TOPICS IN SWS DATA ANALYSIS AND CALIBRATIONS

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ABSTRACT

An overview of the current status of the SWS instrument and its calibration is given. Guidance is given to observers concerning data reduction, what instrumental artifacts may contaminate their data and where further information may be obtained from.

Key words: ISO; SWS

1. INTRODUCTION

The Short Wavelength Spectrometer (SWS) onboard the Infra-red Space Observatory (ISO) has been described by de Graauw, T. *et al.* 1996, and the preliminary results of the photometric and wavelength calibration were described by Schaeidt, S.G. *et al.* 1996 and Valentijn, E.A. *et al.* 1996.

Excellent results have been obtained from SWS, with very low noise measured, especially in band 1. The Off-Line Processing (OLP) products (Auto-Analysis Results, AAR, or to a lesser degree Standard Product Data, SPD) can be used for data analysis, with special processing only needed for exceptional cases.

These exceptions include cases where the source flux is very low (leading to dark-current subtraction problems), the source flux is very high (leading to partial saturation of the detectors), and for users trying to determine narrow line shape and strength from fast AOT 1 observations (as the standard OLP may mark such lines as being glitched).

Information on SWS, its behaviour in-orbit, the data processing pipeline and products and how to start reducing SWS data can be found in the SWS Instrument Data Users Manual (IDUM), Leech, K. *et al.* 1997a – much of the information in this paper has been taken from the IDUM. This document in available on the data CD-ROMS in the aboutiso/docs/sws/idum directory and on the SWS pages of the ISO web site at http://isowww.estec.esa.nl/. It is updated approximately twice a year, and between updates relevant information is posted to the ISO web site. Observers should check the ISO web site every few weeks for relevant new documentation.

Observers should also note that Space Research Organization Netherlands (SRON) Groningen has an ISO page at http://www.sron.rug.nl/iso/ and that the ISO Spectrometer Data Centre at the Max-Planck-Institut für extraterrestrische Physik (MPE), Garching, Germany has a web page at http://www.mpe-garching.mpg.de/iso/isosdc.html.

Two tools are available to general observers for displaying and analysing ISO data. These are the IPAC First Look tools and ISAP, the ISO Spectral Analysis Package for SWS and LWS Auto Analysis Results. Information on the First Look tools can be found at http://www.ipac.caltech.edu/iso/software.html and ISAP may be obtained from http://www.mpe-garching.mpg.de/iso/observer/isap/isap.html.

2. CURRENT CALIBRATION AND INSTRUMENTAL PROFILE

2.1. Flux Calibration

Four main effects limit the flux calibration accuracy:

1 The Spectral Energy Distributions (SED's) of the astronomical sources used for flux calibration are only known to between 4 and 10%.

2 Pointing, see section 5.5.

3 Memory effects, see section 5.3.

4 Dark current subtraction.

In the photometric calibration of the SWS detectors, a flux scale is set for converting calibration sources. Most of these calibrators are non-variable stellar point sources of K1-5 III, whose absolute flux levels are given by careful selection of observed photometry and spectrophotometry with traceable calibrations (e.g., Cohen, M. *et al.* 1995), and non-LTE model atmospheres (e.g., van der Bliek, N.S. 1997).

During the conversion of the signal from an observer's science observation, responsivity drifts in the detection system are taken into account by comparing signals from the science target to those of the astronomical calibrator at particular "key" wavelengths (or passband), and to those of an internal calibration source. One key passband is used for each AOT band, whose central wavelength is chosen on the basis of detector responses and spectral liabilities of the astronomical calibrators. The internal measurements are done in every observation, and establish linearity between external science and calibration target signals. This linearity can be ensured over windows of approximately 200 revolutions. Over longer periods, linearity is difficult to maintain due to separate drift properties of the internal calibrator and detectors. The wavelength dependent responsivity variations are accounted for with relative spectral response functions determined prior to launch, modified inflight for point-source diffraction losses and other low order instrument or telescope effects.

