ISOPHOT Calibration Accuracies

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1 Introduction

1.1 Short Instrument Overview

The ISO Photo-polarimeter ISOPHOT spans the full wavelength range accessible to ISO, from 2.5 out to 240 μm. This coverage is achieved with various subinstruments whose wavelength range is given in the subsequent Table 1. For more details we refer to the ISOPHOT Handbook.

Table 1: Covered wavelength range and aperture sizes of ISOPHOT subinstruments. The system bandwidth gives the shortest and longest wavelength cut-offs of rectangular bandpass equivalents to the true bandpasses of the detector subsystem. The wavelength range gives the minimum and maximum photometric reference wavelengths of the filters used in combination with the detector. PHT–S is a spectrometer with a resolution of $\lambda/\Delta\lambda \simeq 90$, in this case the wavelength range gives the spectral coverage. PHOT–P is an aperture photometer for which the column "aperture size" displays a typical range of diameters of concrete apertures used in combination with the individual detectors (out of 13 ranging from 5 to 180 arcsec diameter). PHT–C is an array camera for which the first number in the column "aperture size" denotes the pixel size, the second one the array size.

subinstrument	**detector**	**dimension**	**system bandwidth** [μm]	**wavelength range** [μm]	**aperture size** [arcsec]
PHT–P	P1	1	3 – 17	3.3 – 15	5 – 180
	P2	1	15 – 29	20 – 25	23 – 180
	P3	1	40 – 130	60 – 100	52 – 180
PHT–C	C100	3x3	40 – 130	60 – 105	43.5 / 138
	C200	2x2	100 – 240	120 – 200	89.4 / 182
PHT–S	SS	1x64		2.5 – 4.8	24
	SL	1x64		5.8 – 11.8	24

1.2 Completeness of Calibration Accuracy Assessment and Scientific Validation of Observing Modes

This document provides an overview of global calibration accuracies for the ISOPHOT instrument. Version 4.0 reflects the calibration status achieved with OLP V9.0 and CalG V6.0, while the previous Versions 3.0 and 2.0 referred to OLP V8.4 / CalG V5.4 and OLP V7.0 / CalG V4.0, respectively. It will be updated whenever revised or additional information will be available. This can be expected in the context of an upgraded OLP version which will involve a scientific validation of the products. The scientific validation of a specific observing mode comprises the end-to-end evaluation of a set of test cases, including the comparison with reference photometry (high quality photometry from other observatories, standard star models, etc.). This allows to establish the global calibration accuracies.

This version of the document contains information on

1) the photometric accuracies for point sources (staring and chopped mode)
2) the photometric accuracy for extended sources (staring mode)
3) the photometric accuracy for raster maps (flat-field, flux conservation, point source photometry)
4) spectrophotometric accuracies for point (staring and chopped mode) and extended sources
5) polarimetric accuracy (including instrumental polarisation)
6) accuracy of ISOPHOT-S wavelength calibration

For an individual description of the well-characterised instrumental effects, please refer to the ISOPHOT Handbook, for an overview of the impact of individual calibration steps on the accuracy, please refer to the ISOPHOT Error Budgets Document (note that currently only the calibration steps up to SPD level are described).

The two polarisation modes PHT50 (PHT–P) and PHT51 (PHT–C) are not end-to-end processed by the OLP pipeline. Please contact the ISOPHOT Data Centre in Heidelberg or the ISO Data Centre in Villafranca for details of the data reduction and calibration. For an overview of the processing, please refer to Proceedings of the Workshop on ISO Polarisation Observations.

Currently there are instrumental effects of ISOPHOT which are not yet fully assessed and characterised. This means that

1) the OLP processing of an invidual observation submode is not yet declared scientifically valid and no global calibration accuracies can be provided. An overview of the ISOPHOT Astronomical Observation Template (AOT) validation status is given in Table 2. This table also lists planned upgrades for both validated and unvalidated modes as well as the OLP version for which the upgrade is foreseen or planned.
2) under certain circumstances, usage of extraordinary set-ups in a validated mode may have a significant impact on the final calibration accuracy of a given measurement. Please consult the
   - Caveat chapter of the ISOPHOT Handbook or the
   - Caveat chapter of the Report on the PHT Scientific Validation for OLP Version 9.0

   to which degree a certain observational mode could be affected. The Scientific Validation Report also provides many examples of OLP results for the different product types.

It is a goal of the ISO Post Operations Phase to achieve a high completeness of the scientific validation and characterization status of the OLP processing of all ISOPHOT AOT submodes. Items foreseen for the last OLP upgrade, OLP V10.0, are listed in Table 2. OLP V10.0 will be available in spring 2001 and will be used to generate the ISO legacy archive.

Table 2: Status of Scientific Validation of ISOPHOT OLP AOT Processing, July 2000. AOTs PHT03 – PHT19 are photometric modes with subinstrument PHT–P, AOTs PHT22 – PHT39 are photometric modes with subinstrument PHT–C, AOT PHT40 is the spectroscopic mode of PHT–S. AOTs PHT50 and PHT51 are the two polarimetric modes with PHT–P and PHT–C, respectively. They are processed by the OLP pipeline only to raw data level. For a detailed definition of the individual AOTs, please refer to the ISOPHOT Handbook.

