70μm Warm Campaign 10K Sensitivity Tests

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2005-Jun-16, Version 1.

Abstract

Data were recently taken to quantify the 70μm sensitivity and data quality for the proposed warm MIPS campaigns. We find slight elevations in the observed background (0.58±0.25 MJy/sr) and DARK (0.33 ± 0.18 MJy/sr) levels when the primary mirror is 9.5 K, instead of the normal operating temperatures of 5.6 K. Based on the stacked filtered products of source-free cal-star data, the best estimate for the degradation of sensitivity is 4.0 ± 1.4%. Larger sensitivity changes were measured for the xFLS data. Accounting for the increased background level at the time of the recent observations, we find an increase of noise of 13 ± 5% for the xFLS data. Given the time-lag between the xFLS observations, it is not clear what fraction of the degradation of the xFLS sensitivity is due to the warm optics. Hence, the possible range of increased noise is estimated to be about 4–13%.

1 10K Test Data

Warm campaign 10K test data (21.2MC, MIPS007300) were taken 28 May 2005 and consisted of xFLS-main observations with 1.75deg median scan legs, normal DARK observations, and the observations of the standard Ge calibrator.

1.1 Cal-star HD163588

The standard cal-star was observed four times in 21MC and was observed twice for the ToO observations (once on each side of the 10K test). This provides 4 ”cold” data sets and 3 ”warm” data sets of the same field taken within a two weeks of each other. The SPOT predicted background levels over this time range are roughly constant. These observations allow checking for measured differences in the observed background and sensitivity as a function of the primary mirror temperature.

Table 1: Calibration Star HD163588

REQKey	T(mirror) [K]	Abbreviation (C=cold, W=warm)
13586432 21MC-1	6.00	C1
13587200 21MC-2	5.62	C2
13585664 21MC-3	5.48	C3
13587968 21MC-4	5.48	C4
15355392 ToO1	9.78	W1
13786880 10Ktest	9.53	W2
15356160 To02	9.36	W3

1.2 The xFLS data

Approximately 17hrs of xFLS data were taken during the warm 10K test for comparison with the well studied xFLS data that were taken early in the mission. The original xFLS data were taken with the old bias setting at 70μm and have larger data artifacts than post-bias change data. If the variation of mirror temperature is negligible, we could potentially expect data of high quality for the 10K test. However, the data during the 10K test were taken at a time of higher predicted zody than the original xFLS data which could degrade the sensitivity of the warm xFLS data significantly. These data can be used to test the effects on science quality for the warm campaigns, e.g., point source detection, number counts, and sensitivity.

2 Data Reduction

The data were reduced by processing the RAW data from the SSC sandbox through the public offline GeRT (version 050405). The calibration files are the standard files for S11 reprocessing and the current S12 processing and the SSC pipeline version is S12. The xFLS data were reduced in exactly the same way as previously done with the original xFLS data (gert.pl, cleanup70.tcsh, mosaic.pl). The xFLS analysis was done on the output mosaic/coadd products.

For the cal-star data, the intermediate filtered cal-current cube and the nofilter-cube products were used. The non-prime data during 160μm cal-star observations were used as well to provide better statistics.

3 Results

3.1 Variation of the Observed Background

The non-filtered BCD data for each cal-star reqkey were used. The 70μm data for both 160μm and 70μm observations were combined providing a 176 DCE data cube for each reqkey. The median BCD level for each reqkey was derived, representing the observed background level. The median background level was derived by first taking median of the data cube for each pixel: median(cube[i,j,*]) for every i,j, ignoring stim pixels. Then the median of resulting image was used to derive an array average. If each pixel is independent and there are no systematics, the error on the median would be $\sigma(median) = rms(median[*,*])/npix^{0.5}$, where $npix$ is the number of good pixels on side-A (about 460). However, MIPS-70 data do show systematics so this error underestimates the true error on the median. If we assume column correlations are the dominate source of data systematics, then an approximate error estimate could be made by assuming the number of "independent" measurements of $npix = 16$ (i.e., each column of side-A). We adopt this approximation for the errors shown in Figure 1.

