Linearisation of ISOPHOT-P and C detector signals in OLP8

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Abstract

The responsivities measured for the ISOPHOT P- and C-detectors show correlations with the inband flux. The implications of such a nonlinearity in the system are discussed and a method to correct for it is presented. The correction method is being used successfully in OLP8, but leads to significant changes of the calculated responsivities w.r.t. older versions of the pipeline. Therefore in addition to a number of calibration tables that are related to the FCS calibration, also the orbit dependent default responsivity tables had to be updated.

1 Introduction

The ISOPHOT flux calibration is based on the assumption that there is a linear relation between the photo current and the infrared flux that is transmitted by the filter (inband power). The associated proportionality constant is called detector responsivity and is measured in [A/W]. For calibration standards, where the spectral energy distribution (SED) is known, the inband power can be directly calculated taking into account the transmissions or reflectances of filters, mirrors, field lenses etc. (see [2]). By including the relative response function, we define the responsivity such that it is independent of filter. Thus the responsivity should be characteristic for a detector and is expected only to vary in time due to cosmic radiation and flux history. However, the actual behavior of ISOPHOT detectors was found to be different.

2 Responsivity correlated with flux

In its simplest form we calculate the responsivity from the signals measured on source ($S_{src} + S_{bg}$) and off source (S_{bg}) and the PSF-corrected inband power P_{src} according to

$$R = \frac{(S_{src})C_{int}}{P_{src}}, \tag{1}$$

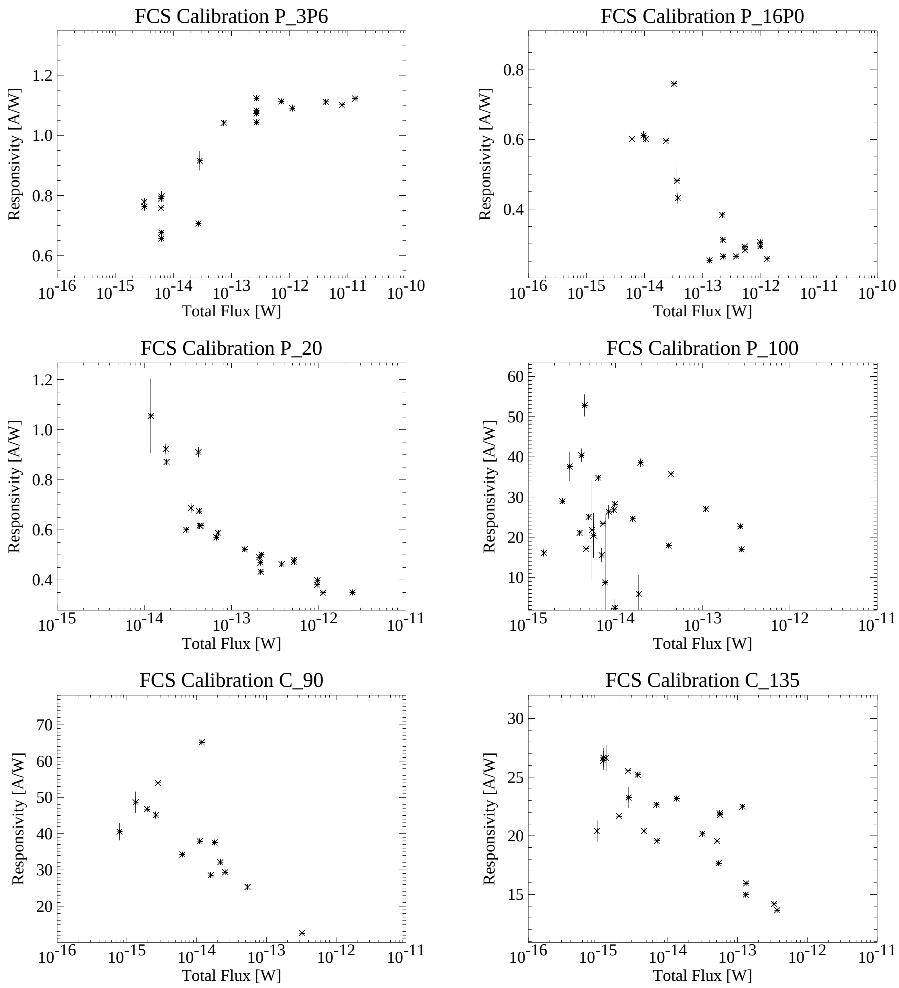

Figure 1: Naive plot of responsivities against inband power, assuming linearity (Equ. 1) for the filterbands P_3.6, P_16, P_20, P_100, C_90 and C_135. For C-detectors pixels 5 and 2 are shown respectively. For P3 (P_100 filter) a correlation is not quite obvious because of a dominant time dependent variability of R.