AOT	**observation type**	**submode**	**scientifically valid since**	**next upgrades**	**foreseen in OLP Vx.y**
PHT03 (P)	multi-filter photometry	staring point source	V6	non-lin R	10.0
		staring ext. source	no	non-lin R	10.0
				beam	10.0
		nodding	V6	non-lin R	10.0
		chopped point source	no	chop & non-lin R	10.0
		raster map	no	map cal	10.0
PHT04 (P)	multi-aperture photometry	staring point source	no	non-lin R	10.0
				beam	10.0
		staring ext. source	no	non-lin R	10.0
				beam	10.0
		chopped point source	no	chop & non-lin R	10.0
				beam	10.0
PHT05 (P)	absolute photometry	staring point source	V6	non-lin R	10.0
		staring ext. source	no	non-lin R	10.0
				beam	10.0
PHT17 (P) 18 , 19	sparse map photometry	staring point source	V6	non-lin R	10.0
		staring ext. source	no	non-lin R	10.0
				beam	10.0
PHT22 (C)	multi-filter photometry	staring point source	V7	non-lin R	10.0
		staring ext. source	V7	non-lin R	10.0
		nodding	V7	non-lin R	10.0
		chopped point source	no	chop & non-lin R	10.0
		raster map	V8.4	flat-field	10.0
PHT25 (C)	absolute photometry	staring point source	V7	non-lin R	10.0
		staring ext. source	V7	non-lin R	10.0
PHT32 (C)	oversampled mapping	chopped mapping	no	map cal	10.0
PHT37 (C) 38 , 39	sparse map photometry	staring point source	V7	non-lin R	10.0
		staring ext. source	V7	non-lin R	10.0
PHT40 (S)	spectroscopy	staring point source	V5		
		staring ext. source	V6		
		chopped point source	V6		
		raster map	V6		
PHT50 (P)	aperture polarimetry	staring point & ext. source	V7	interactive processing & special FORTRAN routine	
PHT51 (C)	array polarimetry	staring point & ext. source	V7	interactive processing & special FORTRAN routine	
		raster	V7		

meaning of calibration upgrades:

non-lin R : correction for non-linearity of detector responsivity
for measurement sets covering a large flux range (further refinement of OLP 9.0 upgrade)
beam : characterization of beam profile effects
chop : chopped photometry corrections
map cal : surface brightness calibration in maps
flat-field : refined flat-field corrections

2 Photometric Accuracies

Three different kinds of photometric accuracies are provided in this document:

- **absolute accuracy** is a measure of the uncertainty of the absolute flux level of any source measured with ISOPHOT w.r.t. well known independently and absolutely calibrated flux standards, either black body standards or standard stars (Vega, Sirius) directly calibrated against black body standards. An absolute flux measurement with ISOPHOT has to involve a measurement against the internal reference source (FCS) in the same filter, because the latter one was calibrated against celestial standards.
- **relative multi-filter accuracy** is a measure of the uncertainty of a spectral energy distribution derived from an ISOPHOT multi-filter measurement with a measurement against the internal reference source in only 1 filter, i.e. the measurements in the other filters have to be tied to the absolute measurement by relative scaling factors. When establishing the relative multi-filter accuracies the systematic offset due to the absolute accuracy term had been subtracted. Therefore, absolute and relative multi-filter accuracy have to be added up for the appropriate measurements in order to derive the total photometric accuracy.
  For PHT-S the term multi-filter accuracy gives the accuracy of the relative spectral shape between different wavelength ranges (covered by groups of $\simeq 20$ pixels).
- **relative flux reproducibility** is a measure how well a many times repeated observation of the same non-variable source gives the same flux.

Table 3 gives a summary overview of the currently achieved photometric accuracies with ISOPHOT. These values have been established as global values from an end-to-end processing involving all likely uncertainty sources. They have been derived during the scientific validation of the OLP V9.0 (cf. Report on the PHT Scientific Validation for OLP Version 9.0).

For the accuracy assessment measurements of sources with known fluxes or calibration standards were used. As far as possible data sets independent of the ones used for establishment of the calibration curves of the internal calibrators (e.g. special OLP validation test cases) were included in order not to restrict the assessment to a self-consistency check of the calibration procedure. This was not always possible, but due to the redundancy of calibration sources per flux decade, inclusion of a single measurement does not mean a circular argument in deriving the calibration accuracies. The names of the sources used for the verification measurements are listed in the special tables, most of them are ISOPHOT calibration standards. Due to limitations, both in the number of test cases processed for scientific validation and in availability of suitable test cases, not all observing modes could be addressed. In case of several examples covering the same flux range and showing somewhat different accuracy numbers the more conservative one should be used.

The calibration curves of the internal calibration sources (FCS) on celestial standards were established flux range by flux range using different sets of standards with appropriate brightness. This takes into account possible non-linearities of the ISOPHOT detector/read–out system. Therefore, we checked the calibration accuracy per flux range as far as possible.

The reproducibility accuracies have been derived from special calibration monitoring programs repeating the measurements 15 to 25 times during a period of more than 1 year and with time intervals between one and six weeks.

Tables 4, 5, 6, 7, 10, 11, and 12 in the subsequent subsections give more details on the calibration accuracy assessment, providing the AOT submode, a more detailed flux range specification, and the names of the flux standards used for the assessment.

Goals for photometric calibration improvements until the end of the ISO Post Operational Phase are provided in the corresponding subsections.