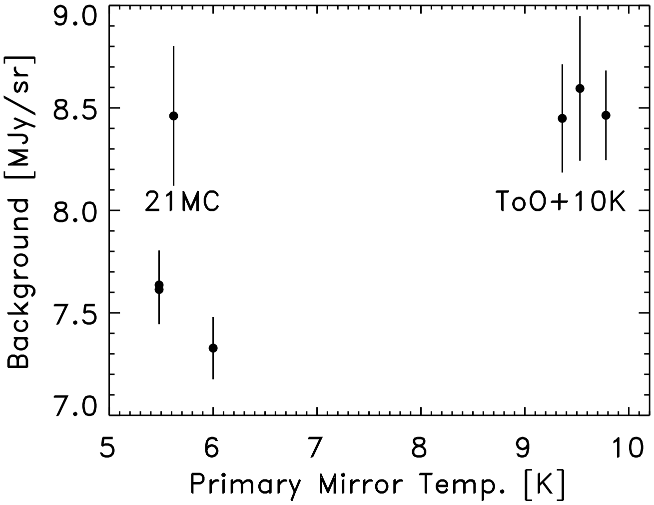

Figure 1: Observed background as a function of mirror temperature.

Figure 1 shows the observed background levels for the cal-star observations as a function of mirror temperature. The predicted SPOT backgrounds do not vary significantly over the two week time range of the observations. The C2 data point appears to be an outlier for the cold measurements. These data were taken about 2.4 hrs after the anneal so the accumulation transients may be starting to contribute slightly to the observed background level (weak banding can be seen in the BQD mosaic). All of the other cold observations were observed within 1 hour of the anneal. The highest data point W2 was taken 3.2hr from the anneal and the other two warm data points were taken about 1.6hr and 2.3hr from an anneal. It has been found that the measured background starts to increase after three hours from the anneal, presumable due to the accumulation of transients/slow response (e.g., ist_mips_cal/daveF_06aug04/bcd_back.ps), but the background levels are not significantly affected for data taken less than 3hours from an anneal. Hence, the anneal effects (by themselves) are not expected to be the dominate cause of background variations in Fig. 1.

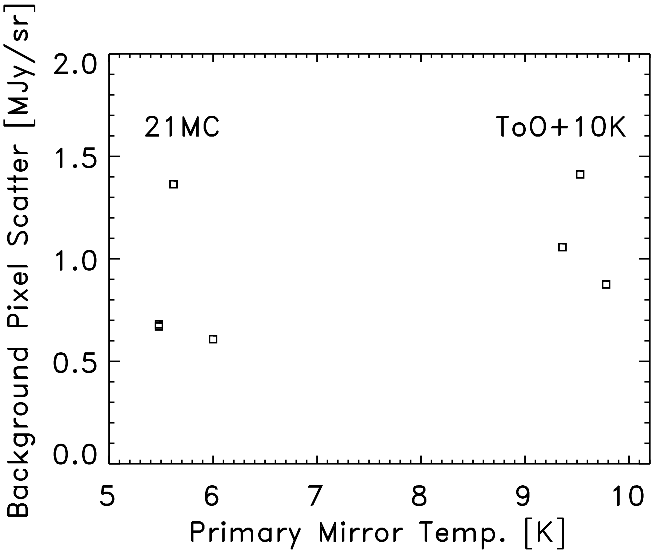

Figure 2: Pixel scatter of background as a function of mirror temperature.

Figure 2 shows the actual scatter of the background measurements observed for the pixels. This scatter was used to derived the error bars for Figure 1 (error_bars=scatter/4, assuming the number of "independent" measurements is equal to the number of side-A columns).

From a weighted average of the measurements shown in Figure 1, we derive an observed cold background level of 7.58±0.09 MJy/sr and a warm background level of 8.48±0.15 MJy/sr (assuming formal error propagation for independent data).

Both data sets were reduced using the standard DARK calibration file. Part of the increased background level for the warm data set could be due to an elevated DARK signal. From the DARK measurements for the 17 MIPS campaigns (post bias change), we find an average DARK signal for cold MIPS data of 4.15±0.13 MJy/sr (where the error is the std of the measured values for the campaigns) with a range of values of 4.02–4.34 MJy/sr. The DARK measurement taken during the warm data (one campaign) was 4.48 MJy/sr. We would need additional campaigns to quantify the repeatability of the DARK for warm campaigns. Currently, this suggests a small but measurable change in the DARK level. The difference in the DARK signal (warm−cold) is 0.33±0.18 MJy/sr (where we have assumed $2^{0.5} \times \sigma(cold)$ for the error).