where C_{int} is the integration capacitance of the integrating amplifier. It should be noted that this definition is different from the one given in [2], since filter to filter correction is not included. Plotting the results for the measurements of various calibration standards versus inband flux however shows strong correlations (see for example Fig. 1), first analysed in [1]. Moreover these correlations even seem to be different among filters of the same detector subsystem.

3 Impact on flux calibration

If the measured responsivity R depends in some way on the infrared flux that falls onto the detector, R can also be expressed as a function of the photo current or the detector signal. Looking in more detail into the question of background subtraction, we can rewrite Eqn. 1 to

$$R(S_{src} + S_{bg}) = \frac{(S_{src} + S_{bg})C_{int}}{P_{src} + P_{bg}} \tag{2}$$

describing the responsivity of the detector when it is pointed at the position of the source, and further to

$$R(S_{src} + S_{bg}) = \frac{(S_{src} + S_{bg})C_{int}}{P_{src} + \frac{S_{bg}C_{int}}{R(S_{bg})}}. \tag{3}$$

bg indicates the background fractions of signal and inband power. In our case $R(S_{bg})$ and $R(S_{src} + S_{bg})$ are not necessarily equal anymore and the ratio between the signals measured on and off source is different from the one of the respective fluxes. Trying to determine $R(S)$ is more complicated, because Eqn. 3 already requires knowledge of $R(S_{bg})$. We can expect that considerable errors are introduced as soon as comparisons of very different signals are performed. This applies in particular to multi filter AOTs, multi aperture AOTs on extended sources, maps with large dynamic ranges and generally all FCS calibrations where the signals from FCS and sky are very different. For measurements on the sky the biggest systematic errors are expected if the fluxes of background and source alone are about equal.

4 Signal linearisation

All further data reduction steps assume a linear system, so we decided to linearise already the detector signals S like $S' = T(S)$, where T is a transfer function, instead of applying a correction to the responsivity value once flux calibration is performed. The condition for $T(S)$ is such that the results of S' inserted into Eqn. 1 should not any more correlate with the detector signal but should be distributed around a constant responsivity with a minimum

pixel #	P1	P2	P3	C100	C200
1	1.17	0.67	30.0	53.10	20.18
2				49.26	25.13
3				56.75	20.84
4				51.99	23.18
5				39.34	
6				44.25	
7				48.35	
8				52.73	
9				42.66	

Table 1: Responsivity values in [A/W] used to normalise the OLP8 linearisation tables. Due to the missing PSF factors the values are in some cases quite far away from the ones appearing in Fig. 2.

dispersion. The absolute value of this constant is arbitrary because it cancels out in the flux calibration. It is normalised according to Table 1 for the Cal-G files[1] of OLP 8.4. It is important to note, that the signal linearisation can only be applied after the dark signal subtraction.

5 Boundary conditions

The signal linearisation is performed through interpolation of a lookup table, spanning the full range of possible signals. This table is only calibrated in the range covered by calibration standards. However in practise signals occur outside this range, that are higher, lower and even negative in case of noisy measurements close to the dark current. Reasonable results for these cases must be defined: a) For the high signal cases, we decided to continue with a constant responsivity, starting from the point where no data is available anymore. b) An already dark subtracted zero signal should not be changed by the signal linearisation. This puts an important constraint on the lookup table. Between the smallest point in the lookup table that is still determined by valid data and zero, the transfer function $T(S)$ is represented by a connecting straight line. This assumes that the responsivity does not vary in that range. c) The most difficult case are negative signals, because negative fluxes are simply not defined. We decided to continue the transfer function such that $T(S) = -T(-S)$. This is clearly only a best guess, to cover all cases that occur in practise. In addition the number of cases falling into this region is low, due to the fact that the correction is done after the signal average (SCP level),where the noise distribution becomes smaller.

[1] In future versions the normalisation value will be the median of the nonlinearised responsivities calculated according to Eqn. 1.

