ISOPHOT Calibration Accuracies

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Contents

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. PHT–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 5.0 reflects the calibration status achieved with OLP V10.0 and CalG V7.0, used to produce the ISO Legacy Archive, while the previous Versions 4.0, 3.0 and 2.0 referred to OLP V9.0 / CalG V6.0, OLP V8.4 / CalG V5.4 and OLP V7.0 / CalG V4.0, respectively. The document may still be updated during the ISO Active Archive Phase whenever revised or additional information will be available. This can be expected in the context of a bulk re-processing or user reduced data activity which will involve a kind of 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 or spectroscopy (high quality photometry or spectroscopy 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 and 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 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.
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 Scientific Validation of PHT OLP Version 10.0

   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.

Table 2: Scientific Validation of ISOPHOT OLP AOT Processing for the ISO Legacy Archive. The 11 AOTs have been divided into 28 submodes and the respective number of executed astronomical observations is given. 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. An observation in multi-filter and multi-aperture mode can comprise several measurements. The sparse map modules have been counted individually. OLP Versions 5 and 6 were released during the ISO mission, OLP Version 7 is the end-of-mission pipeline, OLP Versions 8 and 9 were released during Post Operations Phase and OLP version 10 is the Legacy Archive Version. “No” means that the submode is still unvalidated in the Legacy Archive due to low priority or on-going calibration work and will be validated later during the Active Archive Phase.

AOT	observation type	submode	# of AOs	scientific validation with	comments
PHT03 (P)	multi-filter photometry	staring point source	961	V6	for standard apertures
		staring ext. source	270	no	
		nodding	230	V6	for standard apertures
		chopped	1134	V10	
		raster map	431	no	
PHT04 (P)	multi-aperture photometry	staring point source	219	V10	relative curve of growth
		staring ext. source	36	V10	for extent < 2 arcmin
		chopped	17	no	sequence: ≥ 4 aper. (120”,180”)
PHT05 (P)	absolute photometry	staring point source	57	V6	for standard apertures
		staring ext. source	162	no	
PHT17 (P) 18, 19	sparse map photometry	staring point source	682	V6	for standard apertures
		staring ext. source	524	no	
PHT22 (C)	multi-filter photometry	staring point source	373	V7	
		staring ext. source	123	V7	
		nodding	29	V7	
		chopped	1887	V10	limited by sky confusion
		raster map	2884	V8.4	ff quality for > 20 RP
PHT25 (C)	absolute photometry	staring point source	54	V7	
		staring ext. source	149	V7	
PHT32 (C)	oversampled mapping	chopped mapping	1565	V10	partially validated w.r.t. surface brightness, ff quality
PHT37 (C) 38, 39	sparse map photometry	staring point source	2109	V7	
		staring ext. source	710	V7	
PHT40 (S)	spectroscopy	staring point source	835	V5	
		staring ext. source	102	V6	
		chopped	412	V6	
		raster map	135	V6	
PHT50 (P)	aperture polarimetry	staring point & ext. source	15	V7	interactive processing & special FORTRAN routine
PHT51 (C)	array polarimetry	staring point & ext. source	110	V7	interactive processing & special FORTRAN routine
		raster		V7	beam effects for ext. sources?

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. 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 V10.0 (cf. Report on the Scientific Validation of PHT OLP Version 10.0).

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. For chopped measurements the number of repetitions was restricted to 6 times.

Tables 4, 5, 6, 7, 9, 10, and 11 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.

Table 3: ISOPHOT Photometric Calibration Accuracy Overview for OLP 10.0. For the wavelength range of the detector system, please refer to Table 1. The table distinguishes 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 $1\,\sigma$ 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	–
P1	p, chop	0.06 – 10 Jy	128	<25	<16	<25
P2	p, star	10 – 200 Jy	32	<10	2	5
P2	p, star	0.5 – 10 Jy	≤256	<15	12	–
P2	p, chop	0.2 – 20 Jy	128	<30	<10	–
P3	p, star	0.5 – 25 Jy	32	10	7	<10
P3	p, star	<0.5 Jy	≤256	20	7	–
P3	p, chop	≥0.8 Jy**	128	<25	<15	<25
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 $\mathrm{MJy\,sr^{-1}}$	32	25	10	20
C100	p, chop	≥0.2 Jy**	128	<30	<15	<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 $\mathrm{MJy\,sr^{-1}}$	64	20	10	20
C200	p, chop	≥1.5 Jy**	128	<40	–	–
SS	p, star	1 – 6000 Jy	256	<10	–	<15
SS	p, chop	0.5 – 500 Jy	1024	<10	–	<10
SS	e, star	30 – 3000 $\mathrm{MJy\,sr^{-1}}$	256	<10	–	<15
SL	p, star	0.3 – 1500 Jy	256	<10	–	<15
SL	p, chop	0.2 – 200 Jy	1024	<10	–	<10
SL	e, star	5 – 10000 $\mathrm{MJy\,sr^{-1}}$	256	<10	–	<15

