ISOPHOT–S: CAPABILITIES AND CALIBRATION *

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ABSTRACT

The in-flight characteristics of ISOPHOT–S are presented, in particular spectral response function, beam profile, dark current, straylight suppression, and wavelength calibration. Photometric calibration of point–like and extended sources is described. Sensitivity limits and the actual error budget are discussed. The validation of the pipeline products is addressed. Correction methods for signal transients in staring and chopped mode are outlined.

Key words: Space vehicles; Instrumentation: spectrographs; Methods: Data Analysis; Techniques: spectroscopic.

1. INSTRUMENT CHARACTERISTICS

ISOPHOT–S is the spectroscopic sub-instrument of ISOPHOT (Lemke et al. 1996) onboard the Infrared Space Observatory ISO (Kessler et al. 1996). It is a fast low resolution spectrometer measuring the full accessible wavelength range simultaneously. A major design goal has been the investigation of the dust features.

The ISOPHOT–S entrance aperture is 24 arcsec x 24 arcsec. A dichroic splits the beam into the two simultaneously measuring channels from 2.5 to 4.9 μm, the SS, and 5.9 to 11.7 μm, the SL. The two fixed gratings disperse the light onto the two 64 pixels linear Si:Ga detector arrays. The order sorting filters are mounted in front of the detector blocks, 32 pixels each are covered by the same filter material.

The mean spectral resolution of both channels is 95, ranging from 65 for the shortest wavelength pixel of each array to 130 for the longest wavelength pixel. The pixel-to-pixel wavelength separation is on average 0.0383 μm for the short wavelength array and 0.0918 μm for the long wavelength array. Due to small inter-pixel gaps the spectral width per pixel is 89 % of this pixel-to-pixel wavelength separation, which is 0.0339 μm and 0.0813 μm, respectively. The FWHM of an unresolved line has been measured as 0.0424 μm (SS) and 0.0966 μm (SL), being slightly wider than the spectral width of 1 pixel. Atomic or ionic fine structure lines are only resolved, if there velocity dispersions are higher than 3000 km s^{-1}. The unidentified IR bands always cover several pixels.

The ISOPHOT–S sensitivity is such that within 256 s a typical NEFD of 26 mJy for SS and 10 mJy for SL can be achieved with background levels of 0.5 MJy sr^{-1} and 15 MJy sr^{-1}, respectively.

2. CALIBRATION

The basic ISOPHOT–S calibration parameters have been established. Several of them are documented in the form of data products which are delivered to each observer as cal–G files. Others will be provided in the form of appropriate calibration documents.

2.1. Dark Signals

Dark signals have been established from dedicated long measurements of at least 1000 s duration in

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†deceased in 1997

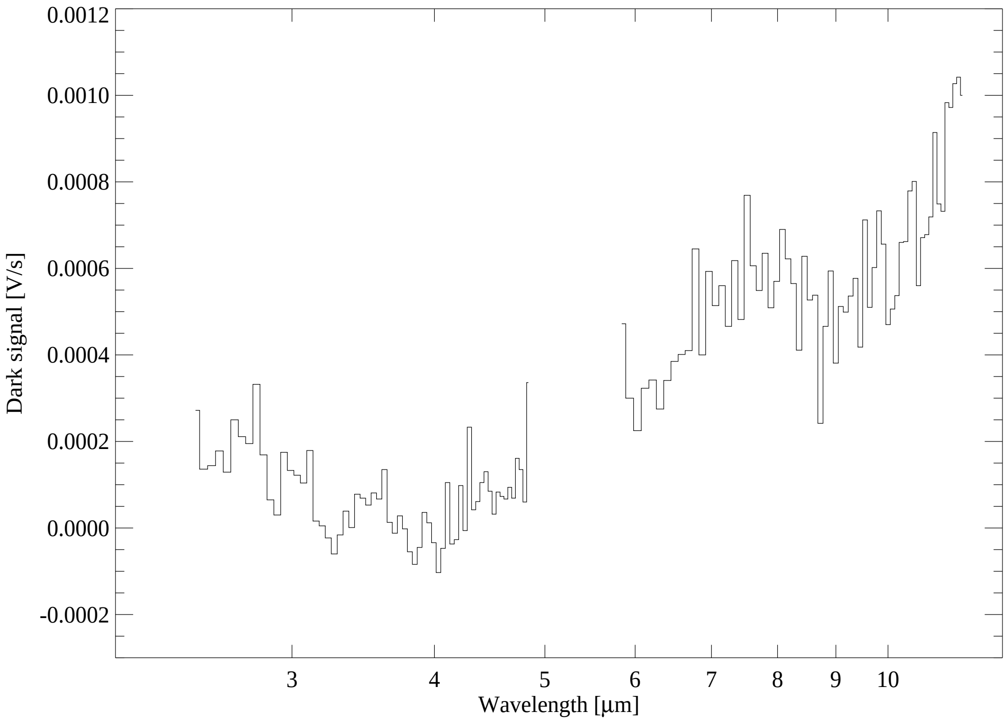

Figure 1. Dark signals for both the SS and SL channels as stored in cal–G file PDARKCURR.

order to achieve stabilised signals. For these measurements the external beam into the instrument was blocked by the selection wheel. The measured dark signals are displayed in figure 1.

