SWS AOT-1 High Resolution processing

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This document describes the implementation and use of the SWS AOT-1 high resolution reduction mode in **DSPD**. In this mode, AOT-1 (and low resolution CUS) observations can be re-reduced with **DSPD** to create spectra with a higher than nominal resolution. This is achieved by fitting multiple connected slopes to the low resolution integration ramps.

1 Introduction

The SWS AOT-1 observing mode was designed to take full range spectra (from 2.38 to 45 μm) in a limited time (from 10 minutes up to 2 hours). This was achieved using instrumental smoothing by moving the grating scanner over several LVDT steps within one integration reset interval. The size and the number of scanner step determines the speed of the observation and the resulting spectral resolution. For AOT-1 observations four speeds exist. Table 1 describes the four speeds in terms of the integration ramp as defined by its length, the time the scanner remains fixed (the dwell time) and the scanner step made between each scanner position. This determines the total number of scanner steps covered by a single integration ramp which convolved with the instrumental resolution in LVDT (ranging from app. 4 to 8 LVDT) gives the spectral resolution.

The basic idea behind the high resolution processing is to reverse the instrumental smoothing by fitting multiple slopes (from now on called subslopes) to the integration ramp in a single reset interval. These subslopes cover a smaller range of LVDT steps and consequently the final resolution of the retrieved spectrum will be higher.

This idea is not new and the possibility to derive AOT-1 high resolution spectra has been investigated and tried before with mixed success. Due to a not optimal **DSPD** calibration and reduction in previous pipeline version the results were in general not good. Now with version 10 of the pipeline the reduction of the **ERD** data, in particular the linearization corrections, are highly improved. This makes the derivation of high resolution AOT-1 spectra much more consistent and the results are in general quite good.

Speed	Duration	Reset	Dwell	Stepsize	Resolution
	[sec]	[sec]	[readout]	[LVDT]	degradation
1	1200	1	3	4	3.2∼5.4
2	1900	2	3	2	3.5∼6
3	3600	2	3	1	2∼3
4	6500	2	6	1	1.3∼1.5

Table 1: Definition of the AOT-1 observing speeds by reset length, dwell time and the LVDT stepsize. In the last column the degradation of the normal AOT-1 wrt. the full grating resolution is given. The degradation varies with detector band and with wavelength.

However, there is a price to pay. By splitting up the integration ramps the integration time on each individual slope becomes smaller and the uncertainty on the slope increases and the noise in the retrieved spectrum will also increase. Figure 2 illustrates the behavior of the different noise components and the overall noise with signal for different values of **SUBSLOPE** for an AOT-1 with a reset time of 2 seconds. In figure 3 and in table 3 another example of the noise behavior is given for two signal levels.

2 Implementation

The impact of the high-resolution processing for the SWS user has been kept to the bare minimum. The derivation of a high-resolution AOT-1 spectrum is done using the standard **DSPD** routine with the addition of a single keyword **SUBSLOPE**. This keyword defines the number of slopes into which each second of the integration ramp is split. So e.g. specifying **SUBSLOPE=1** will result into one slope per reset for an AOT-1 speed 1 (standard for speed 1) and in two slopes per reset for the lower speed AOT-1's. So only for a speed 1 observation **SUBSLOPE=1** will give the nominal result. **SUBSLOPE=0** will give the nominal result for all observations. **SUBSLOPE** values of 0,1,2,4 and 8 are possible.

The subslope fitting is only done on resets where the scanner is changing position. This means that there will be no impact on non-scan data (dark current and grating calibrator data) in an observation. This means that there will be no major change to the basic calibration of the spectrum compared to the standard pipeline. AOT-2 and AOT-6 observations will also not change. Some AOT-99 CUS observations can also change since the low resolution scanning was used for some of the CUS observations.

The new high-resolution **SPD** product will naturally differ in length. The extra slope points are treated like normal slopes. The subslopes are flagged as normal reset in the **SPD** status flag. By convention the **ITK** is defined as the time of the first **ERD** sample of the (sub)slope. In the header a **SUBSLOPE** keyword is added. The **SUBSLOPE** header keyword is used by **DECODE_RESET** together with the low resolution flag in the **SPD** to derive the full reset integration time. This is in particular important for the dark current subtraction to be able to identify the dark currents related to a particular scan. The full reset time is also displayed when using e.g. **PLOTSPD** or **PLOT_FULLSTATUS**.

For the **AAR** the same applies as for the **SPD**. On **AAR** level the **SUBSLOPE** header keyword is used by some routines (e.g. **SWS_REBIN** and **SIGCLIP**) to adapt the resolution used. The **RESOLUTION** module has been adapted to make a theoretical estimate of the resolution of AOT-1 observations at nominal and at high resolution by specifying the **SPEED** and **SUBSLOPE**.