Since the responsivities measured from the dedicated calibration observations, combined, and stored in response tables, are taken from many scans of astronomical sources with a wide range of spectral properties and flux levels, any science target can be flux calibrated over its observed wavelength region. The accuracy to which this can be accomplished, however, is limited by sensitivities, short-term drifts (hourly timescales), and possible memory or hysteresis effects. These impose obstacles for giving a straightforward snapshot of the current photometric accuracies that is at the same time not unrealistic given the complexity of SWS. The current photometric accuracies would best be represented in a series of statistical time-, wavelength-, and signal-dependent RMS curves. These will be made available soon, but an idea of what has been achieved inflight for the grating at the time of the OLP 6 delivery (April 97) is shown in table 1. The FP flux calibration accuracy is tied to LW grating sections.

The quoted accuracies are 1-sigma RMS deviations from expected levels of cross-calibrated flux densities of standard stars and representative science targets. Note that the maximum uncertainties refer primarily to AOT band ends where higher order differences between pre-launch and inflight relative spectral responses continue to be characterized, and remembering that the relative spectral response variation is defined to be unity at each key wavelength.

Flux reproducibility was checked by observing the standard star HR6705 twelve times during various orbits. Fluxes between the various measurements agreed to within 6% for band 1, and 12 to 15 % for bands 2 to 4.

Table 1. Grating flux calibration accuracy as of OLP V6 delivery

Band	Key λ μm	Bandpass μm	Key λ 1 σ %	Worst accuracy 1 σ
1A	2.48	0.05	5	7
1B	2.87	0.07	5	7
1D	3.08	0.07	5	7
1E	3.80	0.10	5	7
2A	4.50	0.10	7	12
2B	5.90	0.20	7	15
2C	7.70	0.20	11	25
3A	14.0	0.30	11	25
3C	17.0	0.30	11	20
3D	24.0	0.60	12	20
3E	28.5	0.60	20	30
4	32.0	0.60	30	35

2.2. Wavelength Calibration

The goal was to achieve an accuracy of between 10 and 20% of a resolution element for the two gratings, with 10% for the LW grating as this is used in the Fabry-Pérot (FP) wavelength calibration.

These goals have been achieved, with the current wavelength accuracy being 1 LVDT (1/8 of a resolution element) in the SW grating section and between 0.5 and 1 LVDT in the LW section. Both FPs are accurate to about $\lambda/10^5$.

The wavelength calibration stabilisation is very good. A slight shift has been seen in the wavelength calibration between PV and rev 450 of about 3 LVDT (about half a resolution element at full grating resolution). This is corrected by updates of the relevant calibration files.

2.3. Instrumental Profile

During ISO's performance verification phase, several objects showing strong, narrow, emission lines (mostly Planetary Nebulae) were observed to investigate the influence of parameters such as the position of the source in the aperture, the size of the target and the SWS AOT band on the instrumental profile (IP). These measurements were based on AOT 2 and 6 observations, but should also be applicable to AOT 7 SW grating observation, and an example IP can be seen in figure 1. Preliminary results can be summarised as follows:

1 The SWS grating instrumental profile is almost Gaussian.

2 The only systematic differences from a Gaussian profile are a slight "shoulder" on the blue side of the base of the profile and a depression on the red side. The only parameter this seems to depend on is the position of the source in the slit.

3 The grating resolving power of SWS for all investigated sources is better than expected for extended sources at all wavelengths. This could

either mean that none of line-emitting regions in any of the sources fully filled the SWS aperture, or that the SWS resolving power for extended sources is better than expected.

4 The resolving power for point-like sources in AOT bands 2 to 4 is slightly better than predicted from the ground.

5 The shape, central wavelength and the line strength can vary drastically as the source moves further away from the aperture center.

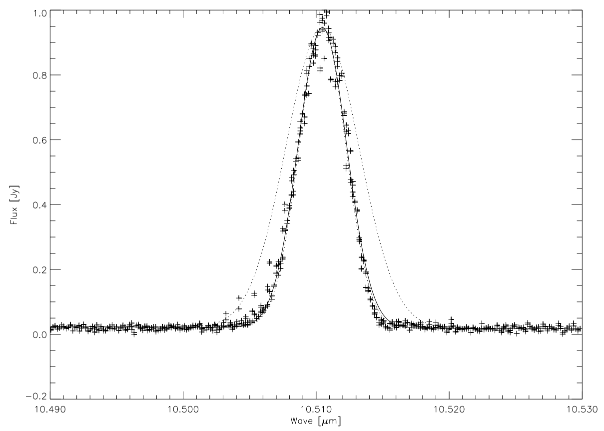

Figure 1. An example of a measured SWS line (crosses) for an unresolved source. The measured IP is compared to a Gaussian fit to the data (solid line), a Gaussian with the expected resolving power for a point source (lower dotted line) and a Gaussian with the expected resolving power for an extended source (upper dotted line).