Table 3: ISOPHOT Photometric Calibration Accuracy Overview for OLP 9.0. For the wavelength range of the detector system, please refer to Table 1. The table has been extended to distinguish between staring (star) and chopped (chop) observations. In the case of PHT–S (SS & SL) the column "multi-filter accuracy" gives the accuracy of the relative spectral shape. Hyphens indicate that measurements of the requested type to establish the calibration figure either have not yet been identified (at least for certain flux ranges) or are not available.

detector	**source type** point / extended	**source brightness**	**typical on-source integration** [s]	**absolute accuracy** [%]	**reproducibility 1 σ of 20 samples** [%]	**multi-filter accuracy** [%]
P1	p, star	50 – 6000 Jy	32	< 10	5	< 20
P1	p, star	0.1 – 50 Jy	≤ 256	40	10	–
P2	p, star	10 – 200 Jy	32	< 10	2	5
P2	p, star	0.5 – 10 Jy	≤ 256	< 15	12	–
P3	p, star	0.5 – 25 Jy	32	10	7	< 10
P3	p, star	< 0.5 Jy	≤ 256	20	7	–
C100	p, star	0.5 – 25 Jy	32	15	≥ 3	< 25
C100	p, star	0.05 – 0.5 Jy	≤ 256	$< 25^*$	20	–
C100	e, star	5 – 15 MJy sr^{-1}	32	25	10	20
C200	p, star	1 – 900 Jy	128	10	10	20
C200	p, star	0.2 – 1 Jy	≤ 256	$< 20^*$	10	–
C200	e, star	4 – 10 MJy sr^{-1}	64	20	6	20
SS	p, star	1 – 6000 Jy	256	< 10	TBD	< 20
SS	p, chop	0.5 – 500 Jy	1024	< 10	–	< 10
SS	e, star	30 – 3000 MJy sr^{-1}	256	< 10	TBD	< 20
SL	p, star	0.3 – 1500 Jy	256	< 10	TBD	< 20
SL	p, chop	0.2 – 200 Jy	1024	< 10	–	< 10
SL	e, star	5 – 10000 MJy sr^{-1}	256	< 10	TBD	< 20

* for mini-map photometry using PCAS products

2.1 Absolute and Relative Filter-to-filter Accuracies for Point Sources

2.1.1 Staring Mode Photometry

The final photometric accuracy depends on a proper background subtraction and colour correction. Therefore, we give in Table 4 the observing mode used for verification of the calibration accuracy. In particular for faint sources, the simpler observing modes (off–on) are much less accurate than the ones optimised for faint source observations (cf. General ISOPHOT observing strategies for faint sources).

Table 4: Absolute and relative (filter-to-filter) calibration accuracies per detector achieved for various flux ranges in multi-filter staring and nodding mode. Hyphens indicate that no test case was available. Bold values indicate a significant improvement w.r.t. OLP V8.4. For the wavelength range of the detector system, please refer to Table 1.

detector	**AOT mode**	**flux range** [Jy]	**abs. accuracy** [%]	**rel. accuracy** [%]	**standard**
P1	P03 off & on	300 – 6000	≤ 5	15	α Boo
P1	P03, P05 off & on	70 – 1250	10	25	γ Dra
P1	P03 off & on	50 – 1000	10	**5**	Sirius
P1	P05 off & on	50 – 1000	5	–	Sirius
P1	P05 off & on	35 – 600	$<$ **10**	–	α Ari
P1	P03 off & on	30 – 300	10	10	Vega
P1	P03 nodding	2	≤ 5	–	HR 5986
P1	P03 nodding	< 0.1	40	–	HD 172323
P2	P03 off & on	100 – 200	≤ 5	5	α Boo
P2	P03, P05 off & on	25 – 40	$<$ **5**	5	γ Dra
P2	P05 off & on	~ 25	**5**	–	Sirius
P2	P05 off & on	13 – 20	$\leq$ **10**	–	α Ari
P2	P03 nodding	0.5	≤ 10	–	HR 5986
P3	P03 off & on	10 - 25	5	10	α Boo
P3	P03 nodding	20	5	–	α Tau
P3	P03, P05 off & on	~ 5	**5**	–	γ Dra
P3	P03 nodding	1 - 2	10	–	HR 617
P3	P03 nodding	0.6	≤ 15	–	HR 7310
P3	P17/18/19 4 times	< 0.2	20	–	HR 5981
C100	P22 off & on	6 - 25	5	10	α Boo
C100	P22, P25 off & on	~ 5	20	25	γ Dra
C100	P22 nodding	~ 3.5	15	–	Sirius
C100	P22 nodding	0.2 - 0.6	40	–	HR 7310
C200	P25 off & on	500 - 900	10	–	Uranus
C200	P25 off & on	40 - 120	10	–	Ceres
C200	P22 off & on	2 - 5	10	**20**	α Boo
C200	P22 nodding	~ 0.5	10	–	γ Dra
C200	P25 off & on	~ 0.5	10	–	γ Dra

2.1.2 Chopped Mode Photometry

The processing of chopped photometry has been further improved in OLP V9.0. The most important outcome of the OLP 9.0 Scientific Validation was the verification of the chopped photometry reproducibility deduced from a set of monitoring measurements (the sample is smaller than for the staring mode monitoring, the sets consist of at most 6 measurements) for P1, P2, P3 and C100: it is better than 15 %. For the C200 sequence a strong trend in the resulting flux was found. This is related to the rotation of the chopping direction and hence the off-position w.r.t. the source due to the focal plane rotation with mission time (see Report on the PHT Scientific Validation for OLP Version 9.0 for more details). For some detectors and flux ranges already reasonable accuracies have been achieved as listed in Table 5, but only P1 photometry is so far within the goals for absolute accuracy.

