Improvements in the OLP 10 RSRF and Flux Calibration of ISO-SWS Bands 2A and 2C

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Abstract

The STARTYPE group led by S.D. Price at the Air Force Research Laboratory has found spurious features present in their SWS observations of early type stars. Two broad and prominent features ($\sim$ 5%) occur between 4 and 6 μm and 7 and 12 μm. Analysis has shown that at least part of these features can be explained by sytematic errors in the calibration caused by deficiencies in the synthetic spectra used for the RSRF and absolute flux calibration. All SWS spectra produced from Off Line Reprocessing OLP 10 are affected by this calibration problem. The OLP 10 products have been publicly available since June 8th of 2001 but available in the SWS Interactive Analysis software since November 2000.

Thanks to the input of the STARTYPE group and the ISO Data Center (IDC), the SWS team was able to correct the problem and include the correction in the final ISO archive. The IDC is currently reprocessing the SWS database in a new version of the Off-Line Reprocessing, OLP10.1. We encourage all users of OLP 10 products to review the reprocessing note available at the IDC and assess the impact on their data. The release of this note is accompanied by the release of OLP10.1, so that, if necessary, corrected data may be obtained from the ISO Data Archive.

1 Introduction

This note is intended to communicate to all SWS users the nature of changes to the SWS calibration delivered to the IDC on 6-11-2001. Given that OLP10 is the last processing of the entire archive at the IDC, it is important to layout all reasons for last minute changes to the calibration.

In this note we describe the problem present in the OLP10 calibration and the changes that are made to correct this problem. We also provide our analysis of the problem which indicates how it is introduced into the calibration. This results in changes to the Relative Spectral Response Function (RSRF) for bands 2A and 2C and a change in the absolute photometric calibration of band 2A. We also discuss the choice of models used for the calibration. Finally, we present a verification of the new calibration and an indication of the role memory effects and satellite mis-pointings still play in the overall calibration of SWS.

2 The Problem

The SWS and the IDC have been contacted by the STARTYPE group (S.D. Price, G. Sloan and K. Kraemer) at the Air Force Research Laboratory about systematic problems with their spectra based on OLP10 data. The problems they describe are emission features of $\sim$ 4-6% in SWS AOT bands 2A and 2C and a systematic slope of $\sim$2% across band 2B in stars where such features are non-physical. Furthermore, the shape of the features are suggestive of the CO fundamental at 4.3-5.5 μm and the SiO fundamental at 8-11 μm. Figure 1 shows the mean ratio from 2.3 to 11.5 μm of stars processed with the STARTYPE post AAR processing and the Cohen et al. absolutely calibrated composite spectra [1, 2, 3] of a sample of stars in the SWS database [6]. The STARTYPE group interprets the systematic differences between composite spectra by Cohen and the result of their processing of SWS spectra as deficiencies in the late-type star synthetic spectra by Decin ([5]) used for the OLP 10 RSRF calibration [8] and absolute photometric calibration [7]. However the problem is not so transparent. It should be noted, that the original validation report of L. Decin for OLP 10 also discusses some of the same RSRF problems as described in this note. It is unfortunate that these earlier warnings went unheeded.