3. HOW DOES SWS TAKE DATA?

As photons fall onto the detectors the current generated charges up a capacitor. The voltage across this capacitor is read-out and digitised into a bit value 24 times a second. At a set interval the capacitor is discharged. The time interval between two detector resets is automatically determined from the user's input data (flux and SNR, or execution speed) and is either 1, 2 or 4 seconds. To observe faint sources, integrations over several reset intervals are used. Raw data is saved in an Edited Raw Data (ERD) file, with an ERD record for one second consisting of an array of 52 ramps of 24 read-out's each. The Standard Processed Data (SPD) and Auto-Analysis Results (AAR) files contain for each detector a single flux estimate for each reset interval.

Example of ERD data can be seen in figures 2 and 4, of SPD can be seen in figure 3, and of AAR can be seen in figure 5.

When observing, the spectrometers scan the wavelength ranges of interest at least twice, once with the grating moving in one direction, then with it moving in another. This is known as an up-down scan. The grating only moves in one direction when observing with the FPs.

4. HOW TO REDUCE SWS DATA

Getting started with SWS AAR data can be broken down into the following steps:

1 Reading the data from CD-ROM into your analysis package

2 Having a quick-look at the data
This usually involves plotting the AAR data as flux against wavelength

3 Selecting data
SWS observations of a source result in data products containing one or more wavelength regions observed in several scans mixed in with internal calibration measurements. The regions of interest must be selected and then checked to ensure they are not contaminated, e.g. by glitches.

3 Re-bin onto equidistant wavelength grid
The assigning of wavelengths to the grating or FP detectors does not involve any re-binning or interpolating. Hence the wavelengths are not on an equidistant grid.

4 Process up-down scans
No combining of up-down scans is carried out by the pipeline. This is because the up part of the scan may have a different zero level from the down part, or a line may have a different shape in the two scans. All scans should be checked to ensure features are present in all and that the scans are not behaving differently. If they do behave differently care should be taken analysing the data and in some cases it may be necessary to throw away any affected data.

5 Join AOT bands together
AAR data spanning two or more AOT bands can be joined together. No attempt is made to do this in the pipeline as the data in different bands may have a different zero level or may be affected differently by memory and pointing effects. Note that observations of extended sources through different apertures are not corrected for the different aperture sizes.

5 Smooth data
Smoothing may be the best option if the AAR data is badly affected by noise or fringes.

ISAP users may also de-fringe and further process their data. The ISAP on-line help should be accessed for further details.

5. WHAT TO BE AWARE OF

There are several effects to be aware of when processing SWS data. They are described in the IDUM, from which the following sections have been taken:

Users are recommended to examine the SPD from their observations to look for glitches, jumps, memory effects etc. If they are present the user can either throw the affected portions of the data away or try to correct for the effect.

5.1. Glitches

Glitches are caused by such events as fast moving electrons and ions inside the earths magnetic field. The effect of a glitch is a sudden increase in the voltage readout across the capacitor which causes a step (a "glitch") in the affected ramp. Glitch effects can last for a long time (glitches can have tails) and a glitch in one detector can affect other detectors in that detector array.

The pipeline attempts to remove glitches by ignoring the corrupted sample(s) and trying to construct two shorter slopes, one either side of the removed sample(s).

Figure 2 shows an example of a small glitch in the 24Hz ERD data. Note that the sets of two points with Bit values of around 2700-2800 are the result of the detector reset every second. The sample immediately after the two high points is also affected but appears okay due to the signal level.

