Processing of ISOPHOT chopped photometry at 25 micron

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Abstract

We have assessed the ISOPHOT photometric calibration of a homogeneous sample of more than 80 main sequence stars which were observed with PHT03 at 25 μm in chopped mode. Photometric data in the optical from Hipparcos were used to obtain independent estimates of the stellar fluxes at 25 μm. We find that the present ISOPHOT calibration for chopped mode can be improved by assuming a default responsivity for the P2 detector corrected for orbital dependence. We have derived a relationship which corrects for the effect that in chopped mode the fluxes of bright objects (>1 Jy) are underestimated whereas the fluxes of fainter stars (<300 mJy) are overestimated.

1 Introduction

The data base of ISO observations generated by the HJHVEGA project contains a large homogeneous subset of 25 μm observations obtained with AOT PHT03. More than 80 main sequence stars later than B9V were observed throughout the ISO mission. One target selection criterion was that the photospheres of these stars should be detectable with ISOPHOT at 60 μm ($F_{60} > 30$ mJy). Consequently, these stars are bright in the visual, and sufficiently bright at 25 μm to be detected by IRAS.

Assuming that the majority of the stars have no excess emission at 25 μm, and assuming that the IRAS calibration can be used as absolute photometric reference, we have used the optical and infrared properties of the stars to perform an accurate calibration of the 25 μm data observations of the HJHVEGA project.

The 25 μm data in the HJHVEGA project are very homogeneous: they were all obtained with PHT03, in triangular chopped mode with the same aperture. This offers a good opportunity to check and refine the ISO calibration for this observing mode thereby using the targets themselves (stars) as calibrators. We rely on the findings that the amount of "peculiar" stars, i.e. stars with excess emission, is low, certainly less than 20% of the entire sample, and that at 25 μm the stellar photosphere dominates the IR flux in the majority of cases, even if an excess is present.

2 Observational data

We have extracted all PHT03 data with user HHABING from the post mission archive. These data were processed with OLP8 up to ERD level. Starting from that stage we used PIA 8.1 for further processing and analysis. Observations of 81 stars were retrieved. The common settings are listed in Table 1.

AOT:	PHT03
Wavelength:	P_25 band, $\lambda_{\mathrm{reference}} = 25\ \mu$m
Aperture:	$52''$
observing mode:	triangular chopped
chop throw:	$60''$
measurement time:	256 s
plateau time:	32 s
reset interval time:	8 s

Table 1: *General properties of the observations.*

Using both the IRAS point source (IPSC) and faint source catalog (IFCS), the IRAS 25 μm data were retrieved for nearly all stars in the sample. In Table 2 we list the stars with no IRAS fluxes. These stars were either not measured by IRAS or were too faint for detection at 25 μm. For the comparison with ISO, the IFSC fluxes have been used if available, otherwise we used the PSC. To convert to a monochromatic flux at 25 μm a colour correction factor of 1.40 has been applied to the IRAS catalogue fluxes.

In addition a prediction of the 25 μm photospheric flux of a given star in our sample was derived from the semi-empirical relation from Plets & Vynckier (1999):

$$\begin{aligned} V - [25] &= a_0 + a_1(B-V) + a_2(B-V)^2 + a_3(B-V)^3 \\ &= 0.01 + 2.99(B-V) - 1.06(B-V)^2 + 0.47(B-V)^3, \end{aligned} \tag{1}$$

which is based on the analysis of photometric data obtained in the optical and with IRAS of a very large sample of stars. Consequently, Eqn. 1 is tied to the IRAS calibration. We adopted a flux density of 6.73 Jy for [25] = 0 mag. The V and $B - V$ values have been taken from the Hipparcos Catalogue. At the low flux end with $F_\nu(25\,\mu m) < 300$ mJy, an uncertainty of $m_V = 0.01$ corresponds to about 2 mJy and $B - V = 0.01$ corresponds to about 5 mJy. Consequently, the uncertainty in the "predicted" flux density according to Eqn. 1 is estimated to be of the order of 2–3%. The advantages of this method of estimating the infrared flux are that (1) fluxes can be derived for all stars in the sample since they are all listed in the Hipparcos Catalogue where accurate V and $B - V$ are given, and (2) only the global IRAS calibration is involved, for individual targets the optical data (and not IRAS) determine the predicted flux at 25 μm.