2.1 erd to spd processing

The implementation of the AOT-1 high resolution data-reduction has resulted in a modification of the slope fitting and wavelength calibration routines. The major changes have been made to the slope fitting routine **ISP_LINEAR**. There a combined fit of the subslopes and glitches over the whole integration ramp is made. The subslopes are defined by their starting points (samples) and the fitted subslopes are of course required to connect.

The wavelengths of the individual subslopes are calculated over the valid samples (the same as used in the slope determination) of the subslopes to always ensure a proper wavelength is assigned.

Besides of having to specify **SUBSLOPE** in the call to **DSPD** there is no extra interaction required from the user besides having to verify the **SPD** has been derived properly.

2.2 spd to aar processing

For the processing of a **SPD** the modules **DECODE_RESET**, **AAS_DARK, DYNADARK** and **RESOLUTION** have been adapted. **DECODE_RESET** uses the subslope header keyword to rederive the proper reset times. In **AAS_DARK** and **DYNADARK**, **DECODE_RESET** is now used to derive the reset times from the **SPD** instead of the original internal routines.

The user however does not notice this and to derive an **AAR** the user uses the normal IA routines.

2.3 aar processing

On the post-daar level the user has to take the higher resolution into account when it comes to the scientific analysis and interpretation of the data. The standard reduction routines **SIGCLIP** and **SWS_REBIN** have been modified to give proper defaults for high resolution AOT-1 spectra. For the rest all routines are expected to work without problems. In case this is not true or in case the default used by the routines are improper please notify Fred Lahuis (freddy@sron.rug.nl). The module **RESOLUTION** has been updated to return the estimated resolution of AOT-1 observations at all speeds combined with the value of **SUBSLOPE**.

TBD

Wavelength	AOT-band	speed	grating resolution					
[μm]			full	AOT-1 subslope				
				0	1	2	4	8
2.5	1A	1	3623	761	761	1715	2652	3623
		2		591	1222	2110	3285	3623
		3		1137	2110	2971	3529	3623
		4		2110	2971	3529	3623	
10.0	2C	1	2617	574	574	1283	1956	2617
		2		446	919	1570	2392	2617
		3		856	1570	2178	2555	2617
		4		1570	2178	2555	2617	
35.0	4	1	1861	691	691	1316	1665	1861
		2		547	1032	1489	1806	1861
		3		975	1489	1743	1847	1861
		4		1489	1743	1847	1861	

Table 2: Summary of the calculated AOT-1 resolution at different wavelengths for the four AOT speeds at the available subslope values for each speed.

subslope	σ @ 0μV/s	σ @ 200μV/s	S/N @ 200μV/s
0	0.6	1.2	165
1	1.0	1.8	110
2	1.8	2.8	72
4	3.2	4.3	47
8	6.2	7.5	27

Table 3: The estimated noise for band 1 and 2 at 0 and 200 μV/s for a reset time of 2 seconds. For the latter the signal to noise ratio is also shown. These are the same values as those in Figure 3. Note that the noise increase for the lower signal is much lager (a factor of 10) than at the higher signal level (a factor of 7).