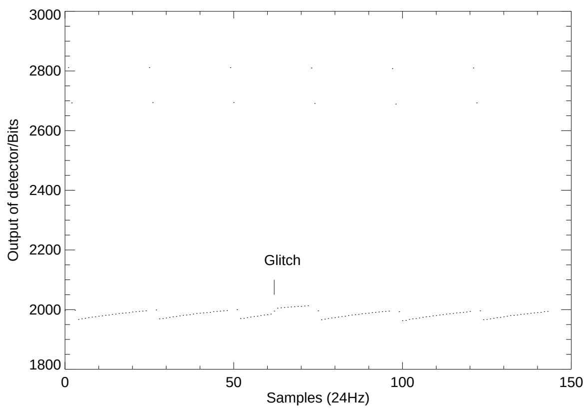

Figure 2. An example of a small glitch seen in the ERD

Another type of upset has been observed, called 'scan jumps'. These appear to be similar to glitches, but they affect an entire detector block. The symptoms are that each detector in a block suffers a sudden rise in sensitivity, that slowly decays with time. They usually affect only one scan of an up-down scan pair, and the recommended solution is to throw the affected scan portion away.

5.2. Single Detector Signal Jumps

The signal jumps considered here occur in only one detector at a time and can be generally described as a sudden increase or decrease of the signal, which remains constant or has a long recovering time (>> 10 s) after the jump. These jumps are normally seen at low signal levels.

Some examples are shown in Figure 3.

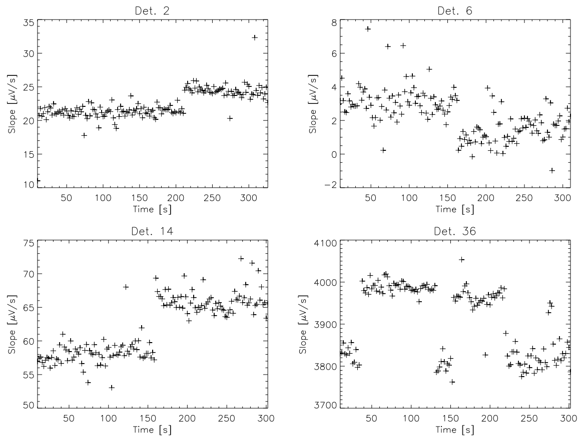

Figure 3. Examples of single detector jumps

5.3. Memory effects

The band 2 and 4 detectors used in SWS "remember" their previous illumination history. Going from low illumination to high illumination, or vice-versa, results in the detectors asymptotically reaching their final value. Currently the only memory effects accounted for in the pipeline are those that affect dark currents.

An example of memory effects can be seen in Figure 4, which shows ERD data from detector 39 (band 4) during a dark current check. The detector takes a few reset intervals to stabilise both on light-dark or dark-light illumination changes.

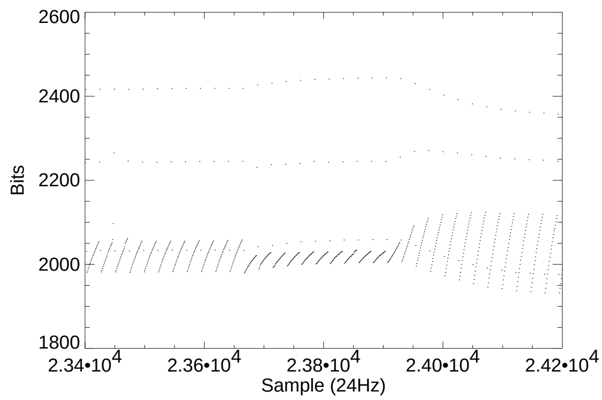

Figure 4. Example of memory effects

Memory effects can also be seen in up-down scans of bright sources. For sources with fluxes greater than about 1000 Jy memory effects cause the up and down scans to differ in response (and hence flux) by up to 20% in bands 2 and 4.

Memory effects can also change the shape of line profiles. As the grating scans across a strong gaussian line the sensitivity of the detectors change. If this change is large enough it will result in one side of the gaussian having a different shape from the other. As lines are scanned in different directions by the up-down scans, the line will have a different shape in both scans. If the scans are averaged the line will be broader than it actually is. These effects mainly happen in band 4, due to it's larger memory effects.