HD	HIP	V mag	$B-V$ mag	$F_\nu(25\ \mu m)$ mJy
4628	3765	5.74	0.89	250
50281	32984	6.58	1.07	168
97603	54872	2.56	0.128	901
101501	56997	5.31	0.723	264
110833	62145	7.01	0.94	86
112758	63366	7.54	0.769	37
114762	64426	7.30	0.525	28
154088	83541	6.59	0.81	97
156026	84478	6.33	1.14	246

Table 2: *Stars for which no IRAS data are available, the last column lists the flux derived from Eqn. 1.*

3 Data processing approach

The PHT03 data in the 25 μm band were processed in PIA according to the following main steps:

- create chopped pattern of 4 off- and 4 on- signals, in that sequence. This step includes ramp linearisation, read-out deglitching, reset-interval correction, and signal linearisation. For most cases the pattern creation algorithm works fine, but, however, becomes not reliable in case of the presence of:
  1. a single large glitch in the data which tend to create patterns in which one of the 8 signals shows a large (positive) excursion,
  2. a strong transient signal trend at the beginning of a measurement. In that case it is better to remove the first part of the measurement, corresponding in time to the first 2 chopper plateaux. This transient tends to increase the difference signal (δs, see below).
- determine the mean on and off signal difference. We used the following method:

$$\delta s = \frac{1}{2}((s_7 + s_8) - (s_3 + s_4)) \qquad (2)$$

$$\Delta\delta s = \frac{1}{2}\sqrt{(s_7 - s_8)^2 + (s_3 - s_4)^2}\ , \qquad (3)$$

  where s_n is the n^{th} signal in the pattern, δs the mean signal difference, and $\Delta\delta s$ the estimated uncertainty. We found that the present OLP8 default method to determine the mean plateau level (removing the minimum and maximum, and taking the average of the remaining signals) is less stable than the method described above. For fluxes in excess of 200 mJy, the OLP method appears to systematically *under*estimate the flux by more than 10%, for lower fluxes the method tends to overestimate the flux. It should be that our method seems to systematically overestimate for $F_\nu < 500$ mJy, but we will show in the next section that this effect can be corrected for.

- perform the absolute flux calibration using the default responsivity corrected for orbital position. Initially we have processed the data according to the OLP 8 method in which the responsivity of the P2 measurement is determined from the FCS1 data. We found that the resulting fluxes show a very large spread when plotted against the IRAS or model data. This spread is much lower when using the default responsivity. Apparently, the FCS measurement introduces an additional noise to the data which is large compared to the assumption of a default responsivity. This finding agrees with the very stable P2 signals measured immediately after activation which suggest that the P2 detector responsivity at the beginning of each revolution is constant within 2–3%.

4 Results

The ISO flux values are plotted against the values predicted according to Egn. 1 and against IRAS in Figure 1. The ISO data have been colour corrected by using a colour correction factor of 1.28. Figure 1 shows two systematic features of the raw ISO data:

- at the high flux end, for $F_\nu(25\ \mu m) > 1$ Jy, the ISO fluxes are systematically *lower* than both the predicted or IRAS flux. For $F_\nu(25\ \mu m) = 10$ Jy we estimate an underestimation of 20–30 %. This trend is most likely due to losses in the (on-off) difference signal as a result of the detector transient.

- at the low flux end, for $F_\nu(25\ \mu m) < 250$ mJy, ISO seems to overestimate both the predicted and the IRAS flux values although the trend appears more prominent for IRAS. We do not have a clear explanation for this trend, it could be that the trend is a result of (1) the transient behaviour of the P2 detector, (2) a low level signal non-linearity, or (3) peculiarities in the IRAS calibration on which the Plets & Vynckier relation is based.

