MADmap extended source calibration I: The Blue Channel

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Abstract

This report summarizes results form comparisons of extended source surface brightness measurements made with PACS Level 2 maps and IRIS images for the PACS 70 and 100 μ m filters. The primary goals of this exercise are to: (i) determine the absolute calibration of PACS maps against the IRIS plates, (ii) determine the effect of data processing on the absolute zero level for PACS.

The results show that PACS data are calibratable to IRIS images. However, as expected, PACS data processing removes both the telescope as well as the local sky absolute levels from the final maps. Most importantly a gain factor of ~ 0.62 exists between IRIS and PACS level 2 maps for the blue channel. The existence of this gain factor implies that for extended sources PACS images are brighter by $\sim 1.6x$ IRIS surface brightnesses.

1 Introduction

The measurement of the brightness of non point-like sources is one of the key functions of any astronomical imager such as PACS. However, surface brightness measurements are more complicated than point-source photometry because simple metrics such as aperture photometry are no longer valid. Further, unlike stars or asteroids, there are no absolute calibrators for the surface brightness (MSX calibration spheres being the exception). The best calibrated instrument for extended emission remains the COBE instruments which measured the theoretically predicted and measured microwave background radiation (see e.g. Meville-Deschenes & Lagache (2005)). The IRAS full sky survey provided another opportunity to determine the absolute flux levels for the extended emission (primarily dust emission) in the mid- and far-IR wavelengths. Meville-Deschenes & Lagache (2005) recalibrated the original IRAS measurements to the DIRBE experiment, thus providing absolutely calibrated all-sky images at the IRAS wavelengths . In the report, we capitalize on the availability of IRIS images to investigate the surface brightness calibration for PACS.

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Table 1:	List o	of Input	data	used	for	surface	brightness	comparison.
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Field	OBSID	Filters	Size (degrees)
RCW 120	1342185553	Green, Red	
	1342185554	Green, Red	
RCW 79	1342188880	Green, Red	
	1342188881	Green, Red	
RCW 82	1342188882	Green, Red	
	1342188883	Green, Red	
L1241	1342188679	Blue, Red	Faint
	1342188680	Blue, Red	Faint
L30	1342186275	Blue, Red	Hi-Gal field
	1342186276	Blue, Red	Hi-Gal field
Lupus III	1342189880	Blue, Red	Faint
	1342189881	Blue, Red	Faint
Polaris	1342185573	Blue, Red	Faint
	1342185574	Blue, Red	Faint

2 The data & data reduction

We chose Galactic H II regions and cirrus dominated fields for this comparison. These are listed in Table 1. NOTE: For completion all cirrus fields are listed even though most of the fields were, in subsequent analysis, determined to produce flux levels in the PACS blue channel that are dominated by photon and 1/f noise and quite unusable for flux comparison. The fields marked as "Faint" are, therefore, excluded for the PACS blue channel calibration.

The PACS data were reduced using a "standard" reduction script for MADmap processing and pre-processing. This procedure is discussed in Ali (2010). The pre-processing is employed to clean the individual bolometer timelines of instrumental effects and mask the effects of cosmic ray hits. The time-lines are also calibrated. Of relevance to this report are the following reduction steps:

- We calculate and subtract the median level for each bolometer time-line from every single readout of that bolometer.
- We remove the lowest frequency drifts in the signal time lines by modeling and subtracting the signal baseline as a polynomial. Ali (2010) describes how the baselines are determined and removed.
- The MADmap algorithm, furthermore, creates a map with somewhat arbitrary zero point.

The end result of including these steps in the data reduction is that the zero level of the final maps is not known in PACS images. Thus, requiring that the absolute zero level must be recovered from independent sources.

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3 Procedure for comparing PACS and IRIS images

We follow the approach adopted by Meville-Deschenes & Lagache $\ (2005)$ and define the comparison as:

$$I_{\lambda}^{\text{IRIS}} = G_{\lambda} \times I_{\lambda}^{\text{PACS}} + B_{\lambda} \tag{1}$$

Where, G_{λ} is the gain correction factor. Since typical PACS maps are much smaller than the all sky survey of IRAS, the spatial scale dependency is ignored in this analysis. Both IRIS and PACS report mono-chromatic equivalent flux densities for their broad-band filters. Hence, color-correction between the two filters are also required to properly interpret the value for the gain factor. This issue is further discussed in Section 3.2.