5.4. Reference Scan Memory Effects

Reference scans and detector memory effects can combine to affect the flux calibration of band 2 and 4 detectors during AOT S06 observations. This possible problem is traceable to memory effects left over from reference scans.

A user entering data for a S06 or S07 SW wavelength range scan has to enter three wavelengths – the start wavelength, end wavelength and a reference wavelength – and two fluxes – the flux at the reference wavelength and the maximum flux expected over the wavelength range. If the signal at the reference wavelength is considerably higher than that in the rest of the wavelength region memory effects may be introduced by the reference scans that remain in subsequent scanning operations.

Only band 2 or 4 observations with AOT S06 may be affected, and only if the reference scan signal is several times the average signal.

The adopted solution to this problem was to delete reference scans from all observations with S06. This change took place for all observations planned after June 10 1997.

5.5. Effects of pointing accuracy

The accuracy of the input coordinates, and of the pointing, have a large impact on the instrumental throughput, of the point source flux accuracy but only a minor impact on the wavelength accuracy for point sources. ISO's random pointing jitter (See section 3.3 of the ISO Satellite Data Users Manual, Leech, K. *et al.* 1997b, for a discussion of pointing and improvements through the mission) can also introduce effects in the data if the target coordinates are incorrect or if the target is in a crowded field. While any wavelength error is of the order of the quoted accuracy, the flux error due to the pointing may well limit the final flux accuracy.

As an example, a star offset from the center of the aperture by 6" in the cross-dispersion direction (y-axis) loses approximately 40% in throughput (example taken in the LW, 17 μm). An offset in the dispersion direction (z-axis) affects the wavelength calibration, with a 4" mispointing in the dispersion direction corresponding to about a 1/8 grating resolution element. The maximum possible offset is therefore about 1/4 of a grating spectral resolution element.

Position error problems may introduce what appears to be 'noise' in data. The noise (in SPD or AAR) can be much higher than for other objects with similar flux levels. In the AAR this effect manifests itself as sudden flux jumps between adjacent wavelength regions and the up and down scans having different flux levels. Both these effects can be seen in figure 5.

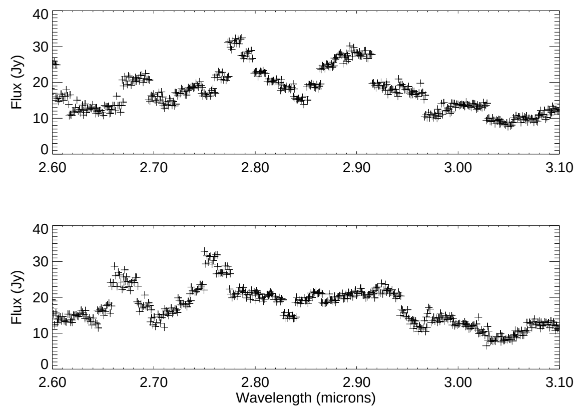

Figure 5. Effect of pointing jitter as seen in AAR. Top plot is the down scan (up in wavelength), bottom plot is the up scan. The difference is due to pointing jitter.

Currently this effect is understood to be a function of incorrect positions being given for the observation (or the object studied being in a crowded field), the instrumental beam profile and the pointing jitter of ISO. At the short wavelengths the instrumental beam profile has a triangular shape in the y direction and a top-hat shape in the z direction. A preliminary reduction of the beam profile data for band 1D (3.1μm) shows that the beam profile goes from 100% to 10% smoothly going from the centre to $\approx$ 15" away in the y-direction. In the z-direction however, it goes from 90% to 10% going from 3 to 9" away – the beam profile is very steep in this direction.

If an object is misaligned from the slit centre in the y-direction then as the pointing jitters the object will move up and down a slowly varying response function. Hence the incident flux seen by the detectors will vary smoothly by small amounts. This will probably not be seen in the data.

If, however, an object is misaligned from the slit centre in the z-direction, slight shifts in the spacecrafts pointing will cause the object to be moved up and down the very steep beam profile. As an example, a misalignment of 5" in the z-direction in band 1D will reduce the incident flux on the detectors by 50%. The 1 arcsec jitter will then move it from the 70% contour to the 30% one – the incident flux can change by more than a factor of 2 on short time intervals.