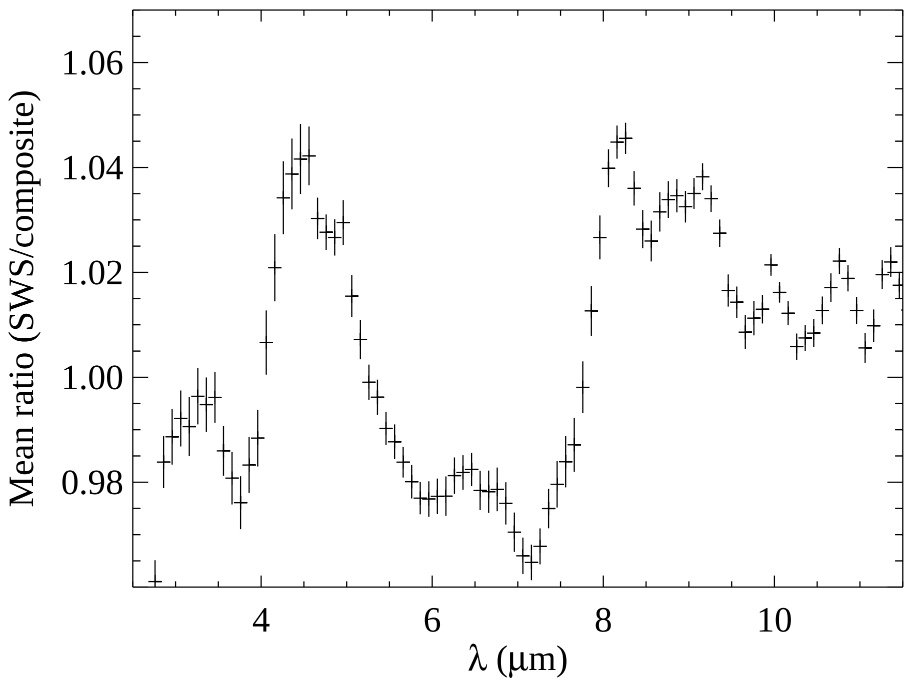

Figure 1: A sample of stars processed with OLP10 calibration and STARTYPE post processing ratioed to Cohen absolutely calibrated spectra of same the stars [6].

3 Analysis

We have analyzed the systematic differences described, and have tried to disentangle systematic RSRF and flux calibration problems, systematic differences introduced by the post-pipeline processing of the data by the STARTYPE group (e.g. splicing together of the bands) and systematic memory effects that look the same on many of the sources used to produce Figure 1. It is clear that any update to the SWS calibration should avoid to correct for the latter two.

Based on the analysis in the following sections, we conclude that there is indeed room for improvement in the RSRF calibration of bands 2A and 2C and in the absolute flux calibration of band 2A.

3.1 RSRF Change

The Relative Spectral Response Function (RSRF) corrects for the different response at any wavelength within an AOT band to the response at the key wavelength of the band [8]. The base RSRF was observed in the laboratory (ILT data) with a fully extended absolutely calibrated black body. Inflight, a series of measurements were made on standard stars for which models and/or composites are available. This revealed important deficiencies in the RSRF as determined in the laboratory. The small-scale accuracy of the ILT RSRF in band 2 is limited by instrumental fringing, less resolved in the ILT RSRF measurements of an extended black body source in the lab than in in-orbit observations of point sources. This inaccuracy however is confined to about 1% in band 2. This is better than the accuracy any in-orbit observation and/or model, composite or template can yield.

The broad-band accuracy of the ILT RSRF is much worse. When we calibrate SWS observations of stellar standards with the ILT RSRF and compare the spectra to synthetic spectra, composites or templates, we see broadband differences of up to 40%. The reasons for this are uncertainties and drifts in the black-body temperature in the lab, laboratory setup filter leaks, etc. It is this deficiency in the ILT RSRF that we correct for based on in-orbit observations.

We determine a continuous, broad-band correction curve to multiply the ILT RSRF with. This guarantees that we keep the high frequency uncertainty of the RSRF as low as the 1% in the ILT RSRF while improving the RSRF broad-band accuracy to the limit imposed by the in-orbit observation noise and the model spectrum or composite uncertainties. Since the RSRF is different for every detector in every AOT-band, we need to determine these corrections separately per band and per detector.

If all models were perfect, and all the SWS observations of calibration stars were perfect (i.e. no noise. no pointing errors, no memory effects, etc), the division of the model by the SWS-observation calibrated with the ILT RSRF would be exactly the same for every calibration star. Figures 2-4 show that this is not the case. We show the SWS data from one detector for a selection of calibration stars divided by the flux densities expected from the corresponding synthetic spectrum (from now on, we refer to these divisions as 'residues').

