Herschel Filter curves and Synthetic Photometry

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1. Data Sources

The various filter transmission curves for which correction factors are determined below were obtained as follows.

For PACS, the transmission curves were obtained on 4/22/2011 from within HIPE[1] v6.1.0. The filter transmission data in the HIPE calibration tree has a generation date of 6/11/2009, by `bmorin@cea.fr`. It appears that these curves include filter transmission and detector QE, as well as all other spacecraft throughput curves.

For SPIRE, I have used the transmission curves in the FITS file linked to and described in the 'Photometer Spectral Response' section of `https://nhscsci.ipac. caltech.edu/sc/ index.php/ Spire/ HomePage`, retrieved on 4/ 22/ 2011. I am not entirely sure of the units of the transmission, but suspect that they are the same as the PACS units. These are the point-source curves. Because the pixels of the SPIRE detector have their own feedhorn, they sample different areas on the sky as a function of wavelength. I thus consider filter curves where the response has been weighted by λ^2 as appropriate for uniform surface brightness sources that fill the FOV.

2. Conventions

The filter curves as provided above are given in terms of signal per flux density (e.g., electrons per ergs^{-1}cm^{-2}Hz^{-1})). Such a curve will be referred to as R_e. Another common convention is to quote filter transmission in units of signal/photon; this is the convention adopted by the `k_correct` code. Such a transmission curve will be denoted R_γ. These curves are related by $R_\gamma = h\nu R_e$. In general, the overall normalization of R is not given in physically useful units, and is only relevant for some specfic cases. In the equations below, it is relatively straightforward to substitute R_e for R_γ.

The Herschel calibration convention is such that the flux densities F_ν^q as provided/quoted in the PACS and SPIRE reduced images scale linearly with the detector signal that would be expected for a source with $\nu_q F_\nu^q = constant$, where ν_q is the HSC defined reference frequency ($= c/\lambda_q$ where λ_q is the HSC defined reference wavelength) for that filter (Table 1). That is,

$$S_H = K \int F_\nu^q(\nu_q/\nu)(R_\gamma/\nu)d\nu \qquad (1)$$

where S_H is the detector signal and K is some scaling constant which absorbs the planck constant h as well as the normalization of the transmission curve.

2.1. AB

AB magnitudes are defined in terms of the ratio of the source signal to the signal from a standard with $G_\nu = constant = 3631$Jy.

$$m_{AB} = -2.5\log\left(\frac{S_h}{K\int G(R_\gamma/\nu)d\nu}\right) \qquad (2)$$

where $G = 3631$ Jy. This is the quantity calculated by the `k_correct` code when given a model SED and R_γ. Combining with Eq. 1, and noting that the scaling factor K cancels, one obtains

$$m_{AB} = -2.5\log(F_\nu^q/G) - 2.5log(\nu_q/\nu_{eff}) = m' + X \qquad (3)$$

where $\nu_{eff} = \frac{\int R_\gamma/nu^2 d\nu}{\int R_\gamma/\nu d\nu}$, $m' = -2.5\log(F_\nu^q/G)$ is a sort of instrumental magnitude constructed from the quoted fluxes, and X is a correction factor to bring this onto the AB system (or alternatively to bring synthesized AB magnitudes onto the Herschel system). Note that for *Spitzer* IRAC (but not MIPS) $\nu_q = \nu_{eff}$. Unortunately, Herschel has decided, for no discernable reason, to use slightly arbitrary ν_q, though the differences are not large. Both $\lambda_{eff} = c/\nu_{eff}$ and X are given in Table 1. Generally the corrections to AB are less than a percent.

[1] following the instructions at https://nhscsci.ipac. caltech.edu/sc /index.php/Pacs/ FilterCurves

2.2. Another possible convention

Not everyone works in AB magnitudes when constructing synthesized photometry from models. What is another way to compare model fluxes to the Herschel quoted fluxes? A common thing to do is to simply calculate the detector signal from the model SED f_ν as

$$S_{model} = K \int f_\nu (R_\gamma/\nu) d\nu \quad (4)$$

Equating this with S_H to obtain the quoted flux in terms of the detector signal, one obtains

$$F_\nu^q = \frac{S_{model}}{K \int (\nu_q/\nu)(R_\gamma/\nu) d\nu} = \frac{K \int f_\nu (R_\gamma/\nu) d\nu}{KD} \quad (5)$$

Note that in the calculation of D in the denominator, it is *imperative* that the R_γ used have the same normalization (and of course the same shape) as that used to construct S_{model}, or at least that the relative normalizations are well known. Otherwise the factors K do not cancel. Thus, while it is possible for me to determine the 'conversion factors' D for a given set of filter curves and provide them, it is not certain that these will be valid for the particular files (or code) used by an individual. It is encouraged to calculate the denominator yourself for the filter curves you use in generating synthetic photometry.

For filter curves normalized such that the *maximum* transmission R is equal to one, the conversions D are listed below. Obviously, these conversion factors scale linearly with the maximum transmission. If you used R_e in the determination of S_{model}, there will be an extra factor of h.

Magnitudes are kind of stupid. They have two advantages though: 1) magnitude error is almost directly related to fractional flux error, at least for errors less than ~ 0.5 and 2) People who give a filter and a magnitude in papers often tell you what system that magnitude is on while people who give a filter and a flux often fail to mention the nature of the reference spectrum and the reference wavelength, requiring a lot of digging and some assumptions.

Table 1: Herschel Synthetic photometry

Band	$\lambda_q (\mu m)$	$\lambda_{eff} (\mu m)$	X (mag)	D
PACS 70	70.0	70.390	-0.0060	0.281
PACS 100	100.0	100.191	-0.0021	0.298
PACS 160	160.0	160.217	-0.0015	0.3965
SPIRE 250	250.0	247.211	0.0122	0.286
SPIRE 350	350.0	346.959	0.0095	0.279
SPIRE 500	500.0	496.630	0.0073	0.319
SPIRE 250 (ext)	250.0	251.528	-0.0066	0.255
SPIRE 350 (ext)	350.0	352.819	-0.0087	0.260
SPIRE 500 (ext)	500.0	511.452	-0.0246	0.336