ABSOLUTE SURFACE BRIGHTNESS PHOTOMETRY WITH ISOPHOT

P. Héraudeau[1], **P. Ábrahám**[1,2], **U. Klaas**[1] **and C. del Burgo**[1]

[1]Max-Planck Institut für Astronomie, Königstuhl 17, D-69117 Heidelberg
[2]Konkoly observatory of the Hungarian Academy of Sciences, P.O.Box 67, H-1525 Budapest, Hungary

ABSTRACT

The cold ISO telescope has allowed absolute sky brightness measurements to be carried out, making it possible to contribute to studies of the zodiacal light and the extragalactic background light. In this paper we discuss the evaluation scheme of such measurements performed with ISOPHOT, with special emphasis on the determination of the photometric zero point. After reviewing the current knowledge on the related calibration aspects, such as dark signal, bypassing sky light and correction for non-standard apertures of PHT-P, we define the remaining open calibration issues, and make some comments on the final expected photometric accuracy.

Key words: Instrumentation: photometers– Space vehicles: instruments–Techniques: photometry–Infrared: general.

1. INTRODUCTION

In this paper we present a short overview of methods of obtaining absolute photometry with the PHT-C cameras and PHT-P photometer of ISOPHOT, the photo-polarimeter on-board ISO (Lemke et al. 1996). For a more detailed presentation of the ISOPHOT calibration strategy we refer the reader to Klaas et al. (2003). Several calibration measurements could be included in the ISOPHOT absolute photometry sequence to correct for instrumental effects and obtain calibrated scientific data (see Laureijs et al. 2000 for details). A full sequence consisted of the following steps:

- dark signal measurement
- bypassing sky light measurement (measured looking at the FCS without any heating power, i.e. cold FCS)
- on-sky measurement in the filter required by the user
- Faint Calibration Source (FCS) measurement in the same filter for assessment of the actual detector responsivity.

Figure 1 shows an example of a sequence with these 4 types of measurement (P05 AOT) for PHT-P2. However, while all observations contained at least one heated FCS measurement, dark signal and cold FCS measurements were only performed within some specific observing programmes and as part of the general calibration assessment. Therefore the available dark and cold FCS databases have to be used to derive a correction for the entire mission (see Sections 2 and 3).

In the following sections we first describe some of the instrumental effects which have to be corrected, for example dark signal (Section 2), bypassing sky light (Section 3), correction for non-standard apertures of PHT-P (Section 4). The calibration strategy based on the stability of the FCS is addressed in Section 5. We then briefly review the main steps of the data analysis necessary to derive the scientific signal in Section 6, while footprints and solid angles used to derive fluxes and surface brightnesses are discussed in Section 7. Finally, we summarise still open questions on the calibration and give expected accuracies from a systematic comparison with the COBE/DIRBE data.

We do not address straylight issues in this paper, as it is extensively presented in Lemke et al. (2003).

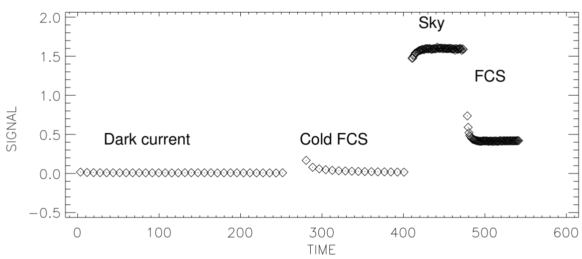

Figure 1. Example of a sequence of measurements as a function of time performed with the PHT-P2 detector at $25 \mu m$ in the absolute photometry mode (AOT P05). The sequence consists of a dark signal and a cold FCS measurements, followed by the on-sky integration and the heated FCS measurement.

2. DARK SIGNAL

An accurate estimate of the dark signal for each detector pixel is required in order to have a good zero point in the calibration. Moreover, the time dependence must be available, so that every observation can be properly corrected, even if no dedicated measurement has been performed. Dark signal tables for each detector-pixel combination have been derived from dedicated in-flight measurements. The dark signal is subtracted for each detector pixel as a function of orbital position. Recently, all dark signal measurements of the ISOPHOT detectors were re-analysed (see del Burgo et al. 2003). Dark signals exhibit significant variations along the orbit for the C200 and PHT-P2 detectors while they are almost constant for C100,

Proceedings of the Conference "The Calibration Legacy of the ISO Mission", VilSpa, Spain, February 2001
ESA SP-481, 2003, eds. L. Metcalfe, A. Salama, S. B. Peschke & M. F. Kessler

PHT-P1 and PHT-P3. The new results only slightly differ from the old ones, except for the C100 detector where the new values are significantly below the old ones. One has to keep in mind that the uncertainties on the average orbit-dependent dark signal significantly contribute to the total error budget for very faint measurements.