The spread in the residues in band 2C (figure 2) amounts to about 10%-40%. In figure 2 we have plotted the residues of early-type and late-type stars separately. This shows a clear difference in the residues of stars later than K0 and earlier typesr:. in the SiO band region the residues of cool sources show a kink that goes 4% below and 4% above the hot star residues. This systematic difference is to a large extent caused by the less reliable depth of the SiO band in the synthetic spectra of the cool sources. For the OLP10 calibration, the correction curve (a smoothing spline, for details see Vandenbussche et al. 2001), was based on all the calibration sources. It is clear that here we gain RSRF accuracy when using the hot stars only. However, the noise in the residues at the red end of the band makes it important to have a large number of observations to get an acceptable accuracy in the correction for e.g. the 10 and 11 μm features. We

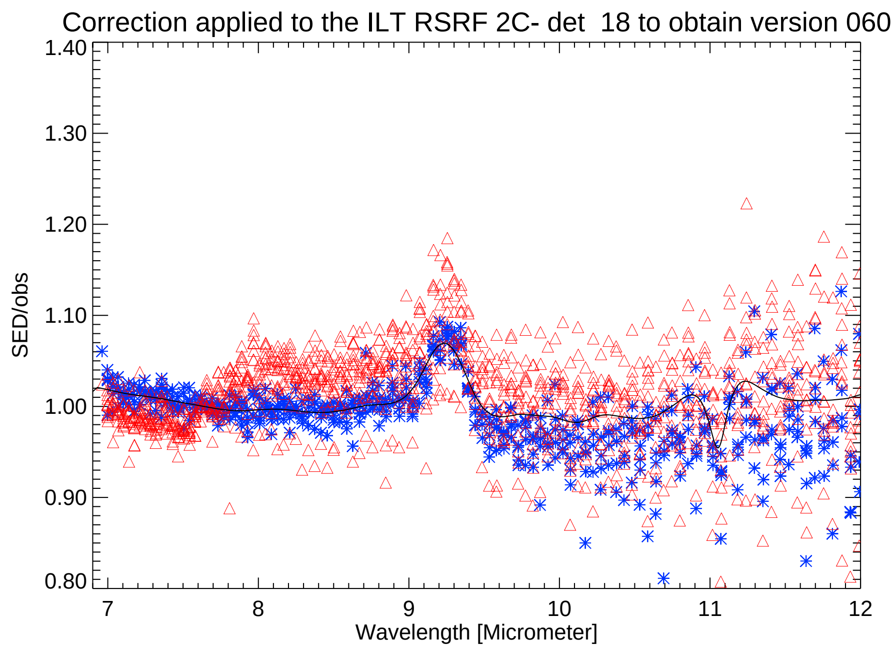

Figure 2: Band 2C - det 18 : the residues (SED/SWS observation with ILT RSRF) for stars earlier than G9 (blue) and later than G9 (red). The black curve shows the correction smoothing spline used to obtain cal25_2c_060.

therefore use the hot sources (as listed above) only for the wavelength region till 9.8 μm. For the rest of the band, we have kept the OLP 10 correction for the ILT RSRF. To avoid artifacts at 9.8 μm we have imposed a continuity criterion in the second derivative of the last spline segment of the new correction spline for the blue end. The result can be seen in Figure 2 where the black curve is the correction curve determined to obtain cal25_2c_060. The calibration sources, observations and models used are the following :

Source	Type	Observation	Model
Sirius HR2491	A1 V	68901202	hr2491_m_ldecin
Vega HR7001	A0 V	17800601	hr7001_m_ldecin
α Car HR2326	F0 II	72902207	hr2326_m_ldecin
α Cen A	G2 V	60702006	alp-cen_m_ldecin
δ Dra HR7310	G9 III	20601232	hr7310_m_ldecin

Figure 3 shows the residues in band 2A of calibration stars cooler than G9 (red) and earlier than G9 (blue). In the wavelength region of the CO fundamental band there is a systematic difference between the hot and the cool star residues. It is clear that the SEDs of the K and M giants are less accurate in this wavelength region. These are also the sources which show the most discrepancy between the MARCS models and the Cohen composites and templates. The general correction applied to the ILT data RSRF is upto 40% for band 2A but there is still a clear difference of a few % between the hot star sample and the