Based on the full set of results per detector given in Table 5, chopped photometry with ISOPHOT-P and

-C can not be declared as scientifically valid because of too severe restrictions and caveats. These are:

1) Except for P1 and partially for C100 the general accuracy is not better than 40 - 50 %.

2) For P2 very often an overestimation of the expected flux value (+50 – +80 %) is observed, for P3 an underestimation (-40 – -70 %). (With OLP 9.0 a signal correction has been introduced for P2.)

3) For C200 no statistically meaningful assessment could be performed yet. This appears to be mainly caused by cirrus confusion.

Further improvements are being worked out for the OLP V10.0 (cf. Table 2).

Table 5: Absolute and relative (filter-to-filter) calibration accuracies per detector for chopped photometry achieved for various flux ranges in multi-filter mode with OLP V9.0. Bold values indicate improvements w.r.t. OLP V8.4. For the wavelength range of the detector system, please refer to Table 1.

detector	**AOT**	**flux range** [Jy]	**abs. accuracy** [%]	**rel. accuracy** [%]	**standard**
P1	P03	2 - 10	< 10	–	HR 6817
P1	P03	1 - 2.6	< **5**	80	BS 5062
P1	P03	2.2	< **10**	–	HR 5986
P1	P03	0.06	< **25**	–	HD 172323(6×)
P2	P03	0.2 - 6	in general fluxes 50 - 80 % too high		
P3	P03	7 - 19	20	–	HR 1457
P3	P03	0.15 - 1	in general fluxes 40 - 70 % too low		
C100	P22	1.5 - 2	< **25**	< **15**	HR 6705
C100	P22	0.2	< **30**	–	HR 7310(6×)
C100	P22	0.15	< **5**	–	HR 5981
C100	P22	0.08	< **70**	–	IRC+60228
C200	P22	2 - 5	40	60	HR 5340
C200	P22	< 1	strong cirrus contamination		

The goals for the improvement of the absolute and relative multi-filter photometry accuracy until the end of the ISO Post Operations Phase are the following:

- absolute accuracy (staring mode) bright sources: 10%
  ($f_\nu > 2$ Jy on intermediate background brightness, minimum on-source exposure time: 32 s)
- absolute accuracy (staring mode) faint sources: 20%
  ($f_\nu < 2$ Jy, S/N > 10, minimum on-source exposure time: 128 s)
- relative filter-to-filter accuracy: 10%
- absolute accuracy chopped modes: < 30%

2.2 Flux Reproducibility for Point Sources

The following Table 6 provides the flux reproducibility both for bright and faint sources. The bright source was measured in standard off-on mode, while the faint sources were measured in optimised faint source observing modes: telescope nodding for PHT–P and mini-map for PHT–C.
A new result from OLP 9.0 is the reproducibility of chopped photometry. The sets of monitoring measurements are much smaller and shorter mission periods are covered. Note that for P2 for technical reasons only 3 repetitions of the measurement could be achieved, so that the resulting reproducibility value is based on small statistics!
The flux reproducibility, a relative photometric accuracy, is not only determined by the detector stability, but also, in particular for wavelengths $\geq 100\mu$m by the structure of the sky background, since, due to the rotation of the focal plane on the sky, different background fields are seen at different times. This seems to be quite obvious for the C200 chopped measurement.

Table 6: 1 σ Flux Reproducibility per Detector for Bright and Faint Fluxes in staring mode and faint fluxes in chopped mode from Monitoring Programs. For the wavelength range of the detector system, please refer to Table 1.

detector	**target**	**flux** [Jy]	**standard deviation 1** σ [%]	**no. of meas.**
P1	NGC 6543	8	5	15
P1	HD 172323	0.085	10	23
P1 chopped	HD 172323	0.085	**14**	6
P2	NGC 6543	100	2	14
P2	HR 5986	0.67	12	15
P2 chopped	HR 5986	0.67	**5**	3!
P3	NGC 6543	100	7	15
P3	HR 7310	0.67	7	15
P3 chopped	HR 7310	0.67	**10**	6
C100	NGC 6543	50	3	15
C100	HR 7310	0.21	20	23
C100 chopped	HR 7310	0.21	**13**	6
C200	NGC 6543	15	10	15
C200	HR 6705	0.67	7	23
C200 chopped	HR 6705	0.67	–[a]	6

[a] strong systematic trend in resulting source flux (-80 % – +70 % w.r.t. nominal value) due to rotation of focal plane and chopping direction.

The goals for the improvement of the flux reproducibility until the end of the ISO Post Operations Phase are the following:

- staring mode photometry: $\simeq 10\,\%$ for both bright and faint sources.
- chopped mode photometry: $\sim 15\,\%$.
- In individual cases, this may not be achievable due to background fluctuations, in particular for chopped observations for which the chopper direction on the sky rotates with time and hence different off-positions are viewed.