* for mini-map photometry using PCAS products

** for fainter fluxes careful estimate of cirrus confusion necessary

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 and absolute mode with OLP V10.0. Hyphens indicate that no test case was available. Bold values indicate an improvement w.r.t. OLP V9.0. 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	10	α Boo
P1	P03, P05 off & on	70 - 1250	10	≤ 30	γ Dra
P1	P03, P05 off & on	50 - 1000	< 10	< 10	Sirius
P1	P05 off & on	35 - 600	< 10	–	α Ari
P1	P03 off & on	0.6 - 6.5	< 10	$<$ **10**	HD 207129
P1	P03 off & on	0.8 - 3.5	< 5	5	HR 6847
P2	P03 off & on	100 - 200	≤ 7	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	< 10	–	α Ari
P3	P03 off & on	10 - 25	≤ 5	$\leq$ **5**	α Boo
P3	P03, P05 off & on	~ 5	< 7	–	γ Dra
P3	P17/18/19 4 times	~ 0.15	$\leq$ **10**	–	HR 5981
C100	P22 off & on	6 - 25	6	$\leq$ **15**	α Boo
C100	P22, P25 off & on	~ 5	20	20	γ Dra
C200	P25 off & on	500 - 900	$\leq$ **5**	–	Uranus
C200	P22 off & on	2 - 5	8	20	α Boo
C200	P25 off & on	~ 0.5	10	–	γ Dra

2.1.2 Chopped Mode Photometry

The processing of chopped photometry has been scientifically validated with OLP V10.0. The most important outcome of the OLP 10.0 Scientific Validation was the significantly improved performance of P2 chopped photometry.
It should be noted that the SPD data product (type: PP1S, PP2S, PP3S, PC1S, PC2S) contains the so-called "chop pattern" which is a robust representation of the signal modulation for this measurement. This should be consulted to check whether the source was clearly detected.

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 V10.0. Bold values indicate improvements w.r.t. OLP V9.0. 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	2.5	< 10	–	BS 5062
P1	P03	2.2	< 10	–	HR 5986
P1	P03	0.3 - 3.5	< 10	~ 25	HR 6847
P1	P03	0.06	< 25	–	HD 172323(6×)
P2	P03	20	$<$ **15**	–	Sirius
P2	P03	10	$<$ **10**	–	Vega
P2	P03	5	$<$ **10**	–	HR 7557
P2	P03	3.5	$<$ **30**	–	HR 7310
P2	P03	0.5	$<$ **30**	–	HR 5986(3×)
P2	P03	0.4	$<$ **10**	–	HR 5914
P2	P03	0.3	$<$ **30**	–	HR 5447
P2	P03	0.25	$<$ **10**	–	HR 7469
P2	P03	0.25	~ 20	–	PG 1700+518
P3	P03	7 - 19	< 25	–	HR 1457
P3	P03	7 - 9	< 15	–	Vega
P3	P03	2.5 - 8	< 10	< 20	HR 337
P3	P03	0.8 - 2.5	< 10	~ 25	HR 617
P3	P03	0.6	< 50	–	HR 7310(6×)
P3	P03	0.15 - 1	in general fluxes 40 - 70 % too low		
C100	P22	11	~ 20	–	HD 216956
C100	P22	1.5 - 2	< 20	< 20	HR 6705
C100	P22	0.4	~ 20	–	PG 1700+518
C100	P22	0.2	< 30	–	HR 7310(6×)
C200	P22	2 - 5	40	60	HR 5340
C200	P22	< 1	strong cirrus contamination for B $> 5\,\mathrm{MJy\,sr^{-1}}$		

2.2 Flux Reproducibility for Point Sources

The following Table 6 provides the flux reproducibility for bright and faint sources, both for staring and chopped mode. Concerning the staring observations, 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.
The sets of monitoring measurements of chopped observations are smaller and shorter mission periods are covered. Note, that for technical reasons only 3 repetitions of the measurement could be achieved for the P2 detector, 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 for chopped observations. 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	HR 6847	3.3	3	3
P1 chopped	HD 172323	0.064	16	6
P2	NGC 6543	100	2	14
P2	HR 5986	0.52	12	15
P2 chopped	HR 5986	0.52	7	3
P3	NGC 6543	100	7	15
P3	HR 7310	0.59	7	15
P3 chopped	HR 7310	0.59	12	6
C100	NGC 6543	50	3	15
C100	HR 7310	0.21	20	23
C100 chopped	HR 7310	0.21	12	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.

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

This overview is restricted to measurements with the ISOPHOT-C arrays, surface brightness photometry with the aperture photometer ISOPHOT-P is not yet scientifically validated. 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.

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

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 somewhat on the ratio of the selected raster step sizes to the array size: There is some 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.

With OLP 10 a statistical flat-field correction has been introduced for raster maps with greater equal 20 raster positions. The flat-field correction is established from the ratio of the %10tile of the surface brightness of each pixel to the average %10tile for all pixels. These correction factors are applied to the PGAI products and are written to the product header. This removes the fixed patterns observed for previous OLP versions, in particular for maps with no pixel overlap.