3. BYPASSING SKY LIGHT

The FCS signal for determination of the actual detector responsivity is obtained by deflecting the focal plane chopper outside the sky field-of-view to one of the FCS positions. In-orbit measurements have shown that the measured FCS signal not only contains the FCS proper signal but also a contribution from bypassing sky light entering the instrument, since no cold shutter was in place during these internal reference measurements. Therefore both the dark and bypassing light signals have to be removed from the FCS signal before deriving the responsivities to calibrate the target signal. Bypassing sky light into the FCS beam is typically 2-3 times higher than the dark signal. For the C-detectors we assessed the bypassing sky light contribution to the FCS signal from the complete calibration database. Figure 2 shows the correlation of the measured signal versus the corresponding sky background surface brightness obtained from DIRBE for one of the C200 camera pixels. The relationship with the corresponding background signals measured with ISOPHOT is under investigation (del Burgo et al. 2003). Preliminary results give, for the bypassing sky light, a level of 5 to 8% of the local background contribution for the C100 and C200 arrays. For the PHT-P detectors, the contribution is smaller, and negligible in the case of PHT-P3 (see Cornwall 1997).

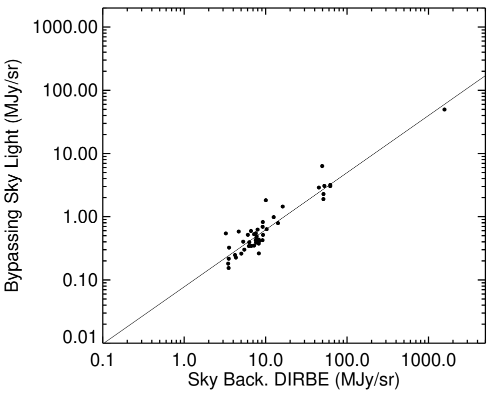

Figure 2. Bypassing sky light for pixel 4 of C200 at $135\mu m$ versus sky background surface brightness measured by DIRBE.

4. NON-STANDARD APERTURES

An additional correction has to be made for the majority of apertures of the PHT-P detectors. For a given filter, the FCS calibration is determined from observations always taken with the same standard aperture. Moreover, the calibration was established with perfect point-sources (stars, asteroids and planets). But many observational programmes were performed in non-standard apertures and the targets were not always point-like. The applicability of the calibration to any given aperture was investigated by Müller (2000c) for 3 filters, for which enough calibration measurements were available, i.e. P1 $12\mu m$, P2 $25\mu m$ and P3 $60\mu m$ (see also Müller 2000a & 2000b). The signals derived from aperture sequences on a bright sky background, and also on the FCS, do not simply scale with the aperture area because the aperture profiles are not flat. This complicates the flux determination of off-centre sources and sky background from measurements performed with non-standard apertures. How to correct for this effect is still an open question but the systematic comparison of FCS and sky background measurements in various apertures as well as multi-aperture observations may help to establish this correction. The comparison of surface brightnesses from ISOPHOT measurements with COBE/DIRBE may also help to establish these correction factors (see Héraudeau et al. 2003).

5. STABILITY OF THE FCS

To correct for variations of detector responsivities, all observations included reference measurements against stable internal sources. The Faint Calibration Sources (FCS) have been absolutely calibrated in-orbit against well known celestial standards(stars, asteroids and planets). These point sources constitute the best known infrared fluxes in the sky. Default responsivities depending on the orbital position were derived to calibrate observations where the FCS measurements failed or are of insufficient quality due to saturation or glitches or used heating powers outside the calibrated range.