2.3 Absolute and Relative Filter-to-Filter Accuracies for Extended Sources

With the establishment of wavelength dependent solid angles for the ISOPHOT-C detector pixels extended source photometry with the ISOPHOT-C arrays is scientifically validated since OLP V7.0. For establishment of both absolute and relative filter-to-filter accuracies a variety of off-source multi-filter background measurements has been compared with COBE/DIRBE annual map data. Note, that this cross-calibration compares 3 arcmin ISOPHOT beams with 0.7 deg COBE/DIRBE beams. Therefore, this comparison can only serve as a consistency check rather than a full accuracy assessment. During the scientific validation campaigns also the average integrated fluxes of a significant number of ISOPHOT maps have been compared with COBE/DIRBE photometry. By this program the covered flux range for establishment of the absolute accuracy of extended source photometry is significantly extended. Each map has its own set of FCS measurements, so that no relative filter-to-filter accuracy can be derived. It should be noted that the full area of most of the maps is still considerably smaller than the beam of one COBE/DIRBE pixel, so that beam size effects cannot be excluded in this assessment program either.

ISOPHOT-P extended source photometry has not yet been scientifically validated.

Table 7: Calibration Accuracy per Detector for Extended Sources for Various Flux Ranges. The calibration accuracy has been estimated from a consistency check with COBE/DIRBE photometry; due to the very different solid angles between the ISOPHOT observations, including most of the maps, and the COBE/DIRBE pixel no perfect agreement of the derived surface brightness values can be expected. The range for which both absolute and relative accuracies can be given is covered by multi-filter background measurements, while the larger range is covered by raster maps. For the wavelength range of the detector system, please refer to Table 1.

detector	**flux range** [MJy sr^{-1}]	**absolute accuracy** [%]	**relative accuracy** [%]	**standard**
C100	5 - 15	< 25	20	COBE/DIRBE
	5 - 400	< 25	–	COBE/DIRBE
C200	4 - 10	< 25	20	COBE/DIRBE
	3 - 600	< 25	–	COBE/DIRBE

The goals for the improvement of the extended source photometry accuracy until the end of the ISO Post Operations Phase are the following:

- absolute accuracy (staring mode) $< 20\%$.
- relative filter-to-filter accuracy $< 20\%$.
- for PHT-P the same quality as for PHT-C, independent of aperture size.

2.4 Photometric Accuracies for ISOPHOT-C Raster Maps

2.4.1 Flat-Field Accuracies

Table 8 lists the flat-field accuracies for PHT22 raster maps. The map flat-field accuracies are determined as the ratio of the standard deviation of the mean background surface brightness to the mean surface brightness value for a flat sky background field with no sources. The resulting flat-field accuracies depend on the ratio of the selected raster step sizes to the array size: There is a clear difference between maps without any pixel overlap (raster step size equal to the array size) and maps with pixel overlap (raster step size equal to half of the array size or less). The flat-field accuracies do not show any filter dependence. There is some trend that for the same set of raster parameters the flat-field accuracy improves with increasing absolute surface brightness. For C100 the flat-field accuracy can vary over the map area.

Maps with no pixel overlap and a flat-field accuracy between 10 and 20 % show a systematic repetition of a fixed pattern which can be explained as a flat-field residual of the array calibration repeated on each raster point. This limits the ability to detect faint sources and perform photometry on low sky background levels. For maps with pixel overlap, these array residuals average out, thereby reducing the standard deviation of the mean surface brightness and hence improving the map flat-field accuracy.

Table 8: Flat-field accuracies for ISOPHOT-C raster maps. For the wavelength range of the detector system, please refer to Table 1.

detector	**flat-field accuracy**	
	no pixel overlap (%)	**with pixel overlap** (%)
C100	8 - 20	4 - 12
C200	7 - 15	3 - 5

The goals for the improvement of the ISOPHOT-C flat-field accuracies of staring raster maps until the end of the ISO Post Operations Phase are the following:

- flat-field accuracy C100 maps $< 10\,\%$
- flat-field accuracy C200 maps $\simeq 5\,\%$

Limitations in the achievable map flat-field accuracy may be the natural sky background fluctuations by either cirrus knots or unresolved extragalactic sources.

2.4.2 Flux Conservation for Different Raster Step Sizes

In Table 9 we list the photometric results for point sources measured by two staring raster maps with different raster step size. Point source fluxes were derived by aperture photometry on-source and from the corners of the map (using the so-called "PGAI" products) for background determination. By appropriate scaling of the relative aperture areas the integral of the surface brightness was converted into a point source flux by applying the effective solid angles per array pixel area. The parameters of the raster map are given, too. For C200 it appears, as if the finer step size (always corresponding to half a pixel) gives a higher flux. The more accurate "PCAS" method as addressed in the subsequent section was not yet applied to this data set.

Table 9: Results from comparison of sets of P22 raster maps with different raster step size. Internal consistency is derived as the ratio of half of the difference in flux to the average flux for a pair of maps on the same target.

target name	**filter** (μm)	**raster parameters** **MxN**	**dMxdN** (arcsec)	**flux** (Jy)	**internal consistency** (%)
C100 detector					
BD+31 643	60	11 x 11	69 x 69	325.757	+1.0
BD+31 643	60	9 x 9	15 x 15	319.498	-1.0
HR 1457	100	9 x 3	69 x 69	5.464	-13.6
HR 1457	100	7 x 7	15 x 15	7.189	+13.6
C200 detector					
HR 2020	170	2 x 2	90 x 90	2.389	-14.3
HR 2020	170	3 x 3	46 x 46	3.187	+14.3
NGC 6543	170	4 x 4	92 x 92	20.884	-16.0
NGC 6543	170	10 x 10	46 x 46	28.817	+16.0
NGC 6503	170	4 x 4	92 x 92	42.828	-5.6
NGC 6503	170	10 x 10	46 x 46	47.932	+5.6
IC 1228	170	4 x 4	92 x 92	8.421	-25.7
IC 1228	170	10 x 10	46 x 46	14.236	+25.7

