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 Observer's Manual.

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 3.0 reflects the calibration status achieved with OLP V8.4 and CalG V5.4, while the previous Version 2.0 referred to OLP V7.0 / CalG V4.0. 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 Data User Manual, 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.

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

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 Data User Manual or the
   - Caveat chapter of the Report on the PHT Scientific Validation for OLP Version 8.4

   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 scientifically validate the OLP processing of the outstanding ISOPHOT AOT submodes. A rough schedule is provided in Table 2. OLP V9.0 will be available around mid 2000, OLP V10.0 around beginning of 2001. The latter one is planned to be used to generate the ISO legacy archive.

Table 2: Status of Scientific Validation of ISOPHOT OLP AOT Processing, January 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 pipeline only to raw data level. For a detailed definition of the individual AOTs, please refer to the ISOPHOT Observer's Manual.

AOT	**observation type**	**submode**	**scientifically valid since**	**next upgrades**	**foreseen in OLP Vx.y**
PHT03 (P)	multi-	staring point source	V6	non-lin R	9.0
	filter			FCS aper	10.0
	photometry	staring ext. source	no	non-lin R	9.0
				beam	10.0
		nodding	V6	non-lin R	9.0
				FCS aper	10.0
		chopped point source	no	chop & non-lin R	9.0
		raster map	no	map cal & drift	10.0
PHT04 (P)	multi-	staring point source	no	non-lin R	9.0
	aperture			beam & FCS aper	10.0
	photometry	staring ext. source	no	non-lin R	9.0
				beam	10.0
		chopped point source	no	chop & non-lin R	9.0
				beam	10.0
PHT05 (P)	absolute	staring point source	V6	non-lin R	9.0
	photometry			FCS aper	10.0
		staring ext. source	no	non-lin R	9.0
				beam	10.0
PHT17 (P)	sparse map	staring point source	V6	non-lin R	9.0
18 , 19	photometry			FCS aper	10.0
		staring ext. source	no	non-lin R	9.0
				beam	10.0
PHT22 (C)	multi-	staring point source	V7	non-lin R	9.0
	filter	staring ext. source	V7	non-lin R	9.0
	photometry	nodding	V7	non-lin R	9.0
		chopped point source	no	chop & non-lin R	9.0
		raster map	V8.4	flat-field	10.0
PHT25 (C)	absolute	staring point source	V7	non-lin R	9.0
	photometry	staring ext. source	V7	non-lin R	9.0
PHT32 (C)	oversampled mapping	chopped mapping	no	chop & map cal	TBD
PHT37 (C)	sparse map	staring point source	V7	non-lin R	9.0
38 , 39	photometry	staring ext. source	V7	non-lin R	9.0
PHT40 (S)	spectroscopy	staring point source	V5	dyn rsrf	9.0
		staring ext. source	V6	dyn rsrf	9.0
		chopped point source	V6		
		raster map	V6	TBD	TBD
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 (refinement of OLP 8.4 implementation)
FCS aper : correction for inhomogeneous illumination of PHT-P apertures by FCS
beam : beam profile corrections
chop : chopped photometry corrections
map cal : surface brightness calibration in maps
drift : correction of non-linear long-term drifts
flat-field : refined flat-field corrections
dyn rsrf : dynamic spectral response function to correct for signal transients

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 scientitifc validation of the OLP V8.4 (cf. Report on the PHT Scientific Validation for OLP Version 8.4).
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 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	< 15	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	< 0.5 Jy	≤ 256	40	20	–
C100	e, star	5 – 15 $\mathrm{MJy\,sr^{-1}}$	32	25	10	20
C200	p, star	1 – 900 Jy	128	10	10	< 30
C200	p, star	0.5 – 1 Jy	≤ 256	< 30	10	–
C200	e, star	4 – 10 $\mathrm{MJy\,sr^{-1}}$	64	20	6	20
SS	p, star	2 – 5000 Jy	256	< 30	< 30	< 30
SS	p, chop	0.5 – 500 Jy	1024	< 10	–	< 10
SS	e, star	50 – 10^5 $\mathrm{MJy\,sr^{-1}}$	256	< 30	< 30	< 30
SL	p, star	1 – 5000 Jy	256	< 30	< 30	< 30
SL	p, chop	0.2 – 200 Jy	1024	< 10	–	< 10
SL	e, star	50 – 10^5 $\mathrm{MJy\,sr^{-1}}$	256	< 30	< 30	< 30

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).

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.

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 reduncancy 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 Table 4, too. In the current version of the table all 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.

2.1.2 Chopped Mode Photometry

The processing of chopped photometry has been significantly improved with new correction algorithms and calibration tables in OLP V8.4 and for some detectors and flux ranges already reasonable accuracies have been achieved as listed in Table 5.

Nevertheless, 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) In general the accuracy is not better than 40 - 50 %.