6 Determining the linearisation curves

Several iterative methods to determine $T(S)$ were tried. All are based on the assumption of an initial flat function $R(S)$ and a subsequent alteration of it. One method is described in [1]. Others that were investigated are automatic χ^2 minimisations of a distribution of resulting responsivities around a reference value. The function $R(S)$ is a polynomial of 2nd to 5th order, that starts as a horizontal line. The main problem is the quite patchy distribution of the data and the fact that in spite of the large overall number of datapoints, the statistics per filterband is quite poor. A good statistics however is important, to minimise the influence of the timely variability of R in the data, which does not only consist of the gradual changes due to the high energy radiation background, but also of arbitrary drifts due to the infrared illumination history and occasional strong impacts of cosmic particles.

In order to obtain reliable corrections while having a non-gaussian distribution of datapoints and small number statistics, we finally chose to implement the fitting process as a semi manual procedure. The function $R(S)$ is represented by a cubic spline interpolation between six points, with responsivities that can be adjusted with a mouse pointer. This curve is transformed into the transfer function $T(S)$ and saved as a calibration table. A dedicated IDL function, that uses these tables, linearises the signals belonging to all the measurements on calibration standards within a given filterband. The responsivities, calculated according to Eqn. 1 from the linearised signals and the proper inband fluxes, appear then on the computer display. Every time the y-coordinates of the support points of the spline are changed, the calculation is repeated and the display is updated. The function $R(S)$ is changed manually using the mouse until the resulting responsivities are close to the normalisation value, which is drawn as a dashed horizontal line (see Fig. 2). The calibration tables, that are automatically saved during each iteration, are direct input to the linearisation routine implemented in PIA. To be used within OLP a conversion to the CALG FITS format must be applied.

7 Discussion and Peculiarities of the OLP8 tables

Different filterbands show different linearisation curves (see Fig. 2). It is unclear why they differ for different filters of the same detector. Consequently the curves have been separated. Different pixels of the C-detector arrays were separated too. The readout electronics is unlikely to be responsible because it can not distinguish wavelengths. Explanations suggesting that we see different parts of the same transfer function are unlikely because different curves of the same detector show no similarities at the same signal levels. For the time being we consider the observed dependencies to be a property