Accounting for the slight variation in the DARK, we estimate a background difference of 0.58±0.25 MJy/sr between the warm and cold cal-star observations.

The variation of the background could also be estimated based on the xFLS data. The constraints here are less restrictive since the previous pre-bias change data showed significant data artifacts (without filtering), and the data for the warm campaign were taken at a different time of year with a larger zody component. Centered on a region within the verification-field (RA:258.9224, DEC:59.7695), the predicted SPOT background on 09 Dec 2003 (original xFLS) is 4.12 MJy/sr. For the recent warm xFLS data taken 28 May 2005 the predicted background level is 4.70 MJy/sr

(14% predicted increase due to zody). The observed backgrounds are 4.37 MJy/sr and 5.51 MJy/sr for the warm and cold data respectively (26% increase). Subtracting the estimated difference in the DARK signal of 0.33 MJy/sr from the warm data and adding the predicted zody increase of 0.58 MJyr/sr to the cold data, we find an estimated excess background of 0.23 MJy/sr in the xFLS data which may be associated with the warmer mirror temperature (error bar is uncertain and is likely larger than the excess).

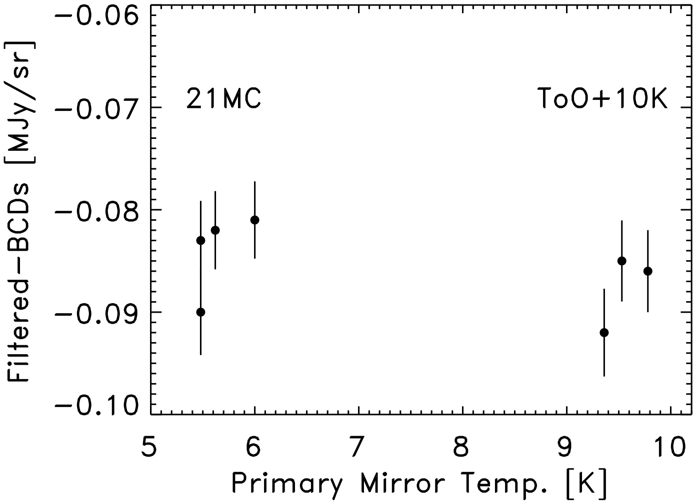

Figure 3: fBCD level as a function of mirror temperature.

3.2 Variation of the fBCDs and rms for the Cal-star Data

For comparison with the BCDs, Figure 3 shows the median signal from the filtered-BCDs (fBCDs) for the cal-star observations. Here both the instrumental additive effects and the background are removed. After filtering the resulting fBCDs are systematically slightly negative (a standard by-product of median filtering). The median was derived in the same way that was described for the BCDs. There are no significant variations of the filtered-BCD levels as a function of mirror temperature. Since the filtering removes pixel systematics, the error bars were derived assuming that each pixel is independent (i.e., $npix = 460$ instead of 16 as assumed for BCDs). Figure 4 shows the pixel-to-pixel scatter of the fBCD measurements.

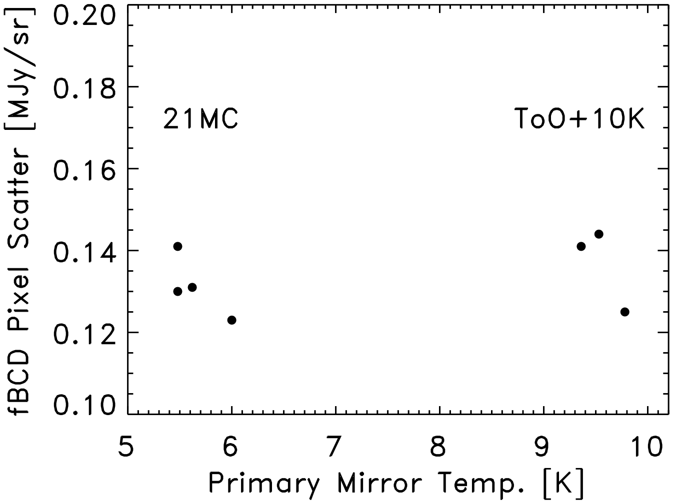

Figure 4: Pixel scatter of fBCD level as a function of mirror temperature.

