Herschel PACS ICC

The bandwidth of the PACS photometric system

Document Ref.: PICC-CR-TN-044

Issue: 1.1

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Date: 7th May 2013

Document Status Sheet

Document Title: The bandwidth of the PACS photometric system				
Issue	**Revision**	**Date**	**Reason for change**	
1	0	30 April 2013	First version	
1	1	7 May 2013	Comments from B. Altieri	

Contents

1 Introduction

The result of a theoretical computation of the spectral energy distribution (SED) emitted by a source, is the monochromatic flux density f_λ in [erg/cm^2/s/cm] or, equivalently, f_ν in [erg/cm^2/s/Hz]. A photometer, on the contrary, integrates the source flux over a large wavelength interval in order to increase the sensitivity of the instrument. The result of the integation depends on the instrument optics, e.g., mirrors, filters, and so on. The result of this integration is no longer a flux density but a flux[1] F in erg/cm^2/s

$$F = \int f_\lambda(\lambda) T_\lambda \mathrm{d}\lambda$$

where T_λ is the function that describes the effect of the optics (including also the response of the detectors).

The above equation implies that an instrument should be calibrated with a number of sources spanning all the SEDs, i.e., f_λ, of physical interest. On the other hand, this is not possible for many practical reasons, one being that for some SEDs we do not have known calibrators. PACS, like any other photometer, is calibrated by observing few sources that generally cover a limited range of SEDs. The output of the detector, a voltage for the bolometers, is then directly converted in a flux density through the responsivity factor which gives the relation between the measured voltage and the known source flux density.

If all the observed sources had the same spectrum the relation between flux and flux density would be the same and we could compare the theoretical monochromatic SED with the measured value. This is, however, not the case and in general the responsivity factor derived within the instrument flux calibration does not apply to all the sources. The measured flux is not necessarily representative of the intrinsic source flux.

To overcome this problem two approaches are usually followed:

Color correction : in this approach we *modify* the observed value assuming a certain input spectrum, and then the measured and the theoretical f_λ can be compared. For PACS color correction terms have been derived for a large number of SEDs (see the note PICC-ME-TN-038[2]). The derived color corrections are significant and variable for T <30 K, which is an important range of temperatures in many astronomical conditions when observing in the far infrared;

Integration of the SED : in this case we do not correct the observed flux density, instead the input spectrum is multiplied with T_λ and integrated; the resulting flux is then converted back in a flux density. This approach is more general than the previous one and it has no limitations on the input spectrum properties. It requires, however, to derive for each band a reference wavelength and bandwidth.

2 Reference wavelength and bandwidth

A common approach to define a reference wavelength λ_{ref} and a bandwidth $\Delta\lambda$ is to consider an input spectrum $\lambda f_\lambda = \nu f_\nu =$ const. Then λ_{ref} and $\Delta\lambda$ are chosen such that for this spectrum $F/\Delta\lambda = f_\lambda(\lambda_{\mathrm{ref}})$.

The theoretical flux is

$$F(\lambda_{\mathrm{ref}}) = \int f_\lambda T_\lambda \mathrm{d}\lambda = \int \frac{\mathrm{const}}{\lambda} T_\lambda \mathrm{d}\lambda \tag{1}$$

where the integral is computed on the wavelength interval over which $T_\lambda \neq 0$; but by definition of $\Delta\lambda$ we also have that

$$F(\lambda_{\mathrm{ref}}) = f_\lambda(\lambda_{\mathrm{ref}})\Delta\lambda = \frac{\mathrm{const}}{\lambda_{\mathrm{ref}}}\Delta\lambda \tag{2}$$

Equating the two equations we find

$$\mathrm{const} \int \frac{T_\lambda}{\lambda} \mathrm{d}\lambda = \frac{\mathrm{const}}{\lambda_{\mathrm{ref}}}\Delta\lambda$$

[1]Quite often the flux density is named simply flux. In this note we have to distinguish between the two terms.
[2]http://herschel.esac.esa.int/twiki/pub/Public/PacsCalibrationWeb/cc_report_v1.pdf

from which

$$\Delta\lambda = \lambda_{\rm ref} \int \frac{T_\lambda}{\lambda} {\rm d}\lambda \tag{3}$$

There is no unique definition of $\lambda_{\rm ref}$: for instance one could define it through a weighed mean (the *effective* wavelength)

$$\lambda_{\rm eff} = \frac{\int \lambda T_\lambda {\rm d}\lambda}{\int T_\lambda {\rm d}\lambda} \tag{4}$$

but this is just one of the many possible definitions. For PACS the adopted values of $\lambda_{\rm ref}$ are 70 μm, 100 μm, and 160 μm.