The photometric system stability depends mainly on the stability of the FCS and the reproducibility of the detector transient behaviour. Schulz et al. (1999) assessed the accuracy of the instrument in terms of reproducibility and consistency of the photometric results. The comparison of derived FCS power curves with measured calibration data gives standard deviations of typically 15% and 5-15% for the low and high part of the fluxes respectively (PHT-P3 having higher values; see Table 3 in Schulz et al. (1999) for details). For multi-filter measurements the uncertainty of the filter-to-filter calibration matrices (2 to 9%) has to be included into the overall error budget.

6. SIGNAL DERIVATION

Signal derivation is probably the most crucial step in the data analysis and the calibration accuracy is strongly linked to its quality. This includes mainly: deglitching, ramp linearisation, ramp fitting, reset-interval correction, transient recognition and signal linearisation.

6.1. The reset-interval correction

To achieve consistency among signals obtained with a different reset interval setting, all signals are corrected as if they were measured with a common reset-interval of $t_{reset} = 1/4s$ (see Braun 1997). This correction is independent of the inband power and only depends on the reset-interval used during the measurement. It changes both the zero point of the signals and scales the signals. The correction is most critical on the faint signal level, because the calibration measurements used to establish this correction needed a reasonable signal to switch through all reset interval combinations. The correction factors are derived from linear regression fitting of the relations for pairs of reset intervals. The offset term might have uncertainties as high as 100%. This is crucial for signals close to dark signal which are dominated by this term and the recent analysis of dark signals indicates an open question (see del Burgo et al. 2003).

6.2. Transient recognition

The far infrared detectors suffer from transient effects, i.e. their signal output does not instantaneously reflect the final value. The transient behaviour depends on the level of the incoming flux, the flux step and flux history. It can be directed upwards or downwards as illustrated in Figure 1. Several methods exist to derive signals which are independent of measurement time. For example, a "stability check" is conducted in the PHT Interactive Analysis (PIA) software (Gabriel et al. 1997). One can also fit transients with empirical functions usually constructed from exponentials. A proper transient correction is important to derive both the signal from on-sky measurements and also the responsivities of each detector-pixel from the FCS measurements. Thus, uncertainties about the final calibrated values are directly proportional to the ones on signal derivation.

6.3. Signal linearisation

The responsivity of the ISOPHOT detectors varies in time due to cosmic radiation and flux history, but it also depends on the total infrared flux that falls onto the detector. Signal linearisation tables were thus determined using the FCS calibration data. At the faint level the proper correction factors still need some fine tuning and relatively large residual uncertainties may still be present.

7. FOOTPRINTS AND EFFECTIVE SOLID ANGLES

A good knowledge of the detector footprints is necessary to perform:

- accurate flux determination of sources and surface brightnesses
- accurate flux determination of off-centred sources in the case of the PHT-P detectors
- image reconstruction
- determination of faint extensions around bright sources (e.g. with multi-aperture measurements).

The absolute flux calibration of the ISOPHOT-C arrays has been obtained by comparing the FCS signal for a given FCS heating power with the signal of a calibration point source centred on each individual pixel. The fraction of the Point Spread Function falling on a C100 or C200 pixel has been determined per filter for a number of typical pointing configurations (Laureijs 1999). Moreover, dedicated observations were also carried out to measure the footprints of the C100 detector array pixels at 60 and $105\mu m$ and of the C200 array at 120 and $200\mu m$ (Héraudeau et al. 1997 and Surace et al. 1997). Comparison between model predictions and the measured footprints (Herbstmeier 1998 & Klaas et al. in preparation) shows reasonably good agreement. The theoretical model was therefore used for filters without any dedicated footprint measurement. The effective solid angles derived from the beam profile for each filter or aperture are used to determine the sky surface brightness from the flux density per pixel. Although a single value is used per filter for all pixels of an array, as for the C-detectors, differences between the real pixels may be expected and are under investigation (Klaas et al. in preparation).

8. OPEN ISSUES AND EXPECTED ACCURACIES

Significant progress has been achieved for the ISOPHOT calibration accuracy. The version 10 of the offline pipeline provided improved calibration files. However, with regard to absolute surface brightness calibration, the following points are still under investigation and the results of these studies will be presented in forthcoming papers:

- correction for dark signal after the re-analysis of these measurements (see del Burgo et al. 2003) and improvement of the reset-interval correction
- derivation of a correction for the contribution from bypassing sky light entering the instrument during internal reference measurements
- determination of accurate solid angles for all apertures of the P1/P2 detectors
- determination of the discrepancy of true solid angle for each C100/C200 pixel from the theoretical one.