One of the primary goals of the 10K test is to quantify any lost of 70μm sensitivity in running the telescope at a warmer temperature. The rms sensitivity was estimated as a function mirror temperature using the cal-star data. As done previously, data cubes of 176 DCEs were made from the bcds and fbcds. The rms for each pixel was derived by calculating a clipped stdev (ignoring stims and outliers of more than 3-sigma) through the data cube. The median of the resulting rms(i,j) image was used to derive an array average rms.

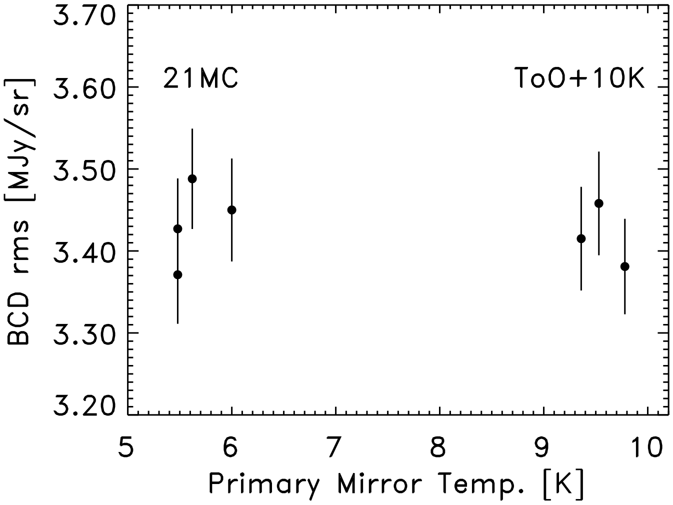

Figure 5: BCD rms as a function of mirror temperature.

Figure 5 and 6 show the BCD rms and the BCD rms pixel scatter respectively. The BCD rms does not change measurably as a function of mirror temperature. The error bars on the BCD rms assume that the rms for each pixel is independent (i.e., $npix = 460$).

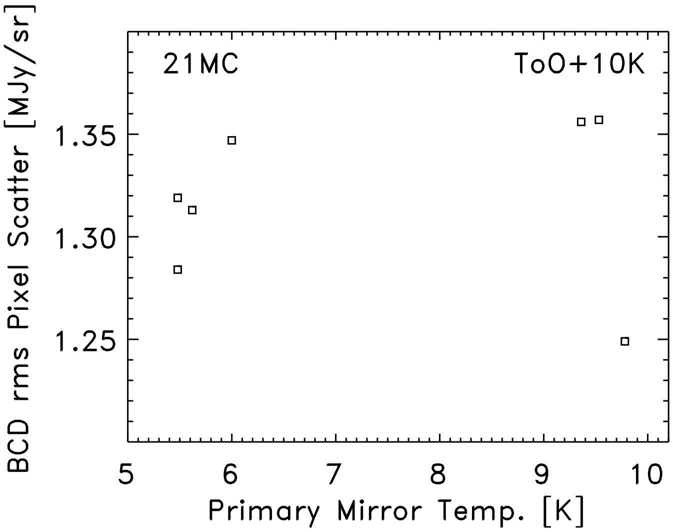

Figure 6: Pixel scatter of BCD rms as a function of mirror temperature.

Figure 7 and 8 show the fBCD rms and the fBCD rms pixel scatter respectively. The sensitivity of the fBCD products is about a factor of two better than the BCDS for point sources. There is a small, but measurable, decrease in sensitivity as a function of mirror temperature for the filtered BCDs. Taking a weighted average, we find fBCD(rms)_cold= 1.813±0.015 MJy/sr and fBCD(rms)_warm= 1.886±0.019 MJy/sr. This corresponds to a decrease of sensitivity of

4.03±1.36% for the warm cal-star data. The pixel-to-pixel scatter for the fBCD rms is about 11% larger for the warm data than the cold data (Figure 8), i.e., the error distribution of the errors is 11% larger.