For the SS channel the dark signals are very low with values between 0 and 0.3 mV/s, except for the longest wavelength pixel 64 which has a more than 10 times higher dark signal. Equivalent flux densities are between 0 and 100 mJy (2 Jy for pixel 64). The SL channel has significantly higher dark signals raising from 0.3 mV/s at the short wavelength side to 1 mV/s at the long wavelength side. Equivalent flux densities are between 50 mJy and 700 mJy. The average dark signals of ISOPHOT–S are provided in the cal–G file PDARKCURR.

2.2. Orbit Dependence of Dark Signals

Dark signal measurements which are randomly distributed over the duration of the Science Window have been collected during ISO's Routine Phase. When compiling the results in dependence of orbital position, no systematic trend is found for the SS channel. The SL pixels, however, show a systematic dark signal enhancement at the beginning of the Science Window which is most drastic for the longest wavelength pixels (more than a factor of 5). A more detailed description is given in Ábrahám et al. (1997). The reason is a memory to a bright illumination of the SL detector during the daily instrument activation by the internal Fine Calibration Source in order to establish the calibration performance after curing. This behaviour will be fully characterised in a future cal–G file.

2.3. Wavelength Calibration

As ISOPHOT–S has fixed gratings, the establishment of the wavelength calibration is quite straight forward and robust. For a first approximation the wavelength scale can be treated as being linear with the numbers quoted in section 2. A refined analysis shows that a quadratic fit gives more accurate central wavelengths over the whole array. For SS this fit was established with 7 lines between 2.6259 and 4.654 μm, most of them being hydrogen recombination lines of the Bracket and Pfund series. For SL the fit was established with 9 lines between 5.918 and 11.309 μm, 4 being hydrogen recombination lines and the others forbidden lines of Ar, Ne, and S. The following relations were established:

1 SS: $2.4687 + 0.0407652 * (X - 1) + 0.000041563 * (X - 1)^2$
X = pixel number (1..64)

2 SL: $5.8396 + 0.094263 * (X - 65) + 0.000039702 * (X - 65)^2$
X = pixel number (65..128)

The wavelength calibration is as accurate as 0.0020 μm at the centre of the array and 0.0044 μm at the edge for SS, and 0.0035 μm at the centre and 0.0078