In practice, we perform a pixel-by-pixel comparison of the surface brightness values after PACS mosaics are manipulated to match the sampling and spatial resolution of IRIS images. Said manipulation entails the following steps, which are also illustrated in Figures 1 & 2:

- Convolve PACS images with IRIS beam sizes provided by Meville-Deschenes & Lagache (2005). We used a circular Gaussian beam with full width half maximum value of 4.3 arc-minutes using the IDL procedure *CONVOLV*. Any remaining glitch values are masked and ignored during the convolution using the appropriate keywords in the IDL call.
- Convert PACS signal units from Janskies per pixel to MJy per steradians. The conversion factor is 1 Jy/pix = 4154.80 MJy/sr for the PACS blue channel.
- The PACS image is then resampled to the pixel scale of the IRIS images using the IDL procedure *HASTROM*. No astrometry offsets correction was required to register PACS and IRIS images. Likely, this is because the astrometry error associated with both surveys is much smaller than the final sampling size (pixel size) of IRIS images.

Only the region containing an overlap between the scan and cross-scan observations is actually used for the flux comparison. To achieve this, we either defined a usable pixel mask, or simply ignored the non-overlap region during the mosaic creation.

3.1 Which MADmap map to use?

The MAD map software produces two maps: (i) a so-called naive map in which the final map is produced by projecting (averaging together) all valid readouts for each sky pixel. There are no corrections for 1/f drifts. The naive maps, thus, contain the striping artifacts from the 1/fnoise drifts in the final maps. (ii) The second map is the optimally extracted map from the time-lines. The procedure is described by Cantalupo *et al.* (2010). This map removes the 1/fnoise and creates an "optimal" solution for the projected sky values.

We chose the naive maps for this comparison. The primary motivation is the assumption in MADmap (and indeed in all map-makers) that the noise has a zero mean. Thus, averaged time-lines from the bolometers preserve the relative fluxes even when clear noise artifacts (e.g. striping) are present in the data. Further, naive maps are free of any changes in the understanding about noise filters (the so-called INVNTT files) and are thus not sensitive to any

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Figure 1: The PACS observation of the field RCW 120 convolved and resampled to IRIS spatial resolution. Clockwise from top left are the original PACS "naive" map, the convolved PACS image, the convolved and resampled PACS image. For comparison, the bottom left panel shows the IRIS image of the same region.

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Figure 2: Same as Figure 1 but for the L30 Hi-Gal field. Note only the region containing overlap between scan and cross-scan direction is used for flux comparison.

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Table 2: Color-corrections for the ISM.				
Wavelength(s)	IRAS	PACS	Ratio (IRAS/PACS)	
$(\mu { m m})$				
60, 70	1.22	1.21	1.01	
100	1.03	1.02	1.01	

subsequent changes in our understanding of the noise properties. The naive maps are also always consistently available for all MADmap reductions; Thus, if we calibrate the naive maps, then any optimally extracted map can subsequently be internally (re)calibrated to the naive maps, if necessary.

3.2Color corrections

The gain factor in equation (1) has two dependencies: the calibration itself and color terms. Equation (1) compares mono-chromatic flux densities between IRIS and PACS images because the two experiments (IRAS/IRIS and PACS) chose to represent measured in-band brightness as their equivalent mono-chromatic flux densities. Thus, in comparing the two filters, it is necessary to ensure that color-corrections are accounted for. Fortunately, as described below, these color-correction turn out to not be a factor in the analysis presented here.

We have used two types of fields in our analysis: Galactic cirrus dominated fields and H II regions. We discuss the color-corrections for these individually below.

3.2.1The interstellar medium fields

The dominant emission in these fields, by definition, is from the ISM itself. Figure 3 shows the expected (and normalized) emission from the ISM with the IRAS and PACS filter transmissions. The ISM spectrum itself is taken from the ISM model used by Spot and HSpot software. The filter profiles for IRAS are taken from the IRAS explanatory supplement and the PACS calibration files for IRAS and PACS filters, respectively. We derive color-corrections for the ISM in the same manner as Meville-Deschenes & Lagache (2005). The resulting values are listed in Table 2. We note that while the color-terms for the 60 and 70 μ m filters are significant, the *relative* correction between the two is not. This is likely because the two filter differ most significantly in their transmission profiles at the shortest wavelengths, where the ISM emission itself is the weakest. We have not used more sophisticated ISM models; though, little change is expected for the 60 and 70 μ m bands.

In the green (100 μ m) band, both filters have very similar effective wavelengths as well as symmetric profiles. Such an arrangement produces very little overall color term for the ISM. Given these results we have ignored the effect of color-correction for the ISM from subsequent analysis.