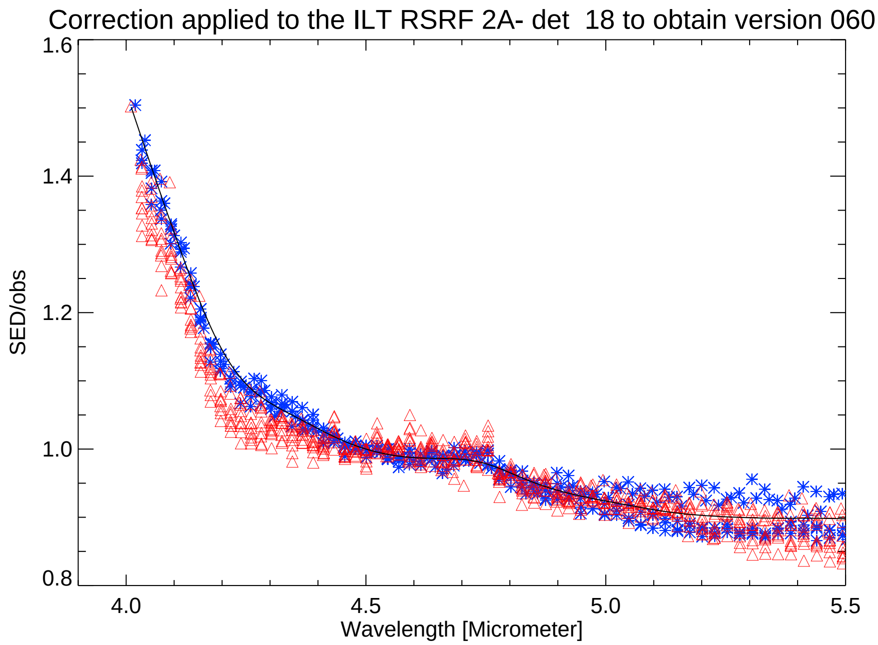

Figure 3: Band 2A - det 18 : the residues (SED/SWS observation with ILT RSRF) for stars earlier than G9 (blue) and later than G9 (red). The black curve shows the correction smoothing spline used to obtain cal25_2a_060.

cool star sample. We confirm that we can improve the accuracy of the RSRF correction by a few percent if we correct for the hot star residues only. The black curve in figure 3 shows the correction curve determined for detector 18.

Figure 4 shows the residues for detector 18 in band 2B. No significant difference is seen between hot and cool stars, so we have not produced a new RSRF based on hot sources only.

3.2 Absolute Flux Calibration Change

The absolute flux calibration at the key wavelength shows a difference only for band 2A when calibrating purely against the hot stars (4%). For bands 2B and 2C no significant differences were found in the signal-to-flux ratios with respect to the OLP10 calibration. The three time dependent cal42 (114, 214, and 314) files have been updated accordingly.

We note here that SWS AOT bands are notoriously difficult to match at their overlap regions. There are two main reasons why the bands do not naturally line up. Slight satellite mis-pointings, on the order of 1.5”, are enough to introduce uncertainties of 4% in absolute photometry of bands between 1A and 2C. Mis-pointings also make the relative photometry uncertain by 4% between AOT bands of different apertures (bands 1B-1D, 1E-2A, 2B-2C and 2C-3A). Secondly, a more elusive cause for band mis-matches is detector memory effects which can have significant influence on the band 2 overlap regions (bands 1E-2A, 2A-2B, 2B-2C and 2C-3A).