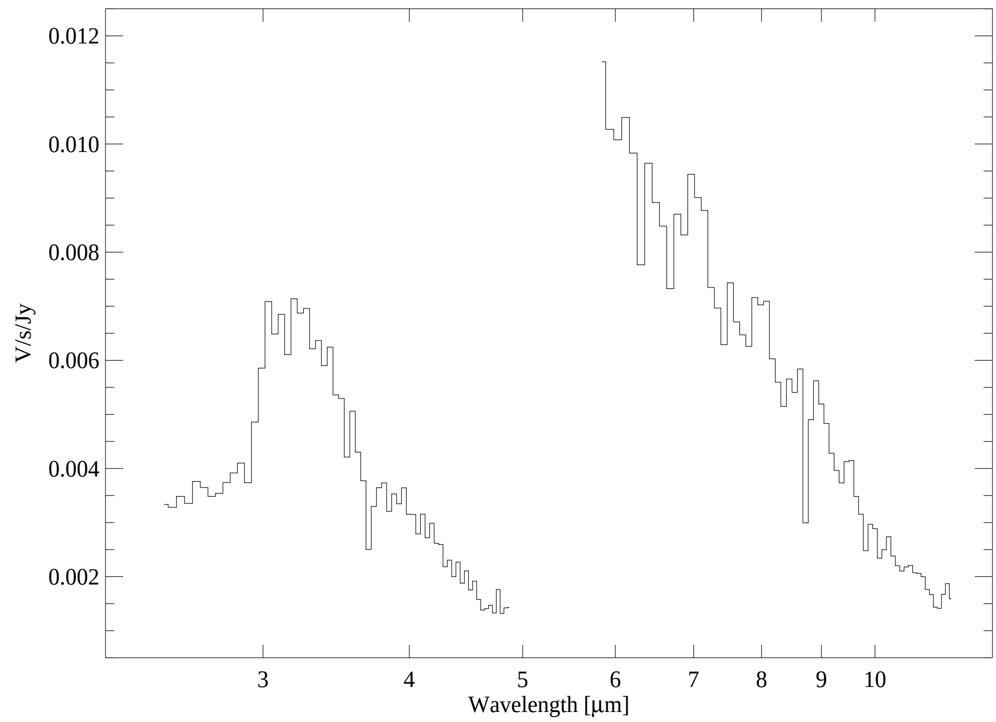

Figure 2. Spectral Response Function for both the SS and SL channels as stored in cal–G file PSPECAL.

μm at the edge for SL, respectively. This corresponds to 1/20 to 1/10 of the pixel-to-pixel wavelength separation.

The ISOPHOT-S wavelength calibration is provided in the cal–G file PSPECAL. In future versions also the uncertainty of the wavelength calibration will be given.

2.4. Spectral Response Function for Point Sources

The spectral response function provides the direct conversion from measured signals into the astrophysical flux units [Jy] or [W m^{-2} μm^{-1}], thus removing the instrumental profile. The current function which is contained in the cal–G file PSPECAL, was generated from 40 spectra of the 4 standard stars HR 6705, HR 6688, HR 6817, and HR 6514. The accuracy of this basic photometric calibration is provided in section 3.2. Effects by the non-flat beam profile are discussed in section 2.5.

The overall shape of the spectral response function (figure 2) is mainly determined by the grating efficiency and the relative response function of the Si:Ga detector material. Furthermore, a somewhat different behaviour of the first 13 pixels of the SS array can be recognized, as well as two pronounced minima at mid-wavelength of each array. The latter ones are caused by a slight mis-match of the order sorting filter transmission range edges w.r.t. the true central wavelength of this pixel.

2.5. Beam Profile Determination

Beam profile information was acquired in-orbit by performing a cross-scan forward and backward over the bright star HR 6705 (γ Dra). The scan length was $\pm$ 60 arcsec, thus reaching as far out as 50 arcsec over the edge of the aperture on both sides in order to assess possible straylight in addition. The step size inside the aperture and out to a distance of 15 arcsec was 3 arcsec, and was then increased from 5 arcsec over two times 10 arcsec to 20 arcsec. These scans complemented full rastering of the ISOPHOT–S aperture during ground calibration.

In figure 3 the shapes of the beam profile both in dispersion and cross-dispersion direction measured for pixel 60 of the SS array are displayed as representative examples. The beam profile in the dispersion direction (corresponding to the S/C z–axis direction) turned out to be relatively flat with a drop off to about 60 % intensity 2 arcsec near the aperture edge. In the cross-dispersion direction the beam profile is much steeper and more of triangular shape. It is also asymmetric and for some pixels the maximum intensity is not achieved at the very CFOV. An off-centre position of a point source by 5 arcsec leads to intensity loss (or sometimes gain) of 20 to 30 %.

Correction factors for point sources depending on the location in the aperture will be made available with the release of the OLP V7.0.

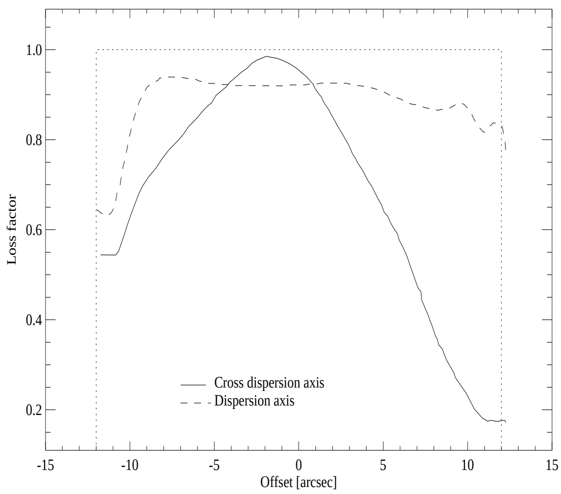

Figure 3. Beam profile cuts along the central axes of pixel 60 as measured in-orbit.

2.6. Spectral Response Function for Extended Sources

From the beam profile data the integral over the whole ISOPHOT–S aperture was derived which provides the correction factor w.r.t. a flat profile. This was applied to the spectral response function for point sources and yielded a separate response function for the case of a source which is flat over the entrance aperture of ISOPHOT–S. This function is a second entry in the cal–G file PSPECAL and provides the direct conversion from measured signals into [MJy sr^{-1}] or [W m^{-2} μm^{-1} sr^{-1}]. As the correction was established as a smooth function per order sorting filter range (sets of 32 pixels each), it gives in essence an increase of the final spectral surface density by factors 1.25 to 1.42. The main features of the point source spectral response function are maintained by this correction.