2) For C100 and C200 these accuracy values are limited to fluxes above 0.2 Jy and 1 Jy, respectively. For smaller fluxes the current chopper offset correction, being the zero point of the signal correction, is not yet sufficient. In case of C200, however, another factor has to be carefully considered in selecting test cases for the faint flux range accuracy assessment: cirrus confusion is practically always the sensitivity limit of the detector and can completely dominate any flux determination below a few Jy, depending on the absolute surface brightness of the sky.

3) For P2 very often an underestimation of the expected flux value is observed. A better accuracy should be achievable by establishment of signal correction factors which are currently not yet available.

Further improvements are being worked out for the OLP V9.0 (cf. Table 2).

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 V7.0, which provided the basic data set of the ISO data Archive (for more recent OLP versions on-the-fly reprocessing must be requested). 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	$\leq$ **5**	15	α Boo
P1	P03, P05 off & on	70 - 1250	10	25	γ Dra
P1	P03 off & on	50 - 1000	10	10	Sirius
P1	P05 off & on	50 - 1000	**5**	–	Sirius
P1	P03 off & on	30 - 300	**10**	**10**	Vega
P1	P03 nodding	2	$\leq$ **5**	–	HR 5986
P1	P03 nodding	< 0.1	40	–	HD 172323
P2	P03 off & on	100 - 200	$\leq$ 5	5	α Boo
P2	P03, P05 off & on	25 - 40	< 10	**5**	γ Dra
P2	P05 off & on	$\sim$ 25	$\leq$ **15**	–	Sirius
P2	P03 off & on	$\sim$ 25	20	–	Sirius
P2	P03 nodding	0.5	$\leq$ 10	–	HR 5986
P3	P03 off & on	10 - 25	10	**5**	α Boo
P3	P03 nodding	20	$\leq$ **5**	–	α Tau
P3	P03, P05 off & on	$\sim$ 5	10	**10**	γ Dra
P3	P03 nodding	1 - 2	**10**	–	HR 617
P3	P03 nodding	0.6	$\leq$ 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	$\sim$ 5	15	**25**	γ Dra
C100	P22 nodding	$\sim$ 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**	< **30**	α Boo
C200	P22 nodding	$\sim$ 0.5	< **10**	–	γ Dra
C200	P25 off & on	$\sim$ 0.5	**10**	–	γ Dra

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%

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 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	2.5 - 10	**5**	–	HR 6817
P1	P03	1 - 2.6	**5**	**40**	BS 5062
P1	P03	2.2	**10**	–	HR 5986
P1	P03	0.06	$<$ **50**	–	HD 172323
P2	P03	25	$<$ **20**	–	Sirius
P2	P03	3.5 - 6	$<$ **40**	–	HR 6132
P2	P03	5	$<$ **40**	–	HR 7557
P2	P03	3.5	**10**	–	HR 7310
P2	P03	0.5	**10**	–	HR 5986,HD 185144
P2	P03	0.2 - 0.5	$<$ **40**	–	BS 5062,HR 5447 HR 5914,HR 4983 HD 185395
P3	P03	7 - 19	**20**	–	HR 1457
P3	P03	6 - 7	**15**	**20**	HR 7001
P3	P03	1.5 - 4.5	$<$ **40**	**30**	BS 6056
P3	P03	0.6	$<$ **40**	–	HR 7310
P3	P03	0.15	$<$ **60**	–	HR 5981
C100	P22	4 - 12	**20**	**60**	HR 8775
C100	P22	1.5 - 2	$<$ **60**	**30**	HR 6705
C100	P22	0.15 - 1.1	**10**	**10**	HR 7310,HD 203280 HD 12311,HD 187642
C100	P22	0.07 - 0.15	$<$ **20**	–	HR 5981, SAO248381 HD 142373
C100	P22	0.03 - 0.15	$>$ **+60**[a]	–	HR 5986,HR 7180 BS 5062,HR 5304 HD 142373
C200	P22	2 - 5	**15**	**20**	HR 5340
C200	P22	0.6	– [a]	–	HR 6705
C200	P22	0.02 - 0.15	– [b]	–	HR 7180,HR 7557

[a] insufficient chopper offset correction (frequency and pixel dependent)

[b] selected stars are not useful, since source flux is significantly below expected cirrus confusion noise for background surface brightnesses $\geq 15\,\mathrm{MJy\,sr^{-1}}$.

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.
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.

Table 6: 1 σ Flux Reproducibility per Detector for Bright and Faint Fluxes 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
P2	NGC 6543	100	2	14
P2	HR 5986	0.67	12	15
P3	NGC 6543	100	7	15
P3	HR 7310	0.67	7	15
C100	NGC 6543	50	3	15
C100	HR 7310	0.23	20	23
C200	NGC 6543	15	10	15
C200	HR 6705	0.67	7	23

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

- for both bright and faint sources < 10%.
  This needs mainly improved signal processing (deglitching and drift removal). In case of the faint sources background fluctuations may limit the measurement accuracy due to the rotation of the focal plane with respect to the sky and hence different background positions with time.