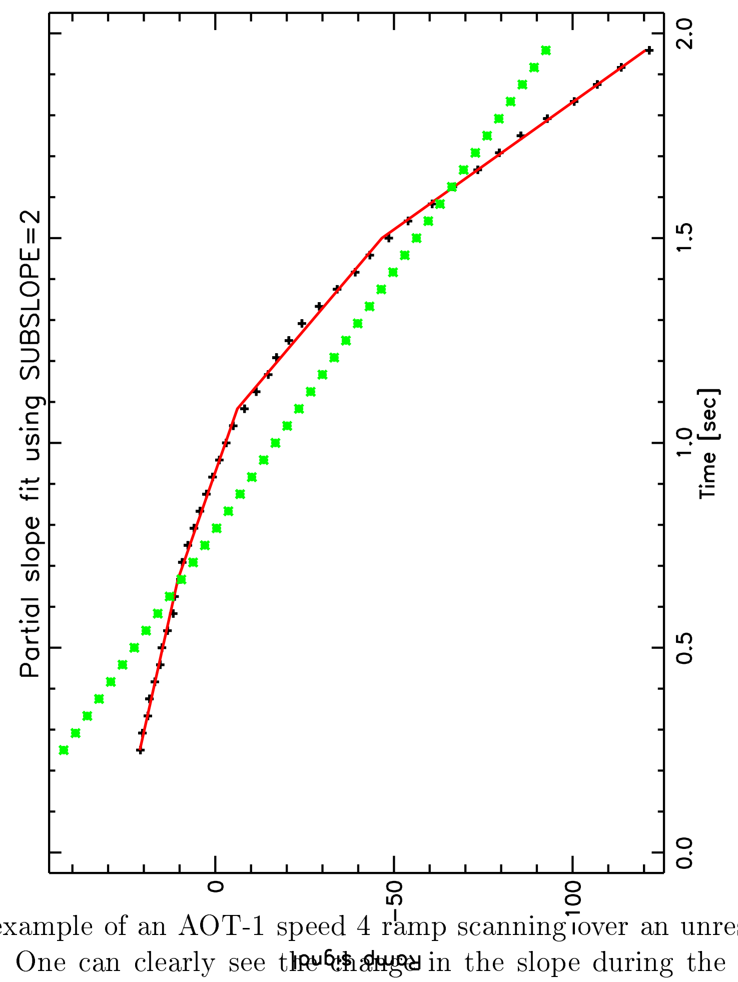

Figure 1: An example of an AOT-1 speed 4 ramp scanning over an unresolved emission line. One can clearly see the change in the slope during the integration. In green a single fit to the ramp is made as it is done in the pipeline (when using DSPD in the default mode). In red the slope fit is shown using subslope=2. This example is from a Ne II emission line for which the standard and high resolution spectra are shown in Figure 4.

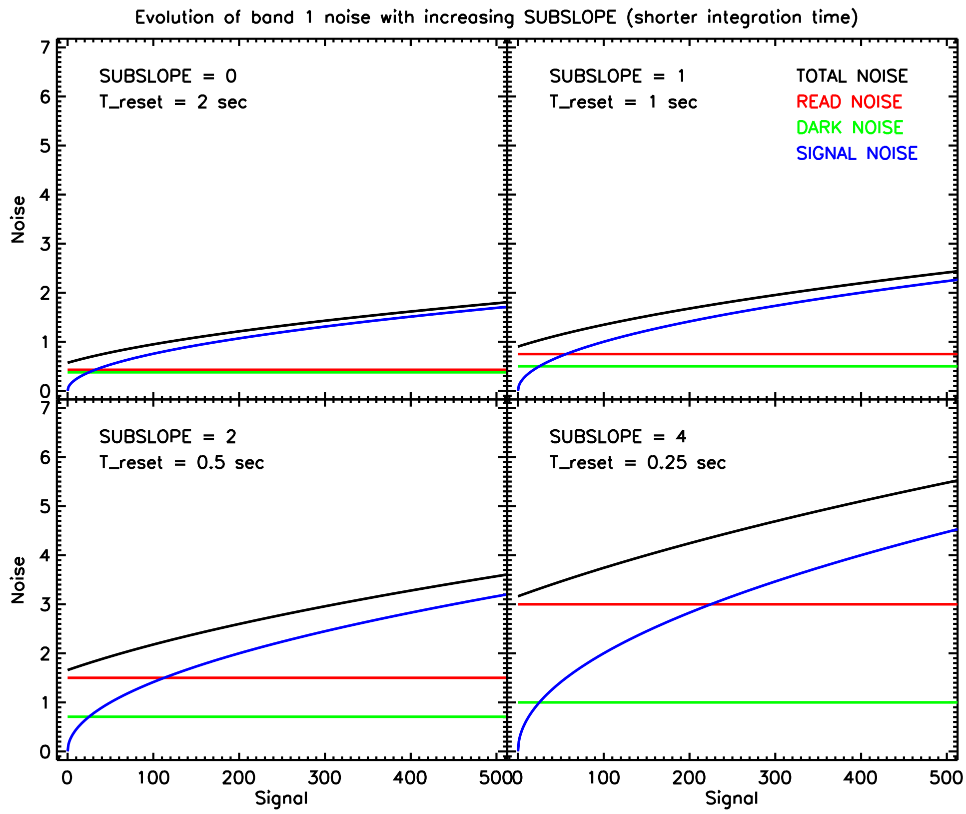

Figure 2: Shows the relation between the subslope value used and the resulting slope noise for nominal band 1 behavior. It will be clear from this figure that the dominating source of noise when going to higher values of subslope is the read noise.