2.7. Level of Scattered and Diffracted Light outside the Aperture and Straylight Rejection

The extended scans were used to assess the light levels at various distances outside the ISOPHOT–S entrance aperture by bright sources due to diffraction, scattering and stray radiation. At 20 arcsec distance from the centre (8 arcsec outside the rim of the aperture) the intensity is measured to be between 2 % of the maximum intensity for the shortest wavelength and 10 % for the longest wavelength. At 60 arcsec away from the centre (48 arcsec outside the rim of the aperture) the intensity drops down to the dark signal level on all sides of the aperture.

3. SCIENTIFIC VALIDATION OF ISOPHOT–S PIPELINE DATA AND SPECTROPHOTOMETRIC ACCURACIES

The ISOPHOT–S measurement mode, the AOT PHT–40, was scientifically validated with release of the ISO Pipeline Processing Software (OLP) V5.0 in August 96. Further upgrades were done for the OLP V6.0 in May 97, introducing the extended source relative spectral response function, the final wavelength calibration, and improving the processing of chopped measurements.

3.1. Scientific Validation Procedure

This scientific validation does not only comprise the technical check-out of the software but also a check of the resulting data products for qualitatively and also quantitatively meaningful contents. In order to achieve that the following steps were done:

1 Selection of a reasonable test case sample comprising continuum and line sources of different flux levels, continuum sources with different spectral shapes, including standard sources with well modelled SEDs.

2 Compilation of literature data for a comparison with the ISOPHOT–S results.

3 Careful interactive analysis of all test cases in order to produce expected results as references for the pipeline processing.

4 Check-out of the calibration (cal–G) files.

5 Check of reproducibility of results by analysis of repeated measurements.

The results were compiled in test reports and caveat lists were generated providing the limitations of the automatic (and interactive) processing. It has to be pointed out that the comparison with data from other instruments has its limitations, mainly due to beam size effects. Figure 4 presents an example of a validation case.

In addition all pipeline data products are systematically quality checked w.r.t. certain criteria in order to sort out mainly real-time observation problems which result in re–scheduling. But also impacts on data quality, e.g. by saturation, can be assessed in this way.

3.2. Spectrophotometric Accuracies of ISOPHOT–S

As part of various calibration programmes and the scientific validation of the pipeline the accuracies as listed in Table 1 could be established. In particular the absolute and relative accuracy of the spectral response function will be further improved.

The limiting factor for the currently achieved relative accuracy, i.e. the consistent spectral shape of groups