3 The PACS photometry system

In the PACS calibration tree there are two set of files which define T_λ: the filter transmission, one for band, and the bolometers response. In HIPE the filter transmissions can be read with the following lines

```
calTree = getCalTree()
llb = calTree.photometer.filterTransmission.blue.getColumn(1).data
ttb = calTree.photometer.filterTransmission.blue.getColumn(0).data

llg = calTree.photometer.filterTransmission.green.getColumn(1).data
ttg = calTree.photometer.filterTransmission.green.getColumn(0).data

llr = calTree.photometer.filterTransmission.red.getColumn(1).data
ttr = calTree.photometer.filterTransmission.red.getColumn(0).data
```

while the bolometer response is read with

```
aaa = calTree.photometer.absorption.transmission
lla = calTree.photometer.absorption.wavelength
```

In Figure 3-1 the three filter transmissions are shown, along with the bolometer response curve. In Figure 3-2 the overall optical transmissions are shown.

The bandwidths computed with Equation (3) are reported in Table 1: for each band the values are given in μm and Hz. The latter are defined simply as $\Delta\nu = \Delta\lambda \cdot c/\lambda^2$ (just for comparison: $\Delta\nu$=2.58$\times$10^{12} Hz and 1$\times$10^{12} Hz for IRAS 60 μm and 100 μm bands).

λ (μm)	$\Delta\lambda$ (μm)	$\Delta\nu$ (10^{11}Hz)
70	10.6	6.48
100	17.0	5.09
160	30.2	3.54

Table 1: Reference wavelengths and bandwidths for the three PACS photometry bands

3.1 Comparison with the color corrections reported in PICC-ME-TN-038

In the following tables the color corrections computed with the $\Delta\lambda$ reported in Table 1 are compared with those reported in the note PICC-ME-TN-038, for some representative models.

In the first table we show the color corrections for a blackbody at different temperatures. Differences are less than 1% for $T \geq 10$ K. At very low temperatures deviations are significant, we warn the users that the flux calibration may be quite uncertain at such a low temperatures.

