



**[Venus Express]-[SPICAV/SOIR]**

SOIR calibration description

Issue 001

17 May 2011

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## Change Log

<b>Date</b>	<b>Sections Changed</b>	<b>Reasons for Change</b>
17/05/2011	All	Creation of document from SOIR_CALIBRATION_DESC.TXT



## Table of Contents

<b>Change Log</b> .....	<b>1-2</b>
<b>Table of Contents</b> .....	<b>1-3</b>
<b>1 Introduction</b> .....	<b>1-4</b>
<b>2 Calibration steps to create the PSA data level 2</b> .....	<b>2-4</b>
2.1 Step 1: Detector non linearity correction .....	2-4
2.2 Step 2: Wavenumber calibration.....	2-6
2.3 Step 3: Order number calculation and AOTF frequency to wavenumber calibration.....	2-6
2.4 Step 4: Full Sun referencing .....	2-6
2.5 Step 5: Tracing the calibration history .....	2-7
<b>3 Calibration steps to create the PSA data level 4</b> .....	<b>3-7</b>
3.1 Step 1: The AOTF transfer function .....	3-7
3.2 Step 2: The blaze function .....	3-7
<b>4 Description of the CALIB directory</b> .....	<b>4-7</b>
4.1 Introduction.....	4-7
4.2 Pixel to wavenumber calibration file .....	4-7
4.3 The AOTF frequency to wavenumber calibration file .....	4-8
4.4 The AOTF transfer function calibration file .....	4-9
4.5 The blaze function calibration file .....	4-9



## 1 Introduction

This file describes the different calibration steps to bring SOIR raw data (PSA level 1B) to calibrated data (PSA level 2). It also describes the files contained in the CALIB directory.

## 2 Calibration steps to create the PSA data level 2

### 2.1 Step 1: Detector non linearity correction

For low signal intensity the detector has a non-linear response. The definition of linearity by the manufacturer is not fully understood. Nevertheless, one has the impression that the pixel is linear within 2 % if it is filled less than 98 % and more than 25 %. Between 10 and 25 % of full well the error grows to about 4 %. Non-linearity correction has to be applied.

It is understood that this correction routine is only applicable on data sets that contain signal values with on board subtracted background.

#### 1) Calculate exact number of accumulations for this observation

$$n\_accum = (dcbf+1) * (nracc-1)/2$$

with *dcbf* and *nracc* two parameters in the SOIR telemetry.

*dcbf* is number of lines binned and *nracc* is number of bins accumulated.

For details see TMTC TM/TC document in DOCUMENT directory.

#### 2) Calculate exact integration time for this observation (in milliseconds)

$$integ\_time\_ms = deit1/1000$$

with *deit* a parameter in the SOIR telemetry.

*deit* is integration time in microseconds.

For details see TMTC TM/TC document in DOCUMENT directory

#### 3) Read the background value corresponding to this integration time (ADC codes) in the *bkgcodes\_vs\_integtime* table (based on measurement during CRUISE phase on Feb 21st 2006)

## background codes vs. integration time for *integtime* = 0, 1, ..., 150 ms

```
bkgcodes_vs_integtime =  
[663, 663, 679, 693, 706, 721, 738, 755, 772, 790, 808, 827, 846, 866, 886, 908,  
930, 952, 975, 1000, 1024, 1050, 1077, 1104, 1134, 1164, 1194, 1225, 1257, 1289,  
1323, 1357, 1391, 1427, 1463, 1500, 1536, 1574, 1611, 1650, 1688, 1727, 1766, 1806,  
1846, 1886, 1926, 1966, 2008, 2048, 2089, 2131, 2173, 2215, 2257, 2299, 2340, 2383,  
2426, 2469, 2511, 2555, 2599, 2641, 2684, 2729, 2772, 2815, 2860, 2903, 2947, 2992,  
3035, 3080, 3125, 3168, 3213, 3257, 3302, 3346, 3391, 3437, 3481, 3527, 3572, 3616,  
3661, 3706, 3752, 3797, 3842, 3887, 3933, 3977, 4022, 4068, 4113, 4159, 4205, 4250,  
4296, 4342, 4387, 4432, 4479, 4524, 4570, 4616, 4661, 4707, 4753, 4799, 4844, 4891,  
4936, 4982, 5028, 5075, 5121, 5166, 5212, 5259, 5305, 5350, 5396, 5442, 5488, 5534,  
5581, 5627, 5672, 5719, 5765, 5811, 5858, 5903, 5950, 6042, 6088, 6134, 6182, 6227,  
6274, 6319, 6366, 6412, 6458, 6504, 6551, 6597]
```

The ADC values correspond to different integration times and hence to different quantities of thermal background photons. The collected pixel charges are converted by the read-out process into ADC units. There is a non-linear relation between



collected photons and observed ADC units. The ADC values include an offset (about 660 units) in the video amplifier electronics introduced to allow for aging margin.