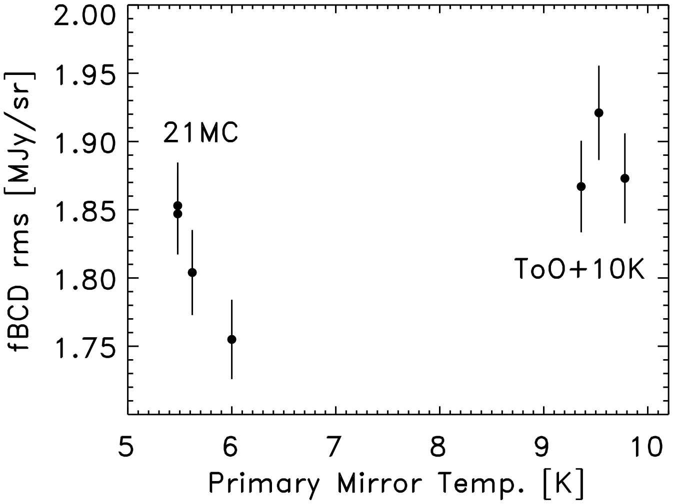

Figure 7: fBCD rms as a function of mirror temperature.

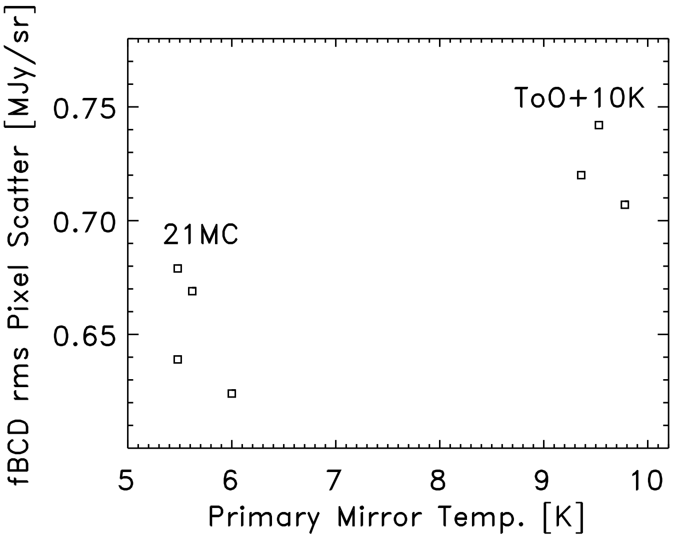

Figure 8: Pixel scatter of fBCD rms as a function of mirror temperature.

By analyzing the stacked data cubes, we can detect weak variations in the noise. However, we do not measure the noise spatially which is typical done for science analysis. To analyze the spatial noise across the mosaic, we coadded the non-prime 70μm data taken during the 160μm cal-star observations. These 70μm data represent blank field observations (no bright sources). Figure 9 shows the resulting noise from the filtered BCD mosaics. There is a slight hint for an increase in noise with the warm temperatures, but the mosaic data are basically consistent within the errors with no change in sensitivity. The average point source noise for the cold data is 2.905±0.085 mJy, while the point source noise is 3.08±0.15 mJy for the warm data. Formally, the noise is increased by 6.0±5.7% in the mosaics.

In Figures 7 and 9, there appears to be an inverse trend in sensitivity for the 4 warm data points. These data points are in the inverse order of time since the start of the campaign (21MC was cooling down slightly throughout the campaign). It is unclear if this actually indicates that data taken near the start of the campaign (after instrument turn-on) has better sensitivity than