The internal consistency for a pair of maps is on average $\pm$ 15 % for both C100 and C200 maps. The conclusion is, that the OLP gridding algorithm is flux conserving within this range. The encountered differences in point source fluxes may be rather due to the achieved flat-field accuracies, the ability to measure a proper background level in small maps (contamination by central source), different background determination areas (cirrus confusion?), or residual uncertainties because of different instrumental set-ups (e.g. different reset interval length). This will be investigated in more detail.

The goals for the improvement of the flux independence from raster step size (flux conservation) for ISOPHOT-C staring raster maps until the end of the ISO Post Operations Phase are the following:

- point source flux conservation for C100 maps: $\pm$ 10 %.
- point source flux conservation for C200 maps: $\pm$ 10 %.

2.4.3 Accuracy of Point Source Photometry from Mini-maps

Table 10 gives an overview of absolute accuracy achieved for point source photometry from ISOPHOT-C raster maps, and here in essence from mini-maps, i.e. raster maps with a small map area. The quoted values are derived applying a special evaluation technique on the OLP "PCAS" (photometry per raster point) products (see Report on the PHT Scientific Validation for OLP Version 9.0 for more details). The parallel OLP products "PGAI" (maps) do not give the same accuracy when applying aperture photometry, as was done for the previous OLP Version. This is in particular true for faint sources (see the ISOPHOT Handbook for a definition of the data products "PCAS" and "PGAI"). The exact reason(s) for the less good photometric accuracy with PGAI products is currently unknown: Background fluxes were determined off-source in the edges of the map. The off-source positions might be contaminated by source flux (beam) or sky background fluctuations (cirrus). Also, the mapping algorithm may not be fully flux conserving, the currently achieved accuracies (see previous section) are not good enough to exclude this.

In order to achieve good accuracies for point source photometry from mini-maps it is strongly recommended to use the "PCAS" (photometry per raster position) products and apply the method as outlined in Report on the PHT Scientific Validation for OLP Version 9.0 in order to derive the point source fluxes.

Table 10: Absolute calibration accuracies achieved for various flux ranges in mini-map mode using the "PCAS" products. For the wavelength range of the detector system, please refer to Table 1.

detector	**flux range** [Jy]	**abs. accuracy** [%]	**standard**
C100	1 – 5	$<$ **5**	Sirius
C100	1.0	**5**	HD 187642
C100	0.2 – 0.3	$<$ **25**	HD 203280,HR 7310
C100	0.1 – 0.2	$<$ **10**	HD 12311, HR 6464
C100	0.05 – 0.1	**25**	HD 142373,HR 7469
			HD 185144,HD 1581
C200	500 – 900	**10**	Uranus
C200	40 – 120	$<$ **20**	Ceres
C200	0.6	$<$ **20**	γ Dra
C200	0.25 – 0.4	$<$ **15**	HR 1654

The goals for the improvement of the absolute photometric accuracy for ISOPHOT-C raster mini-maps until the end of the ISO Post Operations Phase are the following:

- absolute accuracy bright sources: 10%
  ($f_\nu > 2$ Jy on intermediate background brightness, minimum on-source exposure time: 32 s)
- absolute accuracy faint sources: 20%
  ($f_\nu < 2$ Jy, S/N > 10, minimum on-source exposure time: 128 s)

2.5 Spectrophotometric Accuracies for Point and Extended Sources

For PHT–S there is a direct conversion from the measured signal into flux density per wavelength range F_λ using spectral response functions established from sets of standard stars. The internal calibration reference sources are not used for the spectroscopic mode.

Since OLP V8.4 ISOPHOT-S chopped measurements are calibrated using a dedicated spectral response function derived from chopped measurements of standards plus a first order correction taking into account the signal transient behaviour dependence on the flux modulation between on and off chopper plateaux.

Since OLP V9.0 ISOPHOT-S staring mode observations are calibrated using the so-called dynamic spectral response function rather than a static one which cannot account for the signal transient behaviour of the individual ISOPHOT-S pixels for the wide range of fluxes. Two restrictions apply to the quoted accuracies:

- The calibration is valid within the temperature range 2.7 K < T < 3.1 K. For other temperatures the transient behaviour of the detector was different which is not covered by standard star measurements (this concerns e.g. measurements of the Performance Verification Phase, revolution < 79). The detector temperatures can be found in the raw data product "PSER" under the keywords PSERTEM1 and PSERTEM2. If the detector temperature was outside the above specified range, a warning is given in the header of the SPD products "PSSS" and "PSLS".
- A certain wavelength interval of a measurement may be in a flux range outside the range covered by the standard star library. In that case a warning message will be written to the SPD product header, too.