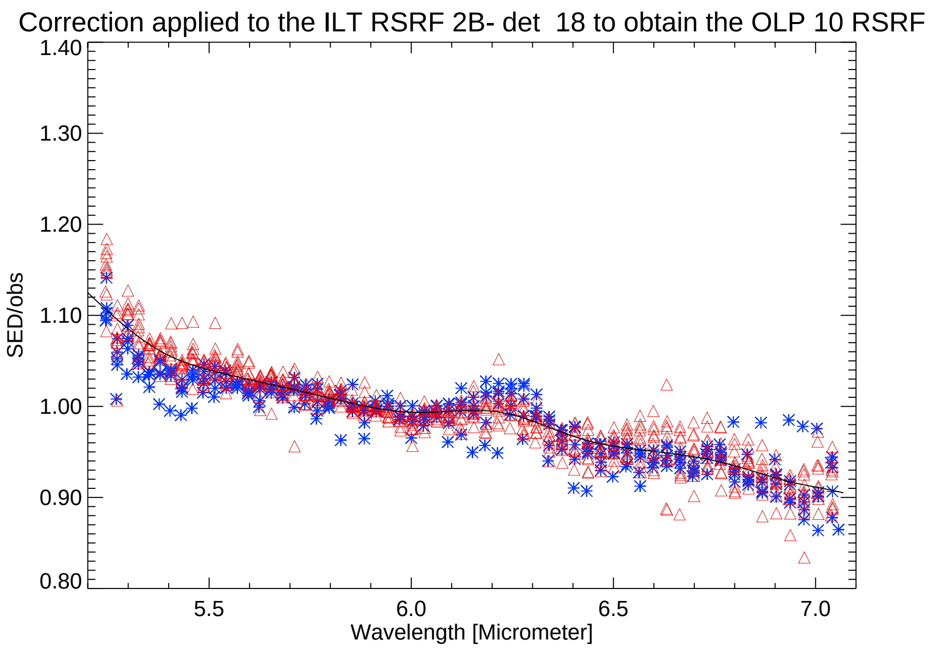

Figure 4: Band 2B - det 18 : the residues (SED/SWS observation with ILT RSRF) for stars earlier than G9 (blue) and later than G9 (red). No significant difference is seen between hot and cool stars. The black curve shows the correction smoothing spline used to obtain the OLP 10 RSRF.

Any code which combines all AOT bands of SWS to form a smooth final spectrum will necessarily re-calibrate every AOT band (except one) based on the data observed within the overlap regions.

4 Choice of Models

Although the calibration problem of OLP 10 was a deficiency in the models of the standards used, we believe that this deficiency is quite localized to wavelength regions where the models have the least information (CO fundamental and SiO fundamental). All the models used have been extensively validated against band 1 data (2.3 to 4 μm). The models are fully described in the PhD Thesis of L. Decin [4] and references therein. Since the models are well documented and validated at the shortest wavelengths, we prefer to use one consistent set throughout the entire short wavelength section of SWS.

Furthermore, the absolute calibration of the synthetic spectra applied the same photometry as the photometry used by Cohen for the absolute calibration of composites and templates. The scaling of the models to the photometry of the composites guarantees the consistency with the use of the Cohen composites and templates for the long-wavelength section.

For the early-type stars used in band 2A and the short-wavelength end of 2C, the differences between the composites/templates by Cohen and the synthetic spectra by Decin are less than two percent. We are confident that the models themselves are not introducing 2% features in any AOT band of the short wavelength section of SWS.

5 Verification of the New Calibration

In figure 5 we show a rebinned aar with the new calibration divided by the OLP10 AAR. This can be compared to the mean ratio curve of the STARTYPE group (figure 1). We see a qualitative agreement in the differences around 4.5 μm and the difference in the short-wavelength end of 2C. We interpret the 2% features in the 9-12 μm region in the curve in Figure 1 as noise in the residues due to large differences in memory effects.

During the scientific validation of OLP 10.0, L. Decin described two wavelength regions where the RSRF correction could be improved in band 2A and 2C. The features she described in the comparison of synthetic spectra and OLP10 SWS spectra compare well with the changes to the RSRF calibration for OLP10.1.

We believe the accuracy of the absolute and relative flux calibration has improved with the new delivery. The improvement, however, is at a level smaller than the typical reliability of individual band 2 observations because of memory effects. An example can be seen in Figure 6. We have plotted an AOT1 and an AOT6 observation of sirius, processed with OLP 10 and the new calibration. One can see that the difference between the two observations (with different scanning strategies and hence different memory effect regimes) are comparable to the differences between the two calibrations (we only consider the short wavelengths, at longer wavelengths the situation only gets worse).