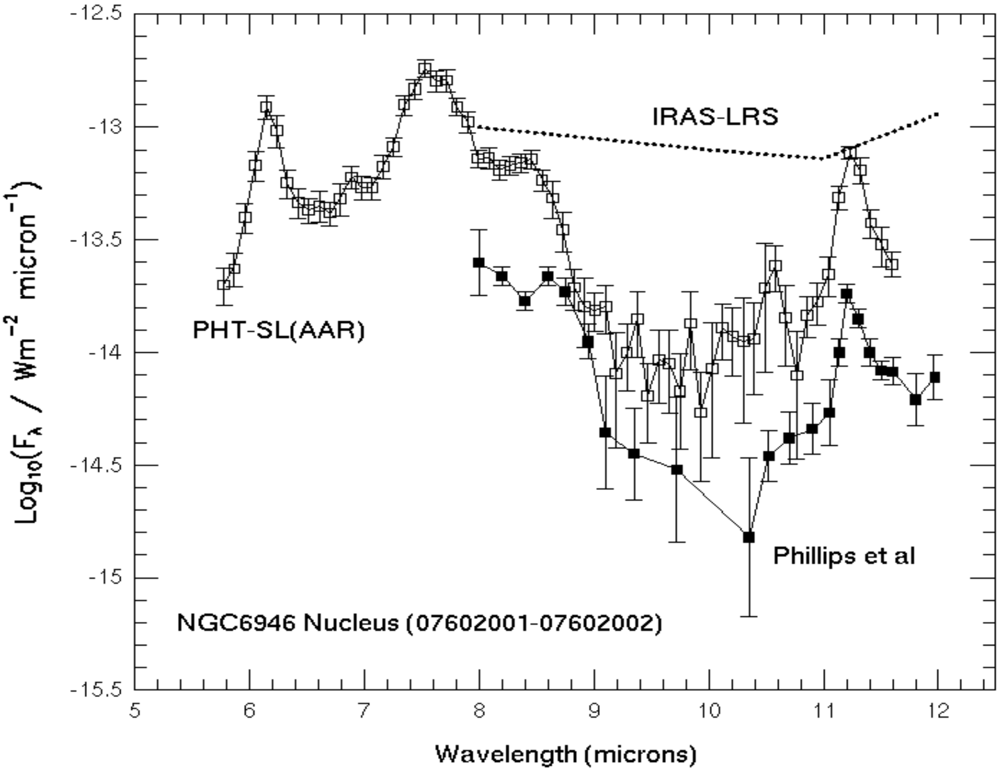

Figure 4. Evaluation of an ISOPHOT–SL spectrum, including error assignment, of the nuclear region of the galaxy NGC 6946. This is compared against literature data of 1) the IRAS Low Resolution Spectrum which provides only an upper limit and 2) a ground-based 8 – 13 μm spectrum by Phillips et al. (1984) using a 6 arcsec aperture. The latter one reproduces the dust feature at 11.3 μm and the relatively low continuum level between 9 and 11 μm, possibly due to silicate absorption.

Table 1. ISOPHOT–S spectrophotometric accuracies

	SS	**SL**
dark signal	0 - 0.33 mV/s	0.24 - 1.02 mV/s
	< 100 mJy	< 700 mJy
dark signal noise	0.05 - 0.2 mV/s	0.05 - 0.4 mV/s
dark signal stability [a]	15 %	15 %
non-linearity	< 10 %	< 10 %
responsivity reproducibility [b]	better than 4 %	better than 4 %
responsivity stability [b]	better than 5 %	better than 5 %
absolute accuracy SRF	< 30 % (15 % aver.)	< 30 % (15 % aver.)
relative accuracy SRF	< 30 % (15 % aver.)	< 30 % (15 % aver.)
photometric accuracy ± 5" offset	± 30 %	± 30 %

[a] except systematic drift along revolution (cf. section 3.2)
[b] except for revolutions with geomagnetic storms

of 10 to 20 pixels, are signal transients because of different time constants of the detectors to adjust the signal to a certain infalling flux. The signal transient times depend on the flux step between two illumination levels (the initial one is dark for most measurements) and the direction of the flux step. Typical signal levels for a 100 Jy source are 0.25 V/s for SS and 1 V/s for SL. Transient times between this flux level and a 100 times fainter flux level are:

1 S(ini) = 0.01 V/s $\longrightarrow$ S(fin) = 1 V/s:
t(10%) = 21 s

2 S(ini) = 1 V/s $\longrightarrow$ S(fin) = 0.01 V/s:
t(10%) = 592 s

Therefore, for some flux step combinations a stable final signal may never be achieved during a reasonable measurement time. This has to be overcome by transient correction methods which are described in the subsequent two sections.

3.3. Signal Transient Corrections for Chopped Measurements

The signal time series of chopped measurements are well reproduced by using a physical model as worked out by Fouks & Schubert (Schubert et al., 1995). Application of this model to the detector data provides the final signal levels of the two or three chopper plateaux. A prerequisite for a good functioning of this correction method is that the flux history is well known. This is the case due to the signal modulation. For consistency of the spectral response function with this signal correction method chopped measurements of calibration stars are being performed in the course of autumn '97.

This correction method is already implemented into the ISOPHOT Interactive Analysis (PIA) and detector specific parameters determining the time constants of the signal transients were confined by special calibration measurements. Details of the implementation and the parameter derivation will be described in a future paper (Acosta–Pulido et al., 1997).

3.4. Dynamical Spectral Response Correction Method for Staring Measurements

The transient correction method presented in the previous section is working only with restrictions for staring mode measurements. It does not well describe initial switch-on instabilities which significantly impact on the shape of the transient curve. For the staring measurements an alternative method has been proposed.

This method is based on the reproducibility of the transient behaviour within the measurement time when an ISOPHOT–S detector is exposed to similar flux. This is valid, if the initial conditions are the same which is guaranteed by the PHT–40 measurement sequence. By measuring sources with a known SED, a direct calibration can be done without correcting for the transient effect. A kind of "dynamical spectral response function" has to be constructed during run time of the flux calibration by identifying for each individual pixel the signal and the appropriate calibration source from a library of standards covering the whole possible ISOPHOT–S flux range. In particular for objects with strong lines the resulting response function may be composed from many different calibration sources and matched uniquely to this object. A full implementation of this method into the ISOPHOT Interactive Analysis (PIA) is planned for spring '98.

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