Despite remaining open points in the calibration, we performed a systematic comparison of the ISOPHOT and DIRBE surface brightnesses (see Héraudeau et al. 2003). The data analysis was performed using PIA V7.3 (i.e. without signal linearisation) and will be repeated with the calibration of the legacy archive (Héraudeau et al., in preparation). Even though some discrepancies exist between the different sets of observations (absolute photometry, mini maps, big maps) we used in the comparison, we can already draw the following preliminary conclusions:

- there is no systematic zero point difference between ISOPHOT and DIRBE for any of the detectors. The C100/C200 detectors show a mean zero point slightly above zero (about 1 MJy/sr)
- the statistical uncertainties from the relationship between the 2 photometric systems show that for ISOPHOT one can achieve absolute accuracies in surface brightness better than 3% at $\lambda \leq 25\mu$m and 5–10% at $\lambda > 25\mu$m.

Finally, the latest improvements in the calibration will be applied to faint sky background measurements, and results concerning the study of the extragalactic background light will be published in a forthcoming paper (del Burgo et al., in preparation).

ACKNOWLEDGEMENTS

C. del Burgo acknowledges the support by the EC TMR Network POE. The ISOPHOT Data Centre at MPIA is supported by Deutsches Zentrum für Luft-und Raumfahrt e.V. (DLR) with funds of Bundesministerium für Bildung und Forschung, grant no. 50 QI 9801 3. The authors take sole responsibility for this report.

REFERENCES

del Burgo, C., Ábrahám, P., Klaas, U. & Héraudeau, Ph., 2003, this volume

Braun, M., 1997, "CRE signal dependence on reset interval length", Internal report

Cornwall, J., "Report on FCS straylight investigation", 1997, Internal Report

Gabriel, C., Acosta-Pulido, J., Heinrichsen, I., Skaley, D., Morris, H., Tai, W.-M.. In: Hunt, G. & Payne, H.E. (Eds.) Proceedings of the ADASS VI conference, ASP Conf.Ser. 125, 1997, 108

Héraudeau, Ph., Surace, C., Herbstmeier, U., 1997, "Beam profiles measurement of the ISOPHOT C100", Internal report

Héraudeau, Ph., Ábrahám, P., del Burgo, C., Klaas, U. and Kiss, C., 2003, this volume

Herbstmeier, U., 1998, "ISOPHOT footprints: Comparison between modelled and measured footprints- the derived parameters", Internal report.

Klaas, U. et al., 2003, this volume

Laureijs, R.J., Klaas, U., Richards, P.L., Schulz, B., and Ábrahám, P. in: "The ISO Handbook", Vol V, "PHT- The Imaging Photo-Polarimeter", SAI/99-069/Dc,Version 1.1, 2000

Laureijs, R.J., "Point spread function fractions related to the ISOPHOT C100 and C200 arrays", 1999, Internal report. http://www.iso.vilspa.esa.es/users/expl_lib/PHT/c200fpsf02.ps.gz

Lemke, D., Klaas, U., Abolins, J. et al., 1996, A&A, 315, L64

Lemke, D., Kranz, T., Klaas, U. et al., 2003, this volume

Müller, T. G., 2000a, "ISOPHOT aperture profiles and background measurements", in: "ISO beyond point sources", ESA SP-455, p. 33

Müller, T. G., 2000b, "ISOPHOT aperture sequences on point- and extended sources", in: "ISO beyond point sources", ESA SP-455, p. 41

Müller, T. G., "PHT apertures and absolute photometry", 2000c, Internal report. http://www.iso.vilspa.esa.es/users/expl_lib/PHT/TM_aperture.ps.gz

Schulz, B., Huth, S., Kinkel, U. et al., 1999, "ISOPHOT - Photometric Calibration of Point Sources". In: Cox, P. & Kessler, M.F. (Eds.) Proceedings of conference "The Universe as seen by ISO",Paris 1998, ESA SP-427, 89-94

Surace, C., Héraudeau, Ph. & Herbstmeier, U., 1997, "Report on beam profiles analysis and straylight measurements from NGC7027 observations"