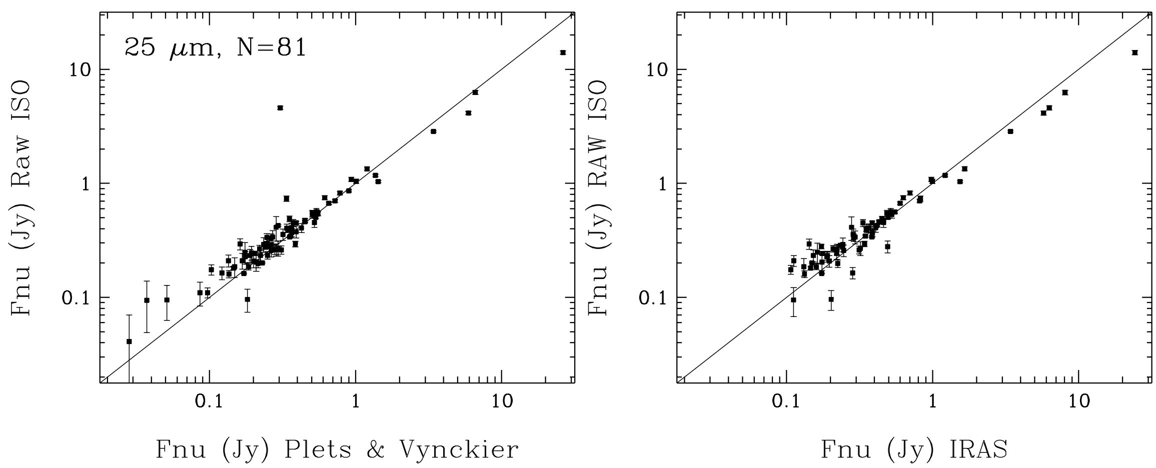

Figure 1: *The 25 µm flux densities obtained according to the processing steps described in section 3 versus predicted flux (left panel) and IRAS flux.*

Figure 1 also shows that the correlation between ISO and IRAS is very tight for stars brighter than 1 Jy. Based on the tight and linear correlations in Figure 1 we corrected the ISO photometry by determining the linear relation in log-log space between "raw ISO" (F_ν^{raw})and the Plets & Vynckier values:

$$\log_{10}(F_\nu) = A \times \log_{10}(F_\nu^{raw}) + B \tag{4}$$

For the fitting of the linear relation we excluded 9 sources that are clearly outside the tight correlation. The sources are listed in Table 3. Several sources are just too far at the low end of the flux range and were excluded to avoid a bias towards these values in the fitting procedure which gives all targets equal weight. The star HD 207129 has an unreliable ISO value, probably due to e prominent glitch. For the remaining targets in Table 3, the measured fluxes (both ISO and IRAS) are far from the photospheric flux predictions and were therefore excluded.

HD	$F_\nu(25\ \mu m)$ IRAS (Jy)	$F_\nu(25\ \mu m)$ P&V (mJy)	$F_\nu(25\ \mu m)$ ISO (mJy)
10700	1.54	1430	1034±22
13709	0.11	51	95±32
20766	0.20	182	96±22
38678	0.83	337	734±39
39060	6.29	305	4590±160
112758	NA	37	94±45
114762	NA	28	41±29
172167	8.08	6610	6280±230
207129	0.14	162	294±33

Table 3: *Stars which have been excluded for fitting, the IRAS and ISO fluxes have been colour corrected.*

Based on the least squares first order polynomial fitting we find the following correction:

$$F_\nu(25\,\mu m) = 1.0331\,[F_\nu^{raw}(25\,\mu m)]^{1.0948}\ . \tag{5}$$

The correction should be applied before colour correcting the ISO data. Assuming that the flux deviation is caused at the signal level, it is possible to transform Eqn. 5 to the 20 μm filter taking into account the different throughputs of the 25 and 20 μm bands:

$$F_\nu(20\,\mu m) = 1.0553\,[F_\nu^{raw}(20\,\mu m)]^{1.0948}\ . \tag{6}$$

Which is based on the fact that for identical signals and detector responsivity $F_{20}/F_{25} = 1.25159$. We corrected all 25 μm ISO fluxes, the resulting correlation of ISO flux versus the predicted values are presented in Figure 2. For comparison we also present the IRAS correlation in the same figure. Both diagrams exhibit the same scatter, ISO detected sources below 120 mJy, the detection limit of the IFSC.