We assumed a perfectly linear relationship between integration time and the quantity of photons that is equal for all pixels within a grating order and over all grating orders (wavelengths). This assumption is only valid if pixel quantum efficiency would be constant over pixels and wavelengths. This relationship is most probably also temperature dependent.

```
adc_bkg = non_lin_correction.bkgcodes_vs_integtime[integ_time_ms]
```

#### 4) Reduce the spectrum pixel values to one non-binned non-accumulated values

```
adc_sig = float(data[i]) / n_accum
```

#### 5) Make sum of ADC value of (measured) signal and (estimated) background

For spectra which have the thermal background subtracted on-board, the real charge collected on the pixel capacitor is still the result of the combined input of signal photons and thermal background photons

```
adc_sig_plus_bkg = adc_sig + adc_bkg
```

#### 6) Conversion of ADC units into Arbitrary Charge Units (ACU)

During the measurement with different integration times (Feb 21<sup>st</sup> 2006), we have collected different amounts of thermal background photons that have produced different amounts of electrons or charges in the pixel. Because we do not know the exact thermal background level, these quantities are not calibrated. Therefore we introduce the concept of Arbitrary Charge Units, in which we will express signal levels. It is suggested that the value of the arbitrary charge units equals the integration time value.

The measured relation between ADC units and ACUs can be approximated by the following equation (10 degrees polynomial if ADC units < 6000 and a linear relationship above 6000 ADC units) :

```
adccode_to_charge( x ):  
  
if x < 6000:  
    y=-109.4112717552833+x*(0.3281672408563101+\  
    x*(-0.0003846513541535442+x*(2.869226627796301E-07+\  
    x*(-1.381722060516796E-10+x*(4.459643046851159E-14+\  
    x*(-9.752279474228916E-18+x*(1.426792904826683E-21+\  
    x*(-1.337703563748429E-25+x*(7.266297806363216E-30+\  
    x*-1.738835026549852E-34)))))))))  
else:  
    y = 6.0634764 + 0.02184421*x
```

with x = ADC units and y = ACUs

#### 7) Calculation of new corrected pixel values

```
charge = non_lin_correction.adccode_to_charge( adc_sig_plus_bkg ) - integ_time_ms
```



## **2.2 Step 2: Wavenumber calibration**

The wavenumber to pixel calculation is done using the formula

$$\nu_p^n = (a + b \cdot p + c \cdot p^2) \cdot n$$

where  $\nu_p^n$  is the wavenumber in  $\text{cm}^{-1}$  of pixel  $p$  in diffraction order  $n$  and  $a$ ,  $b$  and  $c$  the coefficients of a second order polynomial. The values of the pixel number range from 0.5 to 319.5, and the order number is a value between 101 and 194. The values of the coefficients are reported in the PIX\_WN.TAB file in the CALIB directory of the repository.

## **2.3 Step 3: Order number calculation and AOTF frequency to wavenumber calibration**

From the AOTF frequency, the value of the diffraction order is calculated. The relation between the AOTF frequency and the wavenumber is given as

$$\nu = a + b \cdot f + c \cdot f^2$$

with  $\nu$  the wavenumber in  $\text{cm}^{-1}$  and  $f$  the AOTF frequency in Hz.

The value of the AOTF frequency programmed in `aofs1`, `aofs2`, `aofs3` and `aofs4` are transformed into their corresponding wavenumber:  $\nu_1$ ,  $\nu_2$ ,  $\nu_3$  and  $\nu_4$ .

Then, for each order, the order center wavenumber is computed using the formula described in the previous section (section 2.2):

$$\nu_{center}^n = \frac{\nu_{0.5}^n + \nu_{319.5}^n}{2} = \frac{(b \cdot 320 + c \cdot (319.5^2 + 0.5^2)) \cdot n}{2}$$

The values of  $\nu_1$ ,  $\nu_2$ ,  $\nu_3$  and  $\nu_4$  are compared to list of  $\nu_{center}^n$  values, and the each order is assigned considering the closest value between the both lists.

## **2.4 Step 4: Full Sun referencing**

### **1) Selection of the zone of interest from the total data set**

The zone of interest is defined using the following criteria:

- Beginning when SOIR altitude of measurement is 220km (defined from the attitude files, refraction taken into account)
- End when SOIR altitude of measurement is 60 km (defined from the altitude files, refraction taken into account)

### **2) Selection of the reference zone**

The reference zone is defined using the following criteria:

- End one second before start of the zone of interest
- Beginning such that reference zone lasts for 39 or 40s

The reference spectrum is calculated for every pixel as a linear regression in function of time on the reference zone as described here above. This is to account for the observed drift of the satellite during the occultation.

### **3) Division of spectra in observation zone by reference spectrum to obtain transmittance values (between 0 and 1)**



## 2.5 Step 5: Tracing the calibration history

Look into the .TRT additional data files on PSA level 2.