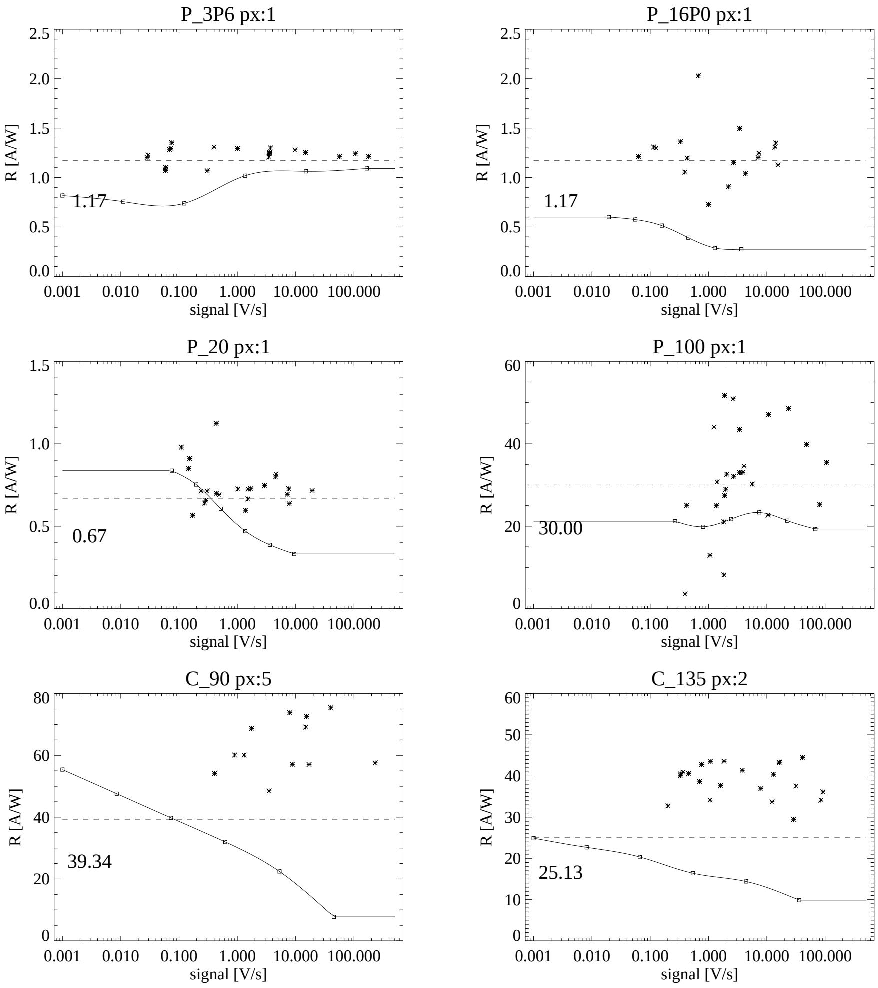

Figure 2: Display of the manual linearisation tool after adjusting the signal dependent responsivity. Due to an error in the procedure, the PSF correction was not applied during the responsivity calculation. This leads to the vertical offset between the datapoints and the dashed line.

of the detector material, triggered by both, photon flux and wavelength.

The definition of R, as mentioned earlier, does not include the filter to filter flatfield. Therefore it is not identical with the responsivity as it is calculated in version 7.x of PIA or OLP. The filter to filter correction intends to account for losses due to unknown effects like internal diffraction, vignetting or transversal variations of the filter transmission. Since these numbers describe flux losses, they were normalised to the maximum transmission of all filters of a detector pixel. Therefore the detector responsivity becomes larger when filter to filter correction is included.

Another increase of the responsivities calculated by PIA and OLP results from a bug in the manual fitting program. The inband fluxes, used to calculate the displayed responsivities, were not corrected for the flux losses due to the point spread function (PSF) of the telescope. This omission is noticeable in particular for the C-detectors, where the single pixels are lower by typically 40 %. Since the schedule did not allow an update of the linearisation files for OLP8, the difference shows up in the diagrams produced by the corrected linearisation procedure. In Fig. 2 the horizontal dashed line represents the ideal responsivity function, that is used to align the datapoints (crosses) with. The six squares connected by a spline interpolation represent the signal linarisation curve expressed as responsivities.

This flaw together with the normalisation in the filter to filter correction to the peak transmission results in markedly elevated responsivities compared to the values in Table 1. The orbit dependent default responsivities that are used, in case appropriate FCS calibrations are not available, had to be adjusted accordingly. However, in general there is no impact on the calibrated fluxes because the filter to filter correction is determined after signal linearisation. In this way the omitted PSF factors are compensated by the filter to filter calibration factors, so that the transmission ratios between different filters are correct. The filenames of calibration tables that needed to be changed due to the introduction of the signal linearisation are given in Table 2.

In future versions of the linearisation tables after OLP8, the PSF omission will be corrected and the normalisation of the linearisation tables will be according to the median of the nonlinearised responsivities. This will ensure a minimum change on the signal level before and after the linearisation. It will also bring the actual filter to filter corrections back into their proper calibration tables and remove the PSF factors from there. The calculated detector responsivities will then be close again to more familiar values from earlier OLP versions. An investigation of the significance of the differences in the linearisation curves between detector pixels within the same filterband is recommended.

Table 2: The following calibration files used by OLP and PIA were affected by the introduction of the signal linearisation.

Signal linearisation tables (new)	Filter to filter corrections
PP1SLINR.FITS	PC1FLAT.FITS
PP2SLINR.FITS	PC2FLAT.FITS
PP3SLINR.FITS	Conversion of inband flux to flux density
PC1SLINR.FITS	PFLUXCONV.FITS
PC2SLINR.FITS	Default responsivities
FCS power curves	PPRESP_01.FITS
PP1FCSPOW.FITS	PPRESP_02.FITS
PP2FCSPOW.FITS	PC1RESP_01.FITS
PP3FCSPOW_01.FITS	PC1RESP_02.FITS
PP3FCSPOW_02.FITS	PC2RESP_01.FITS
PC1FCSPOW_01.FITS	PC2RESP_02.FITS
PC1FCSPOW_02.FITS	
PC2FCSPOW_01.FITS	
PC2FCSPOW_02.FITS	
FCS illumination tables	
PC1ILLUM_01.FITS	
PC1ILLUM_02.FITS	
PC2ILLUM_01.FITS	
PC2ILLUM_02.FITS	

References

[1] Huth, S., Schulz, B., 1998, "Investigation of the flux dependency of the detector responsivity for the ISOPHOT P- and C-detectors", PIDT internal report

[2] Schulz, B., Huth, S., Kinkel, U., Lemke, D., et al., 1999, Proceedings "The Universe as seen by ISO" Paris, eds. Cox. P., Kessler, M. F.