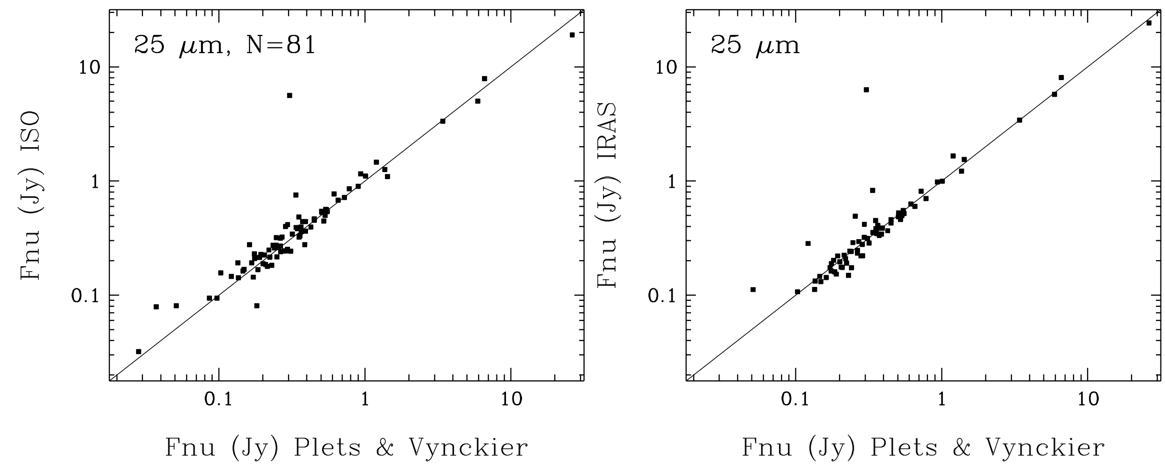

Figure 2: *The final ISO fluxes (left panel) and IRAS fluxes (right panel) plotted as a function of the values predicted according to Eqn. 1. For better comparison the error bars for the ISO data were omitted.*

5 Comparison of processing methods

To test the quality of the processing method described in this report, we have processed in PIA 8.1 a number of calibration stars according to the following methods:
1. OLP 8 processing,
2. OLP 8 processing, using default responsivities,
3. as described in Sections 3 and 4.

HR	TDT	Mode	filter μm	predicted F_ν mJy P&V	OLP mJy	default response mJy	This work mJy
7854	76901706	52″, tri	25	213	101±40	232	206±38
7854	76901816	79″, tri	25	213	195±85	350	327±22
7341	69900503	79″, rec	20	349	261±43	370	440±23
7341	69900503	79″, rec	25	239	189±30	268	272±15
7469	71300503	79″, rec	20	417	240±40	424	483±53
7469	71300503	79″, rec	25	285	167±32	295	260±8

Table 4: *Comparison of different processing methods. The ISO flux densities have been colour corrected, a colour correction of 1.01 is used for the 20 μm data. In all cases the plateau and reset interval times are the same as in Table 1 except for TDT76901706 where the plateau length and reset interval are 64 and 16 s, respectively. The "tri" and "rec" stand for triangular and rectangular chop mode*

A summary of the results is given in Table 4. The calibration stars were observed with the initial purpose to investigate the signal losses of chopped observations. The instrument timing settings