Table 11: Absolute and relative calibration accuracies for ISOPHOT-S spectrophotometry of point sources. Bold values indicate a significant improvement w.r.t. OLP V8.4. For the wavelength range of the detector system, please refer to Table 1.

detector	**AOT mode**	**flux range** [Jy]	**abs. accuracy** [%]	**rel. accuracy** [%]	**standard**
SS	P40 off & on	1 - 6000	< **10**	< **20**	BS 6056, BS 8679 Vega, Sirius α Boo,HR 7469 HR 7924, HR 8487
SS	P40 chopped	0.5 - 500	10	10	HD 23763,HR 7428 HD 23441 HR 6817, HR 6847
SL	P40 off & on	0.3 - 1500	< **10**	< **20**	BS 6056, BS 8679 Vega, Sirius α Boo,HR 7469 HR 7924, HR 8487
SL	P40 chopped	0.2 - 200	10	10	HD 23763,HR 7428 HD 23441 HR 6817, HR 6847

The ISOPHOT–S spectral response function for extended sources is derived from the one for point sources by applying correction factors for the non-flat beam profile. Hence, the uncertainties are in essence the same as for point sources, cf. Table 11. From OLP V8.4 onwards the correct solid angle is taken into account for the conversion of point source into extended source flux. It should be noted that background measurements are often not long enough exposed to achieve the quoted accuracies. Accuracies are then limited by the low signal-to-noise ratio.

The Zodiacal Light level is below the sensitivity limit of the SS detector (typically it is below 1 MJy sr^{-1} for the SS wavelength range). Therefore, COBE/DIRBE photometry could not be used as absolute reference for SS.

Table 12: ISOPHOT-S Calibration Accuracy for Extended Sources for Various Flux Ranges. For the Zodiacal Light these are only valid, if the exposure time is well adjusted (at least 1024 s). For the wavelength range of the detector system, please refer to Table 1.

detector	**flux range** [MJy sr^{-1}]	**absolute accuracy** [%]	**relative accuracy** [%]	**standard**
SS	30 – 3000	< 10	< 20	
SL	5 – 10000	< 10	< 20	COBE/DIRBE Zodi Light IRTS Galactic Disk

The goals for the improvement of the absolute and relative accuracy of spectrophotometry until the end of the ISO Post Operations Phase are the following:

- absolute accuracy PHT-S: < 10% (staring and chopped mode)
- relative accuracy PHT-S: < 10% (staring and chopped mode)

2.6 General Accuracy Limitations of OLP Processing

The previous sections provided an overview of the currently achievable average calibration accuracy using OLP products and the

- Caveat chapter of the ISOPHOT Handbook or the
- Caveat chapter of the Report on the PHT Scientific Validation for OLP Version 9.0

list the conditions of limitations due to yet incomplete corrections or calibrations.
There are, however, a few general accuracy limitations which should be taken into account when using ISOPHOT data products:

- **Accuracy Limitations of Celestial Standards**
  During the course of the ISO project considerable improvements for certain classes of standard sources have been achieved by new observational programmes and refined modelling. One specific case from which ISOPHOT calibration benefited a lot were the new thermophysical models of asteroids (cf. Asteroids as far-infrared photometric standards for ISOPHOT).
  On the other hand, it has to be noted that in the FIR range the stellar spectra a very often extrapolations of measured SEDs up to at most 35 μm. In particular for faint standard stars (< 1 Jy) not much is known about the true SED in the FIR. There are indications that some standard stars do not have good flux predictions. Those will have to be identified by cross-calibration with other stars.

- **Measurement beyond Sensitivity Limit**
  There are measurements in the data base which did not apply the most optimal observing strategy (cf. General ISOPHOT observing strategies for faint sources).
  Then even the best reduction does not achieve a satisfying result. Sensitivity limits and the corresponding minimum exposure times are given in the above cited reference documents, which have been derived from actual ISOPHOT observations.

- **Confusion by Sky Background Structure**
  In the FIR the sky shows a significant structure, mainly due to IR cirrus
  (see Small-scale structures in the far-infrared background for a discussion on actual data).
  This sky confusion limits the ability to adequately determine a sky background and to derive accurate fluxes of faint sources. It can be partly circumvented by an optimized observing strategy (cf. General ISOPHOT observing strategies for faint sources)
  and by determining the sky background as close as possible to the source.

- **Processing Items which Require User Interaction**
  There are several processing steps from the raw data to the final data products for which interactive processing can provide much better results due to visual inspection of the intermediate data products and optimizing the processing parameters or due to interactive input by the user with regard to special properties of the source (extension, structure, etc.). Areas for which improved results can be achieved are described in the next section.

2.7 Calibration Accuracies Achievable by Interactive Data Processing

As the OLP processing is automatic using default parameters for all processed measurements, it allows a homogeneous comparison of data sets of the same type of observing mode and hence to derive a set of commonly applicable uncertainties. Those are not subject to individual preferences of parameter settings during interactive processing and do not require the knowledge of special data reduction tricks. In general, standard OLP-type batch processing in ISOPHOT Interactive Analysis (PIA) provides identical accuracies.

