the second smallest zero crossing and one with the second largest, such that the frequency of any of these realizations is $\sim 20\%$. The figure shows that the power spectrum of diffuse light prior to removal of ACS galaxies reproduces the correlation function after their removal within the uncertainties determined by the field geometry and statistics.

I thank my collaborators Rick Arendt, John Mather and Harvey Moseley for many useful discussions. This work is supported by NSF AST-0406587 and NASA Spitzer NM0710076 grants.

REFERENCES

Cooray, A. et al 2006, Ap.J., submitted. astro-ph/0612609
Gorski, K. 1994, Ap.J., 430, L85
Kashlinsky, A. 2005, Phys. Rep., 409, 361-438
Kashlinsky, A., Arendt, R., Mather, J.C. & Moseley, S.H. 2005, Nature, 438, 45. (KAMM1)
Kashlinsky, A., Arendt, R., Mather, J.C. & Moseley, S.H. 2007a, Ap.J., 654, L1. (KAMM2)
Kashlinsky, A., Arendt, R., Mather, J.C. & Moseley, S.H. 2007b, Ap.J., 654, L5. (KAMM3)
Kashlinsky & Odenwald 2000, Ap.J., 528, 74
Matsumoto, M. et al 2005, Ap.J., 626, 31
Smoot, G. et al 1992, Ap.J., 396, L1
Fig. 1.— Solid lines correspond to $\sqrt{C(\theta)}$ for $C > 0$ and dotted lines to $\sqrt{-C(\theta)}$ for $C < 0$. Left: correlation function for the deeply cut maps C (with ACS galaxies in) and D (with ACS galaxies removed) from Cooray et al. (2006). Map C has only $\sim 30\%$ pixels left, while map D has even fewer pixels left of $\sim 20\%$. Right: For comparison, we show the correlation functions from deeply cut maps for the QSO 1700 field from Kashlinsky et al. (2005). These maps are shown in the Supplementary Information there and have between $\sim 10$ and $80\%$ pixels left, which corresponds to the clipping parameters in the Kashlinsky et al. (2005) procedure of $N_{\text{cut}} = 2 - 4$ and $N_{\text{mask}} = 3 - 7$. As one can see removing ACS galaxies by Cooray et al leaves approximately the same correlation function as when keeping them in.
Fig. 2.— Results of simulations with 10 realizations of the CIB with the power spectrum given by the central points of Map C from Fig. 2 of Cooray et al. The mask was then applied and the correlation function evaluated. Of these ten realizations we plot two: the realization with the second smallest zero crossing and one with the second largest zero-crossing. As in Fig. 1, the solid lines denote $C > 0$ and dotted correspond to the region of negative $C$. The figure shows that it is very common to have large scatter in the values of $C(\theta)$ at scales $>0.5 - 1$ arcmin for the geometries corresponding to the clipped maps used in Cooray et al, but that on smaller scales the correlation function reflects the power correctly.