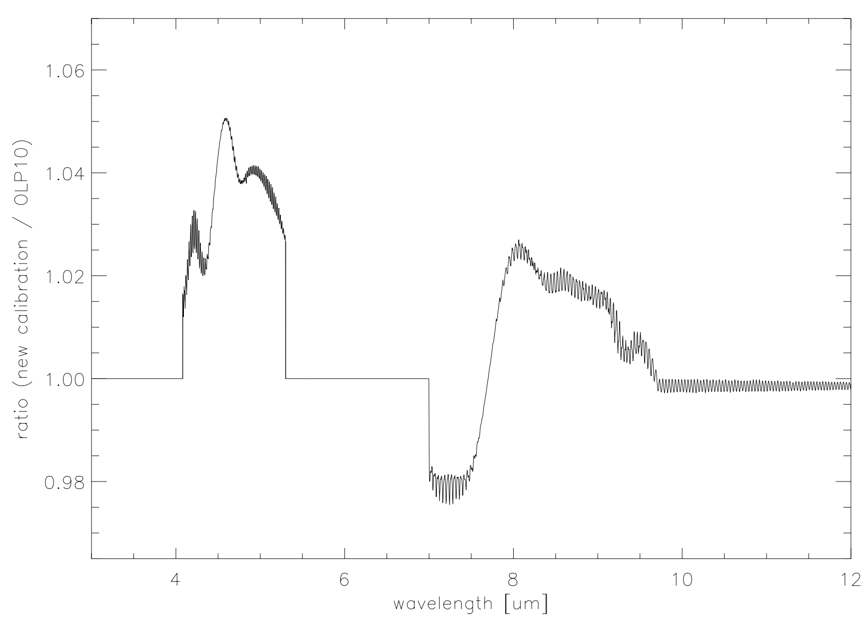

Figure 5: The division of a rebinned OLP10 AAR and an AAR processed with the new calibration.

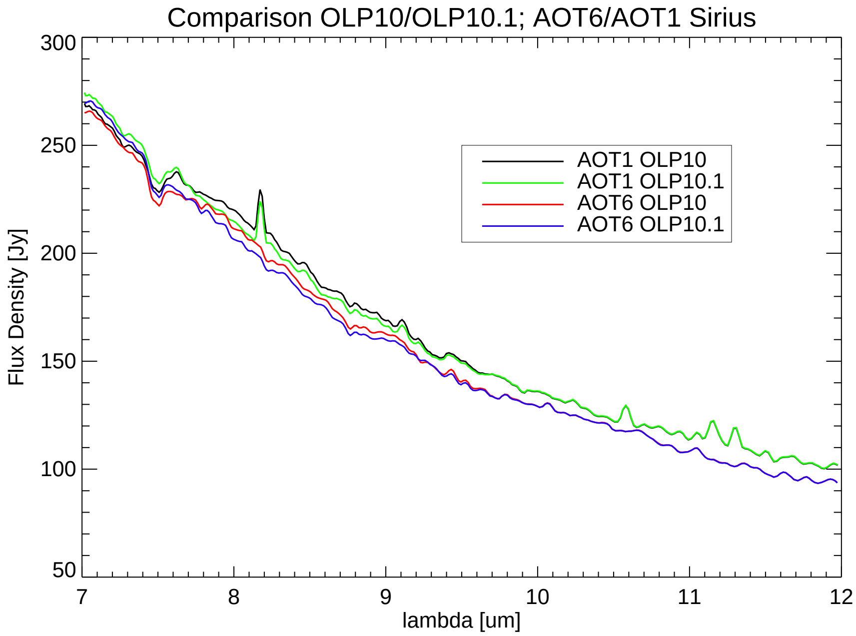

Figure 6: Two observations of Sirius : AOT1 (black) and AOT6 (green) as processed with OLP10. The blue and the red curves show the same data processed with the new calibration used in OLP10.1.

We should be aware of the fact that, although we might have taken away concerns about biasing to errors in synthetic spectra, there is a risk that the (1) low number of observations, (2) the similarity of the spectral shape in the observations and (3) the nearly identical observation mode (AOT1 speed4, Vega is observed with speed 3) in the new calibration can introduce a systematic bias to the typical memory effect signature in AOT1-speed 4 observations of hot stars. We have verified that this bias is in any case not worse than the bias previously present in the olp 10 calibration.

References

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