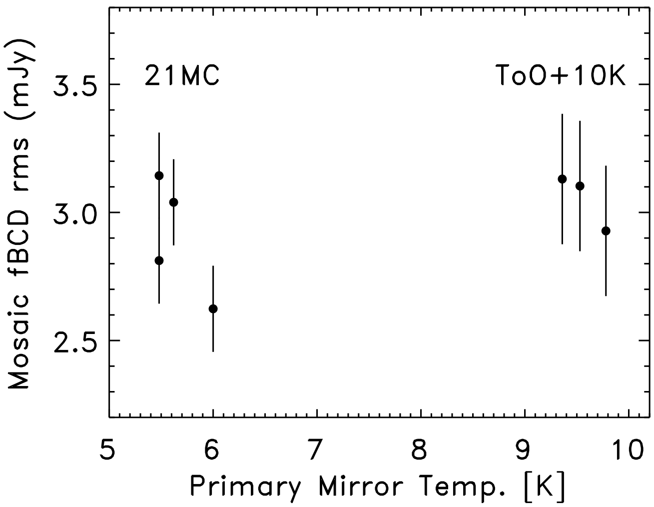

Figure 9: Mosaic fBCD rms as a function of mirror temperature.

data taken near the end of the campaign.

3.3 xFLS Sensitivity

The warm xFLS data were compared with the previous xFLS-main survey data at 70μm. The data were reduced in exactly the same way and coadded with $4'' \times 4''$ pixels. Table 2 shows the comparison of the measured sensitivity for the final mosaics.

Table 2: xFLS Noise

	Old(cold) MJy/sr	New(warm) MJy/sr	Change
RMS(mosaic)	0.3129	0.3746	+20%
STD(mosaic)	0.2398	0.2922	+22%
NOISE(mosaic)	0.2476	0.3062	+24%
UNC(mosaic)	0.1651	0.1834	+11%
SIGMA(mosaic)	0.2668	0.3243	+21.6%

RMS(mosaic) is the rms in the mosaic after clipping out 3-sigma outliers. STD(mosaic) is the median value in the mopex STD mosaic which is derived using the redundancy of the data and is based on the rms of the set of values measured at the same point on the sky. NOISE(mosaic) is the median value of the mopex noise image derived from calculating a clipped rms locally within a $4' \times 4'$ box. UNC(mosaic) is the median value of the UNC image which are the formal uncertainties based on pipeline error propagation. The pipeline errors are known to be systematically lower than the real empirical noise for low background regions. SIGMA(mosaic) is the average of the RMS, STD, and NOISE uncertainty values and is the adopted 1σ error for the data. Unlike the cal-star data, the change in sensitivity in the xFLS data is not subtle. The noise in the new-warm data has increased by $22 \pm 2\%$. The increased noise could be due to several factors which we discussion below.

The predicted 70μm background level is higher for the 28 May 2005 (4.70 MJy/sr via SPOT) than the predicted background for the old 09 Dec 2005 observations (4.12 MJy/sr via SPOT). The observed differences in the background levels derived from the unfiltered BCDs are larger: new-warm= 5.51 MJy/sr and old-cold= 4.37 MJy. Since the sensitivity varies roughly as $\sigma \propto (B/t)^{0.5}$ for low backgrounds and shallow integration times, we would expect a decrease of sensitivity with the new observations. Correcting for the DARK level (subtract off 0.33 ± 0.18 MJy/sr from the warm-data), we find an increase in the background of 19%, corresponding to an expected increase in noise of 9%. The actual background measurements for the old pre-bias change data are fairly uncertain (given the strong stim-latents and slow response variations). Accounting for this error and the uncertainty of the DARK for the new data, the expected noise increase due to the elevated background is 9 ± 4%. The remaining excess noise is 13 ± 5%.

The calibration between the new-warm and old-cold data were checked for consistency. Figure 10 shows the measured point source fluxes detected in common in both fields. There was no detected change in calibration between these data sets (< 10%). This suggests that the observed excess noise above that expected from the change in the background is not due to calibration issues. Other factors could contribute to the excess noise besides the warm optics given that these data were taken at different times with different instrument settings.