The provision of a percentage number characterizing which improvements in calibration accuracy can be obtained by careful interactive processing is impossible, since so far no comprehensive systematic investigation was performed. Interactive Analysis uses the same set of general calibration files (cal-G) as OLP. The limitations due to photometric bias, e.g. the accuracy of the standard source fluxes, fully apply to interactive calibration, too. One can expect, however, to achieve a higher accuracy with IA for the following cases (cf. The ISOPHOT Interactive Analysis - PIA User's Manual):

1) detection of faint sources by refined deglitching and filtering.
   (cf. Deglitching methods by the ISOPHOT Interactive Analysis (PIA))
   a) PIA offers more refined deglitching methods, like the two-threshold algorithm.
   b) Individual ramps or signal sequences can be inspected by eye and can be deselected or corrected manually.
2) measurements with signal transients which do not stabilise during the measurement time, but which are long enough to perform a reasonable transient fit.
   (cf. Transient correction procedures of ISOPHOT measurements)
   a) PIA provides several transient correction tools. The most efficient ones are those for ISOPHOT-S based on the Fouks-Schubert model (full drift modelling and initial signal jump) and the empirical solution for FIR detectors (P3, C100, and C200) based on exponential functions.
   b) PIA allows to view the transient fitting and to accept or reject it.
3) flat-fielding of maps, depending on the sampling mode and the dynamic range.
   (cf. Map co-adding and simulation techniques with the ISOPHOT Interactive Analysis (PIA))
   a) In case of pixel overlap the redundancy information in the individual "pixel" maps can be used to do a flat-field correction using the sky measurement itself.
   b) For maps with large areas of flat sky background systematic flat-field residuals can be removed to a certain degree by determining the average and the relative flat-field residual pattern, even for maps with no pixel overlap.
   c) In case of a sufficient dynamic range in surface brightness a statistical flat-field method can be applied establishing the correlations of the surface brightness per pixel with regard to a reference pixel. This method allows also to correct for additive offsets among the pixels.
4) correction of non-linear signal drifts in maps.
   a) The time sequence of the signals can be interactively inspected and non-linear baseline fits be applied in order to flatten the map.
5) enhancement of map resolution.
   (cf. Map co-adding and simulation techniques with the ISOPHOT Interactive Analysis (PIA))
   a) Various map co-adding methods are offered.
   b) Deconvolution using the theoretical PHT–C footprint matrixes can be performed.
6) simulation of ISOPHOT mapping.
   (cf. Map co-adding and simulation techniques with the ISOPHOT Interactive Analysis (PIA))
   a) Detection and confusion limits for various instrument configurations and sky characteristics are determined.
   b) Photometry of sources dispersed in a map with given map parameters can be checked out and optimal reduction algorithms be selected.

The gain in final calibration accuracy with interactive analysis has to be determined, however, on a case by case basis.

3 Polarimetric Accuracies

Polarisation degree and angle are derived from the relative intensity differences measured with three different polariser settings at 0, 120 and 240 deg orientation w.r.t. the focal plane. A key parameter for the achievable polarimetric accuracies is the source-to-background contrast (Table 13). The background subtraction for each polariser setting has a significant impact on the S/N of the signal by the source alone, beside the relative stability of the detector during the measurement. The uncertainty values are derived from the reproducibility of the intensity per polariser setting in the different polariser cycles per measurement.

Instrumental polarisations are listed in Table 14. The uncertainties are a combination of the reproducibility of the intensity per measurement and the scatter in the set of measurements used to derive the instrumental polarisation.

Table 13: Polarimetric Accuracies for Various Source-to-background Contrasts

detector	**target**	**source flux** [Jy]	**pol. deg.** [%]	**source/ backg**	**S/N source**	**1 σ pol. error per cycle** [%]
P2, P_25 (79")	NGC 7538	400	~ 3	17	150	0.8
	6 Hebe	~ 30	< 2	6.3	120	0.8
	9 Metis	~ 20	< 2	2	130	0.7
	Crab	~ 7	8	0.7	60	1.7
C200, C_160	Crab	~ 15	8	1.4	150	1.4
	3C 279	2.5	6	1.8	70	1.6
	3C 279	2.5	6	0.4	15	7
	3C 279	2.5	23	0.25	25	5
	3C 279	2.5	6	0.25	12	10
	α Boo	2.6	0	0.025	2	60

Table 14: Instrumental Polarisation of ISOPHOT-P2 and ISOPHOT-C200

detector	**filter**	**inst. pol. degree** [%]	**uncertainty** [%]	**inst. pol. angle** [deg]	**uncertainty** [deg]
P2	P_25 (79")	3.0	0.2	-18.6	1.5
C200, pixel 1	C_160	3.6	0.6	-62.0	5.0
C200, pixel 2	C_160	7.8	0.7	+82.8	2.3
C200, pixel 3	C_160	4.0	0.6	-37.4	4.4
C200, pixel 4	C_160	4.6	0.7	+70.8	4.6

For the ISO Post Operations Phase no improvement of the quoted polarisation accuracies of individual sources is expected. The accuracy in the assesment of the instrumental polarisation may be slightly improved by the increase of the measurement data base used for its derivation.

4 Wavelength Calibration Accuracies of ISOPHOT–S

As ISOPHOT–S has fixed gratings, no uncertainties because of mechanical jitter are involved. The wavelength scale has been best described by second order polynomials fitted to the measured central positions of 7 to 9 unresolved lines per detector array. The wavelength calibration is more accurate for the centre of the array than for the edge; both accuracy values are listed in Table 15.

Table 15: Wavelength Calibration Accuracy for ISOPHOT–S

array	**range** [μm]	**accuracy array centre** [μm]	**accuracy array edge** [μm]
SS	2.5 - 4.9	0.0020	0.0044
SL	5.9 - 11.7	0.0035	0.0078

For the ISO Post Operations Phase no further improvement in the quoted PHT-S wavelength calibration accuracy is expected.

5 Reference Documents

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