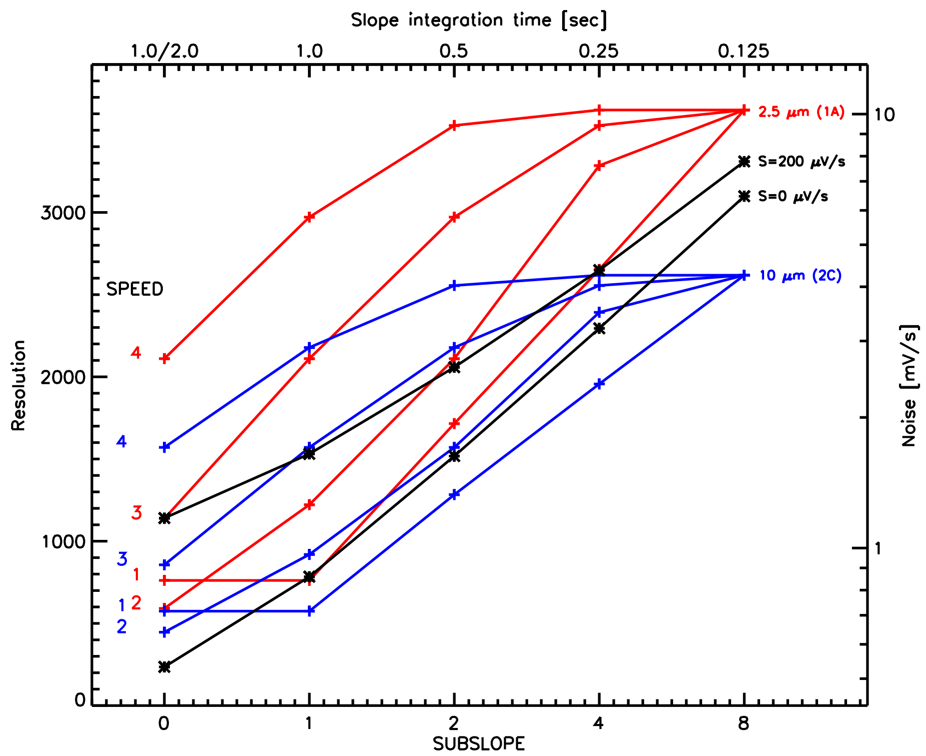

Figure 3: Illustration of the progression of resolution and noise with increasing subslope. The resolution is shown for all speeds at two wavelengths. The noise at two signal levels. Table 3 shows the noise values in numbers and also the signal to noise ration for the higher signal level.

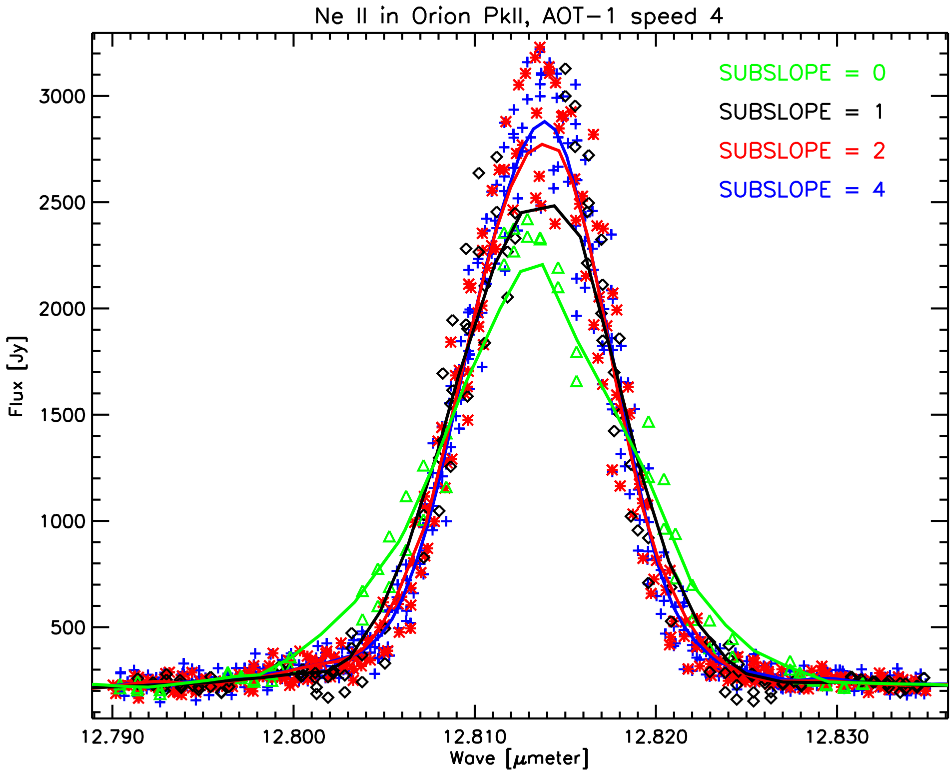

Figure 4: A Ne II emission line reduced with subslope values of 0,1,2 and 4. Besides the increased resolution the higher spectral sampling is evident. Especially the spectral sampling gives quite some improvements in the definition of the line shape (compare the rebinned lines of the subslope=0 line with the others) and in e.g. band 3 the definition of the fringes. It turns out that the results of the defringing is improved when using a high resolution AOT-1 spectrum compared with the results from the standard reduced spectrum.