This also explains the increased noise. Each of the detectors 24Hz readouts (contained in the ERD) are from (slightly) different incident flux levels. This introduces extra noise into the system when the pipeline tries to fit a slope to the 24Hz readout data.

So, this effect, primarily noticeable at short wavelengths, can happen if: the entered pointing is incorrect by more than $\approx$ 4 arcseconds; or there is a nearby bright object, which can happen in crowded fields.

We urge users to examine all entered pointings to ensure no errors have been made when entering coordinates, to go to catalogues to get the latest coordinates and to ensure there are no bright objects within ≈ 10" of the intended target.

5.6. RSRF and effect of fringes

The Relative Spectral Response Function (RSRF) is the total throughput of the system. It arises from the convolution of the detector response as a function of wavelength, the filter response as a function of wavelength and takes such effects as geometrical considerations (e.g. slit width, source structure) into account.

Fringes are a modulation with wavelength of the light falling on the detectors. The fringes arise due to constructive/destructive interference in either in the detector material itself or in the filter material. Bands 1, 2 & 4 are only lightly affected by fringes, whereas the fringes are more pronounced in band 3. An example of fringes in the band 3D spectrum of a star can be seen in figure 6.

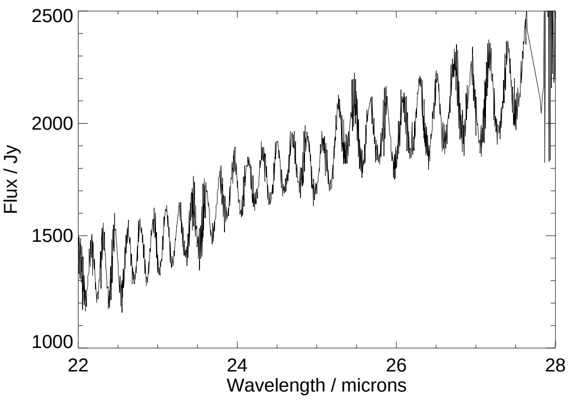

Figure 6. Example of fringe effects in band 3

An attempt is made to remove fringes during the OLP processing pipeline. However, because the fringes may shift in wavelength space depending on where the source is in the slit and whether the objects being observed is a point source or extended, fringe removal may not be perfect. This may cause problems for observations of faint sources. Faint features should be checked against the relevant Relative Spectral Responsivity File, SWS Cal-G 25_x, to ensure they are not artifacts.

Derivation of a complete set of in-orbit RSRFs is needed to obtain an optimal flux calibration accuracy. This calibration is still ongoing, and until complete the RSRFs measured in the lab have to be used for most bands. For the current version of OLP (V6.1) the Cal-G files containing the RSRF's were updated (e.g. with broad-band corrections) leading to a significantly improved calibration of the spectra. The few problems found in the new calibration files were, however, almost always present in the previous set of RSRF's, and are:

1 Band 2C – Spurious Features
Based on analysis of many sources it was concluded that features seen at 9.35, 10.05, 11.05 μm are most likely due to responsivity correction. The features occur at: 9.35 μm in absorption with a FWHM of 0.3 μm; 10.05 μm in emission with a FWHM of 0.1 μm; and 11.05 μm in emission with a FWHM of 0.1 μm.

2 Band 3D – 28 μm leak
Some sources exhibit a slight increase in the flux seen from about 27 μm onwards. This is not real but is due to leakage from approximately 13 μm, is of the order of 10% and will primarily affect objects with flux falling sharply towards long wavelengths.

3 Band 3E – Suspected Slope Change
There is a suspect slope change in the middle of this band in many observations. This is not due to a spectral feature in the source that was used to derive band 3E RSRF.

4 Band 4
This file has not been updated, due to a lack of calibration sources for band 4. It bends down at the short and long wavelength edges.

6. CONCLUSIONS

This paper is based on a small extract of the information available on SWS. It has discussed the steps that should be taken when analysing SWS data, what to be aware of in the data and what the current accuracy of the calibration is.

Users are reminded to read the SWS IDUM (Leech, K. *et al.* 1997a) and to consult the ISO Web site (http://isowww.estec.esa.nl/) for the latest information.

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