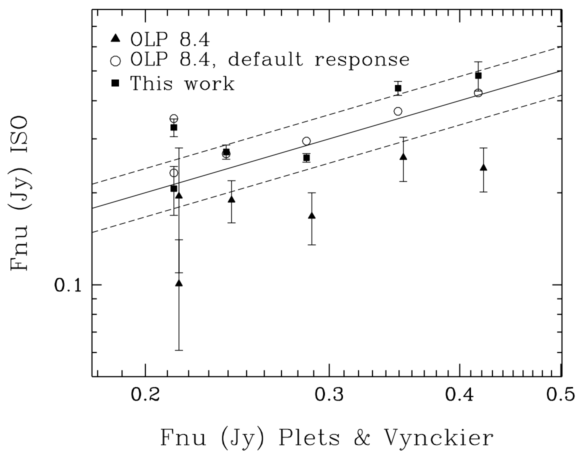

Figure 3: *Comparison of the three processing methods as a function of "predicted" flux. The solid line represents the identity and the dashed lines give ±20% deviation from the identity*

deviate from the HHABING sample for one case, for other cases the aperture and chopper mode were different. We also included calibration observations at 20 μm to test the applicability of the methods. To "predict" the flux at 20 μm we assume that Eqn. 1 is also valid at 20 μm and that $[20] = 0$ refer to 9.83 Jy. It should be noted that the measurements with the same TDT (cf Table 4) use the same responsivity.

The results are plotted in Figure 3. The comparison clearly shows that the photometric calibration method adopted for OLP8 yields large deviations from the predictions, and justifies the conclusion that these results cannot be scientifically valid. The other two methods follow the predicted fluxes, the OLP8 processing using default responsivities appears to give a better match to the predicted values.

We investigated only three stars of which two are not strictly applicable to Eqn. 1 since they are not main-sequence stars but giants (HR7854 is of type B6III and HR7341 is of type K1III). From the comparison presented here it is not clear which method is preferred: OLP 8 with default responsivity or the method described here. In any case, usage of the default responsivity yields fluxes that are a significant improvement over the present OLP method.

References

[1] Plets, H., Vynckier, C., 1999, A&A, 343

[2] Walker, R.G., Cohen, M., 1992, "An atlas of selected calibrated stellar spectra", NASA Contractor Report 177604, NAS2-13327.

A Some notes on the ISO versus IRAS calibration

When comparing the ISOPHOT data to the IRAS data one should be aware that the calibration of the two instruments is based on different absolute photometric references. Especially at the shorter IR wavelengths ($\lambda < 25$ μm) the ISO system is mainly based on stellar calibrators for which the fluxes are tied to the Walker and Cohen (1992) system. In this work we used 6.73 Jy for [25] = 0 mag which is based on the IRAS system (see IRAS Explanatory Supplement, Section VI-C), the corresponding Walker and Cohen value is 6.288 Jy, some 7% lower. Walker and Cohen (1992, page 23) have indicated that their system does not completely match the IRAS system. After analysis of the set of IRAS calibration stars as listed in the IPSC they found that the ratio between their zero magnitudes and those of IRAS are:

$$R(12, 25, 60, 100) = (0.978, 0.936, 0.921, 0.896) \tag{7}$$

Consequently, if we use "pure" Walker and Cohen calibration at 25 μm, our flux values would systematically be about 6% *lower* than the IRAS values. It is not clear how the ISOPHOT calibration fits in detail to the Walker and Cohen system since also the asteroids and planets are used. On the other hand, it is also not clear how the calibration of the IFSC compares to the IPSC at the low flux end ($F_\nu(25\,\mu m) < 300$ mJy) where the IPSC becomes incomplete.

The semi-empirical relation described in Eqn. 1 is based on the IPSC calibration. In our analysis we used the IRAS zero magnitudes to predict the 25 μm fluxes and to be able to make a direct comparison with the IRAS flux densities (cf Figure 1). However, also our derived corrections (Eqn. 5 and 6) are tied to the IRAS calibration and can generate an overestimate of the flux by 6% when comparing to observations in the other ISOPHOT filters.