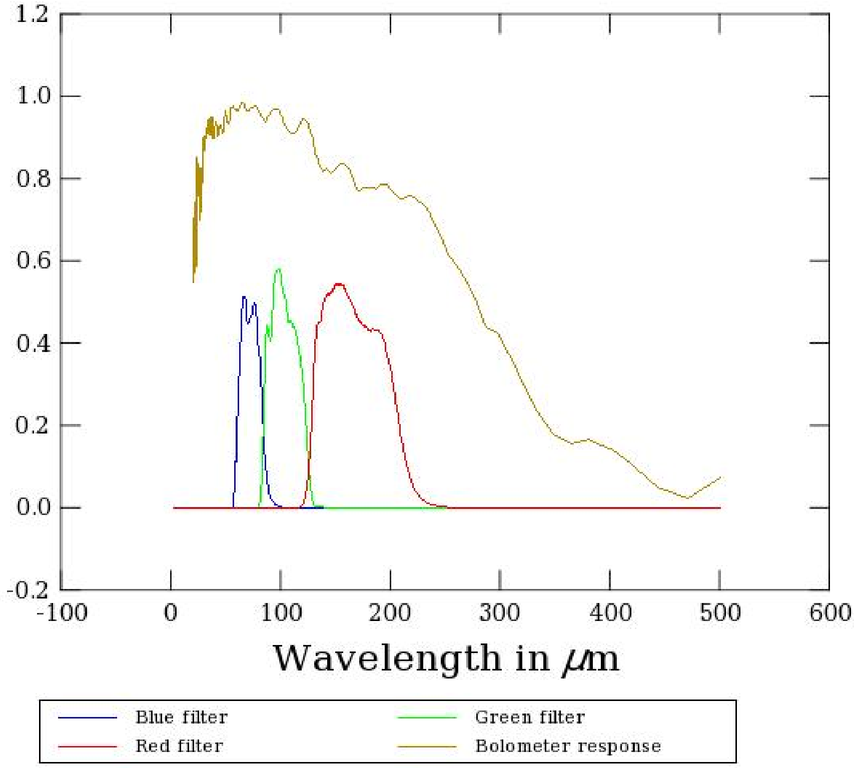

Figure 3-1: Filter transmissions and bolometers response

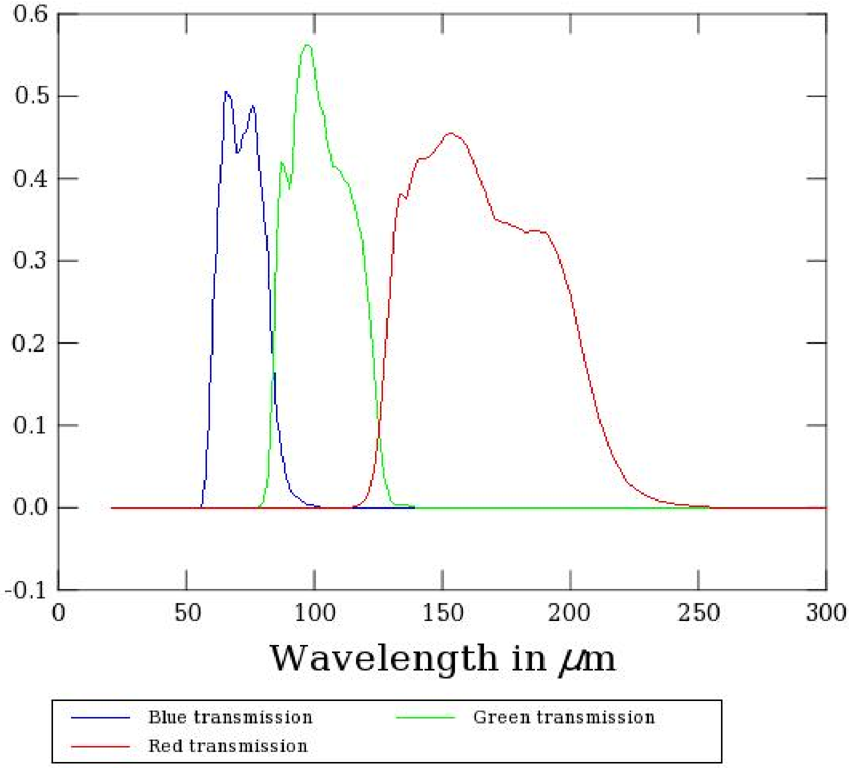

Figure 3-2: Optical transmissions for the three bands of PACS

$B(T)$	Wavelength		
	70	100	160
10 000 K	1.016	1.034	1.074
	1.015	1.032	1.075
1 000 K	1.013	1.031	1.072
	1.012	1.029	1.072
100 K	0.989	1.007	1.042
	0.988	1.005	1.043
50 K	0.982	0.985	1.010
	0.980	0.983	1.010
10 K	3.645	1.711	1.184
	3.640	1.708	1.185
5 K	456.8	12.26	4.278
	625.2	12.24	4.279

Table 2: Color corrections for a blackbody at different temperatures T. First lines give the corrections copied from the note PICC-ME-TN-038; the second lines report the corrections computed in this note.

In the next table we compare the color corrections for a modified blackbody, i.e., $F_\nu = \nu^\beta B(T)$. The corrections have been computed using Eqs. (5) and (6), see next section, in the limit of $\lambda_0 \ll \lambda$, in particular $\lambda_0 = 1\ \mu$m. As in the previous case, the differences between the two sets of data are negligible.

F_ν	Wavelength		
	70	100	160
$\nu^1 B$(100K)	1.001	1.031	1.098
	1.016	1.034	1.075
$\nu^1 B$(10K)	3.116	1.541	1.083
	3.115	1.539	1.083
$\nu^2 B$(100K)	1.023	1.067	1.175
	1.022	1.065	1.176
$\nu^2 B$(10K)	2.691	1.399	1.009
	2.689	1.397	1.009

Table 3: Color corrections for a modified blackbody for some β and T. First lines give the corrections copied from the note PICC-ME-TN-038; second lines report the corrections computed in this note.

In general, if the user knows in advance which model can be used to fit a SED and the model is available among those reported in the ICC note, then it is easier to use those values. On the contrary, if for instance the user is interested in a particular model, then it is necessary to compute the color corrections for that specific model. As an example, in the next section we derive the color corrections for a greybody model.

4 How to compute the color corrections for a generic model

The greybody model is used in this section as an example on how to derive and to use the color corrections. The greybody is a modification of the blackbody $B(\nu, T)$

$$F_\nu = (1 - \mathrm{e}^{-\tau}) B(\nu, T) \Omega \tag{5}$$

where the optical depth is described as a power law

$$\tau = \left(\frac{\lambda_0}{\lambda}\right)^\beta \quad (6)$$

and Ω is the solid angle.

Let's adopt the set of parameters $(T, \lambda_0, \beta) = (15\mathrm{K}, 157\mu\mathrm{m}, 1.5)$. The deconvolved radius of the source at 100 μm is 7" and is located in the Perseus star-forming region (250 pc), so its solid angle is 3.62×10^{-9} sr.

The PACS flux at 100 μm is 9.37 Jy. The numerical integration of the model over the green PACS band gives a flux of 4.81×10^{-7} erg/cm^2/s. To derive the flux density we have to divide this number for the bandwidth (0.0017 cm) and transforming in Jansky we get 9.43 Jy. The monochromatic flux of the model is 8.43 Jy. For this model, then, the color correction is 0.895.

At this point we can either transform the instrumental flux of 9.37 Jy in a monochormatic flux: 0.895×9.37 Jy = 8.37 Jy, which can be compared with the theoretic monochromatic flux; or we compare the measured flux (9.37 Jy) with the PACS-transformed theoretical flux of 9.43 Jy.

For an example of the use of the color corrections in the context of model fitting, the reader may want to have a look at the Appendix A in Pezzuto et al. 2012 (A&A, 547, A54).

Acknowledgements

The procedure described in this note to derive the $\Delta\lambda$ is based on a enlightening discussion with M. Sauvage, and on the document http://www.ipac.caltech.edu/iso/isap/com/headers/syn_phot.html.