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	4 - 10	3 - 6
C200	2 - 6	2 - 4

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 Accuracy of Point Source Photometry from Mini-maps

Table 9 gives an overview of absolute accuracies 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 around a central source. 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. 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 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 9: 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	<10	Sirius
C100	0.9	<10	HR 7557
C100	0.5 - 1.6	**<10**	HR 1654
C100	0.4 - 1.2	**<10**	HR 7980
C100	>0.2	<30	HR 7310
C100	~ 0.12	<30	HR 6464
C100	~ 0.1	**<20**	HD 185144
C100	~ 0.05	<30	HD 185395
C200	500 – 900	**<10**	Uranus
C200	0.2- 0.4	**<15**	HR 1654
C200	0.25	**30**	HR 617
C200	0.15 - 0.3	**<25**	HR 7980

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.

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.

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 $2.7\,\mathrm{K} < \mathrm{T} < 3.1\,\mathrm{K}$. 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 10: Absolute and relative (spectral shape) calibration accuracies for ISOPHOT-S spectrophotometry of point sources for staring and chopped observations. Chopped modes are coded: RC = rectangular chopping, TC = triangular chopping, SC = sawtooth chopping. 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	2000 - 8000	< 5	< 10	HR 5340
SS	P40 off & on	800 - 2500	< 5	< 10	HR 337
SS	P40 off & on	250 - 850	< 5	< 15	HR 617
SS	P40 off & on	150 - 500	∼ 5	< 10	HR 7001 (Vega)
SS	P40 off & on	120 - 400	< 5	< 10	HR 7980
SS	P40 off & on	70 - 240	∼ 10	< 20	HR 7924
SS	P40 off & on	6 - 20	< 5	< 15	HR 7469
SS	P40 off & on	1 - 4	∼ 5	< 10	HR 8487
SS	P40 RC	4 - 15	∼5	< 10	HR 6817
SS	P40 TC	4 - 15	<5	< 10	HR 6817
SS	P40 RC	2 - 6	∼10	< 10	HR 6847
SS	P40 TC	2 - 6	<10	< 10	HR 6847
SS	P40 SC	0.4 - 1	∼10	< 10	HD 23367
SL	P40 off & on	500 - 1800	< 5	< 10	HR 5340
SL	P40 off & on	200 - 700	< 5	< 10	HR 337
SL	P40 off & on	60 - 210	< 5	< 10	HR 617
SL	P40 off & on	30 - 110	∼ 5	< 10	HR 7001 (Vega)
SL	P40 off & on	30 - 110	< 5	< 10	HR 7980
SL	P40 off & on	15 - 50	∼ 10	< 20	HR 7924
SL	P40 off & on	1 - 5	< 5	< 15	HR 7469
SL	P40 off & on	0.2 - 0.7	∼ 10	< 20	HR 8487
SL	P40 RC	1 - 4	< 5	< 10	HR 6817
SL	P40 TC	1 - 4	< 5	< 10	HR 6817
SL	P40 RC	0.4 - 1.5	< 5	< 10	HR 6847
SL	P40 TC	0.4 - 1.5	< 10	< 10	HR 6847
SL	P40 SC	0.15 - 0.24	< 10	< 20	HR 23367

The ISOPHOT–S spectral response function for extended sources is derived from the one for point sources by applying solid angle factors including the correction for the non-flat beam profile. Hence, the uncertainties of extended source products (type “PSAE” and “PLAE”) are in essence the same as for point sources, cf. Table 10.

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.

Due to the unpredictable illumination history the dynamic spectral response function calibration cannot be applied to the PHT40 raster mode (products “PSAS” and “PLAS”). The application of a static spectral response function calibration and hence no transient correction limits the accuracy of this submode to better than 30 % absolute and better than 30 % relative.

Table 11: 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	**AOT mode**	**flux range** [MJy sr^{-1}]	**abs. accuracy** [%]	**rel. accuracy** [%]	**standard**
SS	P40 pointing	30 – 3000	< 10	< 20	
SS	P40 raster	30 – 3000	< 30	< 30	
SL	P40 pointing	3 – 20	10 - < 50	20	COBE/DIRBE Zodi Light
SL	P40 pointing	20 – 10000	< 10	< 20	IRTS Galactic Disk
SL	P40 raster	3 – 10000	< 30	< 30	

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 Scientific Validation of PHT OLP Version 10.0

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 $35\,\mu$m. 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 Sky confusion noise in the far-infrared 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.).

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) 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) 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.

4) 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.

5) 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 12). 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 13. 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 12: 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 13: 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

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 14.

Table 14: 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

5 Reference Documents

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10) Deglitching methods by the ISOPHOT Interactive Analysis (PIA)
C. Gabriel and J.A. Acosta-Pulido
Experimental Astronomy 10
electronic preprint under http://www.iso.vilspa.esa.es/manuals/PHT/pia/public/pia_publ.html

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electronic preprint under http://www.iso.vilspa.esa.es/manuals/PHT/pia/public/pia_publ.html

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C. Gabriel and M. Hur
Proceedings of the workshop "ISO Beyond Point Sources: Studies of Extended Infrared Emission",
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