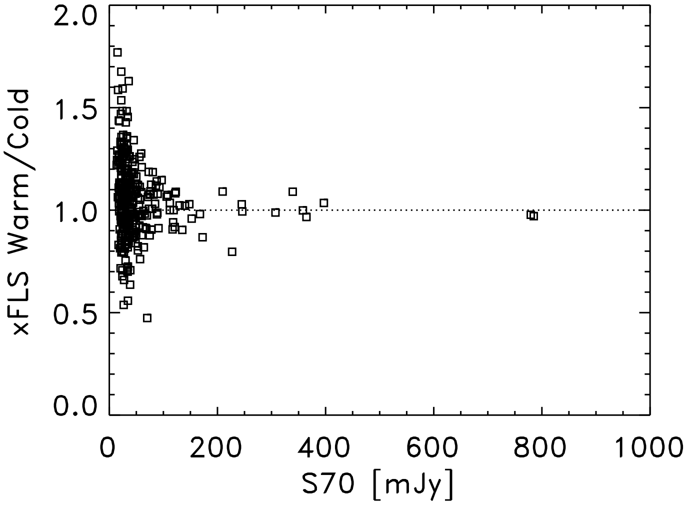

Figure 10: Measured flux ratio for sources detected in the new-warm and old-cold xFLS data sets as a function of flux density.

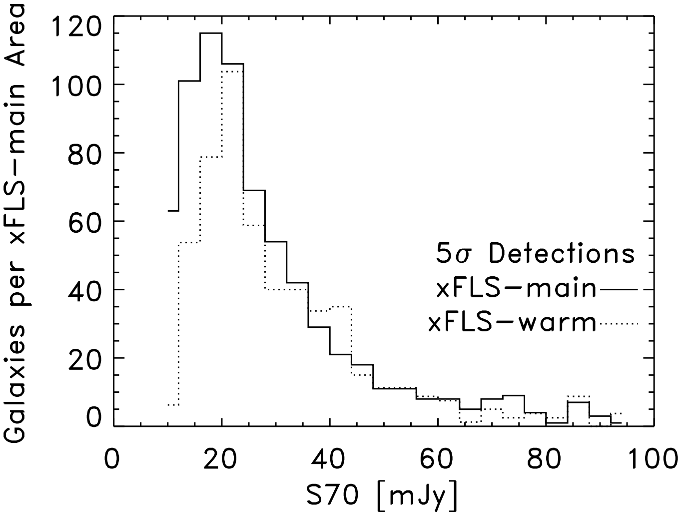

Figure 11: Number of sources per unit area detected above 5σ as a function flux density. New-warm data shown by the dotted histogram, while the old-cold data are shown by the solid histogram.

The decrease in sensitivity affected the number of sources detected. Figure 11 shows the histogram of sources extracted above the 5σ level for the new-warm and old-cold xFLS data sets. The observed difference in the number counts is consistent with the measured sensitivity differences.

4 Conclusions

The 70μm data quality will not be dramatically changed for the warm MIPS campaigns. No change in calibration was detected. The DARK level is slightly elevated by 0.33 ± 0.18 MJy/sr. If the DARK level is found to be consistently higher for the warm-MIPS campaigns, we will need an updated DARK fall-back calibration file for pipeline processing (not a big impact on downlink/IST resources). For the cal-star observations, we find evidence for excess background emission which may arise from the warmer optics (0.58 ± 0.25 MJy/sr), but absolute background measurements are difficult to make and are not a primary science driver for MIPS.

The largest concern for warm MIPS data is the potential impact on the 70μm sensitivity. From the stacked cal-star filtered-BCDs, we estimate an increase of noise of $4.0 \pm 1.4\%$. The mosaiced products yielded an increase of $6.0 \pm 5.7\%$. The sensitivity degraded dramatically for the xFLS data, but a significantly fraction of this sensitivity lose is thought to be due to the elevated background level at the time of the observations. The remaining excess which may be due to the warmer optics is $13 \pm 5\%$ (but note these xFLS data were taken 18 months apart with different instrument settings). Adopting a weighted average of these three results implies an increased noise level of 5%. A straight average of these values yields a noise increase of about 8%, taking a conservative approach and ignoring estimates on the uncertainties. In conclusion, we expect an increase of noise at 9.5 K of about 4–13%.

Although the sensitivity changes are small, observers would need to integrate longer to obtain the same S/N ratios. For a 13% degradation of sensitivity (expected upper limit), observations would need to be 28% longer. Projects requiring only 24μm data and/or only bright 70μm sources would not be drastically effected by warm MIPS campaigns. The sensitivity trade-off would effect observations of faint sources the most. Deep 70μm observations would benefit if taken during cold MIPS campaigns.