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Figure 3: The model interstellar medium spectrum from the Spitzer/Herschel background model and IRAS and PACS filter profiles. The longer wavelength 100 μ m filters are symmetric and roughly equivalent. The bluer 60 and 70 μ m filters are not; however, the ism spectrum shows little or no emission where the differences between the filters are largest. Hence, color-corrections between the IRAS 60 and PACS 70 μ m filter remain roughly the same (see Table 2).

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3.2.2 The H II regions

The Galactic H II fields comprise of both the hotter H II region and the colder ISM components. It is, however, reasonable to assume that at high flux values, the H II region will dominate and at fainter flux values (due to the large field sizes) the colder ISM components will dominate. Thus, we expect that the color-corrections for H II fields may be dependent on the observed fluxes. It is not clear where such a break may be expected and we opted to use an "empirical" approach by dividing the observed fluxes in three different catagories: very faint, faint and bright. The boundaries vary by H II region but are roughly 700 and 1200 MJy/sr for the very faint/faint and faint/bright bins, respectively. Visual inspection was employed to determine where the actual boundary lays for each of the 3 H II regions. The results do not appear significantly dependent on the choice of the boundary itself.

4 Results and Discussion

Figures 4 & 5 show the comparison between IRIS and PACS images for the PACS green and blue filters, respectively. Table 3 shows the resulting gain factors for PACS as defined in equation 1 for two different flux bins. The very faint flux bin is included for completion but is, in fact, excluded from further discussion; It is likely dominated by 1/f noise. A secondary consideration for binning the fluxes in the higher luminosity bin, in addition to any color-correction changes (see Section 3.2.2), is to factor PACS' non-linearity in the higher flux regimes.

Except for RCW 82, we find a roughly consistent value between H II regions and the cirrus fields for the faint flux bin. We expect the ISM emission to dominate in this flux bin. The color-corrections not being a factor for the ISM, the correlations shown in Figures 4 & 5 imply that extended emission seen in PACS maps can be calibrated to the the absolutely calibrated IRIS images using a gain factor of ~0.62 for the PACS blue channel. The existence of this gain factor also implies that PACS measured surface brightness values are ~60% higher than IRIS measurements. The origin for this is unclear as a similar effect does not exist for the point source photometry measurements. We plan to investigate the origin of this gain factor further in subsequent updates of this report.

In the higher flux bin, RCW 79 appears discrepant; however, the values for the other two sources are consistent with the value derived above. The two discrepant values for RCW 79 and 82 may indeed be "real" in the sense that they could reflect unknown color-terms; however, short of obtaining a spectrum there is no way to decouple the color-term from the calibration term.

5 Conclusions

The fields analyzed thus far suggest the following conclusions:

- The PACS fluxes are linearly correlated with IRIS images.
- The absolute "zero" flux level for PACS is not recoverable using the standard data processing; however, PACs images are calibrateable to IRIS images using a gain factor of

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Figure 4: The IRIS surface brightness plotted against the PACS "naive map" surface brightness measurements. The red, black and blue symbols and lines show the results for RCW 79, 120 and 82, respectively. The measured gain factors for all best-fit lines are shown in the inset legend box.

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Figure 5: The IRIS surface brightness plotted against the PACS "naive map" surface brightness measurements for the cirrus field L 30.

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Figure 6: Comparison of MADmap maps derived using Generation 1 and Generation 3 noise filters with the "naive map". MADmap maps are consistent with both the naivemaps and each other.

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Table 3:	Gain	factors	between	PACS	and	absolutely	calibrated	IRIS	images.
		T:114)	\mathbf{D}_{i+1}^{i+1}			$\overline{\alpha}$		

Fillter	λ	Field	G_{λ}		
	(μm)		Faint	Bright	
Green	100	RCW 120	0.65	0.68	
Green	100	RCW 79	0.61	0.79	
Green	100	RCW 82	0.77	0.60	
Blue	70	Cirrus Fields	0.60	0.64	

 ~ 0.62 multiplied by ratio of color-correction between IRAS and PACS images.

- Color correction for the ISM between PACS and IRAS is not significant for the PACS blue channel.
- There is little evidence in this dataset for variation in gain factor either due to nonlinearity or color-correction changes between bright and faint flux bins.
- The absolute zero-levels, as determined relative to IRIS, are not the same between the 4 fields used here. This implies that to properly recover the absolute level, similar comparisons need to be made to IRIS or other absolutely calibrated maps.

References

The MADmap user's guide. Issue 1.0. PICC-NHSC-TN-026

Catalupo et al. 2009 http://arxiv.org/pdf/0906.1775

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