Example:

```
0.1_TO_0.2_SCRIPT_VERSION,[SVN revision nr]
0.2_TO_0.3_SCRIPT_VERSION,[SVN revision nr]
0.2_TO_0.3_REGRESSION_ZONE,20070415053104-20070415053143
0.2_TO_0.3_OCCULTATION_ZONE,20070415053144-20070415053230
0.2_TO_0.3_REGRESSION_ALTITUDE,220
0.3_TO_1.0_PDS_CREATION,[SVN revision nr]
```

## 3 Calibration steps to create the PSA data level 3

### 3.1 Step 1: The AOTF transfer function

The AOTF transfer function describes the behavior as a function of the wavenumber for a given AOTF excitation frequency, corresponding to a diffraction order.

More details about the physics underlying the AOTF and its characteristics can be found in:

- Nevejans et al., *Compact high-resolution spaceborne echelle grating spectrometer with acousto-optical tunable filter based order sorting for the infrared domain from 2.2 to 4.3  $\mu\text{m}$* , Applied Optics, Vol. 45, No. 21, 20 July 2006;
- Mahieux et al., *In-flight performance and calibration of SPICAV SOIR onboard Venus Express*, Applied Optics, Vol. 47, No. 13, 1 May 2008;
- Mahieux et al., *A new method for determining the transfer function of an Acousto optical tunable filter*, Optics Express, Vol. 17, No. 3, 2 February 2009.

### 3.2 Step 2: The blaze function

The blaze function corresponds to the efficiency of the echelle grating as a function of the incident angle to the blaze angle. In the case of SOIR, it takes values between 0 and 1, and these values are given per diffraction order.

The blaze angle has been computed from calibration measurements.

## 4 Description of the CALIB directory at PSA level 4

### 4.1 Introduction

The CALIB directory contains 4 calibration files available in the PDS3 format:

- The pixel to wavenumber calibration file
- The AOTF frequency to wavenumber calibration file
- The AOTF transfer function calibration file
- The Blaze function calibration file.

Each file is accompanied with a CAT file, in the PDS3 format.

### 4.2 Pixel to wavenumber calibration file

The pixel to wavenumber calibration data are given in the PIX\_WN.TAB file. This file is made of 6 columns, the first one giving the relation type (pixel to wavenumber – PIX->WN – or wavenumber to pixel – WN->PIX). The relations are defined in Section 2.2. The second column gives the binning case and the third one the bin number. Table 1 summarizes the detector lines that are summed up for each case and Table 2 gives the different binning cases.

Detector line number	Binning case			
	8 x 3	8 x 4	2 x 12	2 x 16
187	-	1	-	1



188	-	1	-	1
189	-	1	-	1
190	-	1	-	1
191	1	2	1	1
192	1	2	1	1
193	1	2	1	1
194	2	2	1	1
195	2	3	1	1
196	2	3	1	1
197	3	3	1	1
198	3	3	1	1
199	3	4	1	1
200	4	4	1	1
201	4	4	1	1
202	4	4	1	1
203	5	5	2	2
204	5	5	2	2
205	5	5	2	2
206	6	5	2	2
207	6	6	2	2
208	6	6	2	2
209	7	6	2	2
210	7	6	2	2
211	7	7	2	2
212	8	7	2	2
213	8	7	2	2
214	8	7	2	2
215	-	8	-	2
216	-	8	-	2
217	-	8	-	2
218	-	8	-	2

Table 1: List of detector line numbers for each bin of each binning case

Binning case	Number of lines per bin	Number of binning groups
8 x 3	3	8
8 x 4	4	8
2 x 12	12	2
2 x 16	16	2

Table 2: List of the binning possibilities

The three last columns give the values of the second order polynomial coefficients. There is one calibration file for the nominal mission, and for each extension of the mission.

### 4.3 The AOTF frequency to wavenumber calibration file

The AOTF frequency to wavenumber calibrations are given in the AOTF\_F\_WN.TAB with its associated LBL file. This file is made of 6 columns, the first one giving the relation type (AOTF frequency to wavenumber – F->WN – or wavenumber to AOTF frequency – WN->F). The relations are defined in Section 2.3. The second column gives the binning





case and the third one the bin number. Table 1 summarizes the detector lines that are summed up for each case and Table 2 gives the different binning cases.

The three last columns give the values of the second order polynomial coefficients.

There is one calibration file for the nominal mission, and for each extension of the mission.

#### **4.4 The AOTF transfer function calibration file**

The AOTF transfer function values are given in the AOTF\_F\_WN.TAB with its associated LBL file.

The first column gives the diffraction order number, followed by the centered wavenumber values (between  $-100$  and  $100 \text{ cm}^{-1}$  around the maximum, by steps of  $0.1 \text{ cm}^{-1}$ , 2001 in total), the transfer function values for bin 1 (2001 in total) and the transfer function values for bin 2 (2001 in total).

There is one line per order (94 in total).

#### **4.5 The blaze function calibration file**

The blaze function values are given in the BLAZE.TAB with its associated LBL file.

The first column gives the diffraction order number, followed by the centered wavenumber values (between  $-100$  and  $100 \text{ cm}^{-1}$  around the center of the order, by steps of  $0.1 \text{ cm}^{-1}$ , 2001 in total) and the blaze function values (2001 in total), same for bins 1 and 2.

There is one line per order (94 in total).