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 from OLP V7.0 onwards. 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 campaign for OLP V8.4 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 could be 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 a point source measured by two staring raster maps with different raster step size. Point source fluxes were derived from aperture photometry on-source and from the corners of the map for background determination by appropriate scaling of the relative aperture areas and converting with 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.

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. 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 number of examples is still small. It should also be noted that for the various standards measurements in several filters were available (whereever a flux range is given), for which the achieved accuracies were quite different. The quoted values here are quite conservative ones. For details of the assessment, please refer to Report on the PHT Scientific Validation for OLP Version 8.4.

The reasons why the mini-maps give a less good accuracy than than the corresponding staring pointed observations are not completely clear yet. Fluxes were determined by aperture photometry on-source and for background determination off-source in the edges of the map. The off-source positions might be contaminated by source flux (beam) or sky background fluctuations (cirrus). A careful inspection used for background subtraction on mini-maps is mandatory. Just using the average of the background values from all four corners of the map may not be the best choice, since some of them may be affected by cirrus and have a definite excess signal.

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

detector	**flux range** [Jy]	**abs. accuracy** [%]	**standard**
C100	1 – 5	30	Sirius
C200	500 – 900	30	Uranus
C200	40 – 120	30	Ceres
C200	0.6	50	γ Dra
C200	0.4	30	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 staring mode the quoted numbers are derived from a general assessment of the accuracy in deriving the spectral response function. Note, that for PHT–S there is a direct conversion from the measured signal into flux density per wavelength range F_λ using this spectral response function established from a set of standard stars. There is no flux range dependent calibration using the internal calibration reference sources.

The considerably improved accuracy for chopped ISOPHOT-S measurements with OLP V8.4 became possible by 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.

For ISOPHOT-S staring mode observations a similar correction is now foreseen using a 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. Then similar accuracies as for the chopped mode can be expected.

Table 11: Absolute and relative calibration accuracies for ISOPHOT-S spectrophotometry. Bold values indicate a significant improvement w.r.t. OLP V7.0, which provided the basic data set of the ISO data Archive (for more recent OLP versions on-the-fly reprocessing must be requested). 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	2 - 5000	< 30	< 30	global
SS	P40 chopped	0.5 - 500	< **10**	< **10**	HD 23763,HR 7428 HD 23441
SL	P40 off & on	1 - 5000	< 30	< 30	
SL	P40 chopped	0.2 - 200	< **10**	< **10**	HD 23763,HR 7428 HD 23441

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, all uncertainties of the point source spectral response function apply, 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.

Table 12: ISOPHOT-S Calibration Accuracy for Extended Sources for Various Flux Ranges. 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	50 - 10^5	< 30	< 30	
SL	50 - 10^5	< 30	< 30	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 Data User Manual or the
- Caveat chapter of the Report on the PHT Scientific Validation for OLP Version 8.4

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 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) measurements with signal transients which do not stabilise during the measurement time, but which are long enough to perform a reasonable transient fit.
   a) PIA provides already the dynamic spectral response calibration for ISOPHOT-S.
   b) PIA provides several transient correction tools. The most efficient ones are the ones 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.
   c) PIA allows to view the transient fitting and to accept or reject it.

2)

2) flat-fielding of maps, depending on the sampling mode and the dynamic range.
   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. The average surface brightness is quite consistent with COBE/DIRBE photometry (cf. Table 7).
   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.

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) detection of faint sources by refined deglitching and filtering.
   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.

5) photometry from mini-maps.
   a) The areas for determination of the sky background can be visually checked and selected.
   b) Knowledge of the beam footprint of a point source allows to correct for contamination of the background position by the source beam and to measure closely to the source in order to minimize cirrus confusion.

6) enhancement of map resolution.
   a) Various map co-adding methods are offered.
   b) Deconvolution using the theoretical PHT–C footprint matrixes can be performed.

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. 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

1) ISOPHOT Observer's Manual
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Version 3.1 (April 1994)
and
Addendum to ISOPHOT Observer's Manual
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Version 1.0 (August 1996)

2) Report on the PHT Scientific Validation for OLP Version 8.4
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SAI/1999-068/Rp
Version 2.0 (January 2000)

3) ISOPHOT Error Budgets: Derive_SPD Processing Steps
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Version 1.0 (April 1999)

4) ISOPHOT Data User Manual
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SAI/1995-220/Dc
Version 4.1 (October 1999)

5) General ISOPHOT observing strategies for faint sources
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6) The ISOPHOT Interactive Analysis - PIA User's Manual
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PIA V8.1 (November 1999)

7) Asteroids as far-infrared photometric standards for ISOPHOT
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8) Small-scale structures in the far-infrared background
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