Wavelength Calibration

By: Do Kester, Douwe Beintema and Edwin Valentijn (SRON)

During the lifetime of ISO we tried to keep the wavelength calibration fixed to within 1 LVDT. And succeeded in doing so.

The wavelength calibration which was established during PV is extensively described in the PV report. After about one year of operations it became clear from the biweekly done quick grating check that the calibration was shifting a little. In revolution 356 and 370 full grating scans were performed. The analysis and the conclusions from these full grating scans and from the trends in the quick grating checks was written down in a report 'Wavelength Calibration Update' which is added here as an appendix.

Since revolution 370, 3 more full grating scans were performed in revolutions 475/479, 669/670, and in the last month before He-boiloff. They were analysed, in much the same way as described in the appendix, resulting in updates for the grating polynome.

As it became apparent that regular updates of the grating polynome would be necessary, it was also decided to have a regular look at some external source with strong emission lines. For obvious reasons NGC6543 was chosen. Between revolution 360 and 800 27 of these observations were performed. They observed 8 lines in the SW section and 5 in the LW section. The lines were analysed, mainly by Helmut Feuchtgruber. In the figures **??** and **??** the results of his analysis are summarized. Apart from one obviously deviating line both in the SW and in the LW section, which we disregard from now on, there are two noticeable effects. Firstly, there is a constant shift of about 0.2 and 0.7 LVDT resp. for SW and LW. These shifts should not be there. Finally it was concluded that they were due to the different methods HF and DK are using in determining the center of an emission line cq. fringe. HF used Gauss-fitting and as we think the average astronomer is more inclined to use that tool too, we decided to take the effect out by shifting all apertures with the appropriate amount. The second effect is the slowly increaring trend (if we disregard the obvious steps at the points were a new calibration was introduced.) The slow trend indicates that a more precise wavelength calibration is possible by linear interpolation in the calibration files. This is something that remains to be done in the near future.

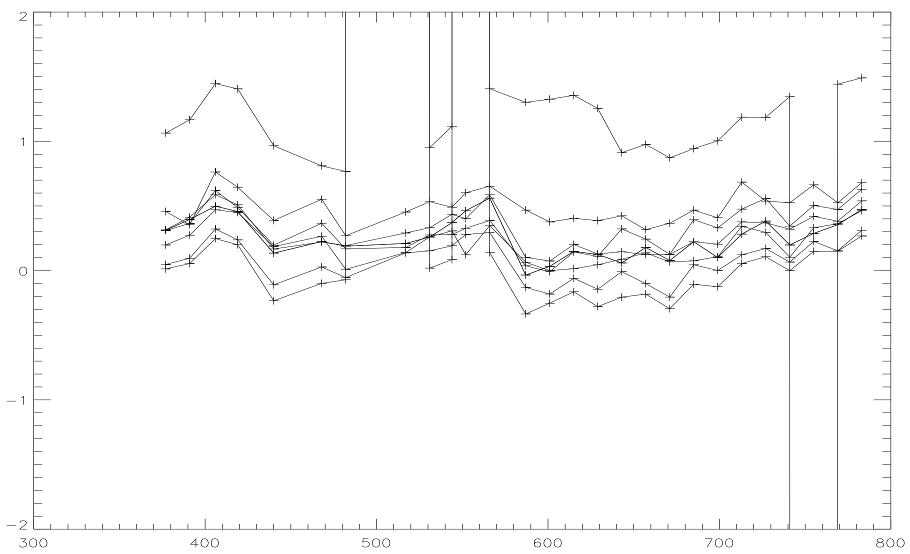

Figure 1: Difference in LVDT between the observed wavelength and the known wavelength for several lines in NGC6543. The difference is plotted versus revolution number. Note that there is an update in the wavelength calibration files around 430 and 580.

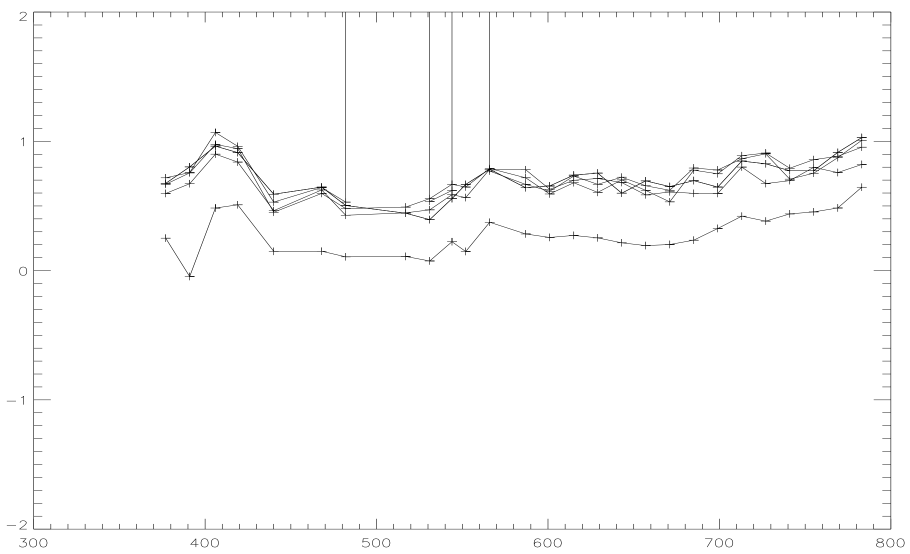

Figure 2: Difference in LVDT between the observed wavelength and the known wavelength for several lines in NGC6543. The difference is plotted versus revolution number. Note that there is an update in the wavelength calibration files around 430 and 580.

Appendix: Wavelength Calibration Update

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A Introduction

After one year in orbit the wavelength calibration is shifted by about 1 LVDT step. This note investigates the origin of the shift and proposes a new calibration. As input we have full grating scans on the grating calibration source with settings low and high (revolution numbers 28 and 32 resp.), and a number of lines on NGC7027 in revolution number 32. Similar measurements were taken about one year later in revolution number 356 (low and NGC7027) and a grating calibration scan high in revolution number 370.

Observations are designated by revolution number, preceeded by either a G or an N, for grating scan and NGC7027 resp. So the observations are called G028 (low), G032 (high), G356 (low), G370 (high), N032 and N356.

All SPDs have been processed using the latest (standard) pipeline version V5.

In the following the LW section is described first and thereafter the SW section.

B LW section

B.1 Present Calibration

Following CAP6331 –Grating wavelength calibration, internal source– we ran the procedure c331_linelist, first on G028 the grating scan on which the present wavelength calibration is (partly) based. This yields a linelist, a table with peak positions which were assigned to wavelengths from CAL08, and a plot, displaying the difference between the old and the new LVDTs of the peaks. Figure **??** is this plot for all detectors in band 3 and 4. Three things are conspicuous.

Firstly, the points are not centered around 0. There is a shift of about 0.5 ± 1.0. This should not be the case as the wavelength calibration was based upon G028. At first the new pipeline version (V 5.1) and especially the new AC constants were deemed the culprit. But later investigations revealed that the AC constants have never been changed except for the FP. A check with the same data, processed by an old version of DSPD (V 2.0) showed the same displacements. Obviously the shift is just present in the calibration. Reasons could be that only part of the displayed data (i.e. band 4 with LVDTs greater than 4000) were actually used to derive the original calibration.

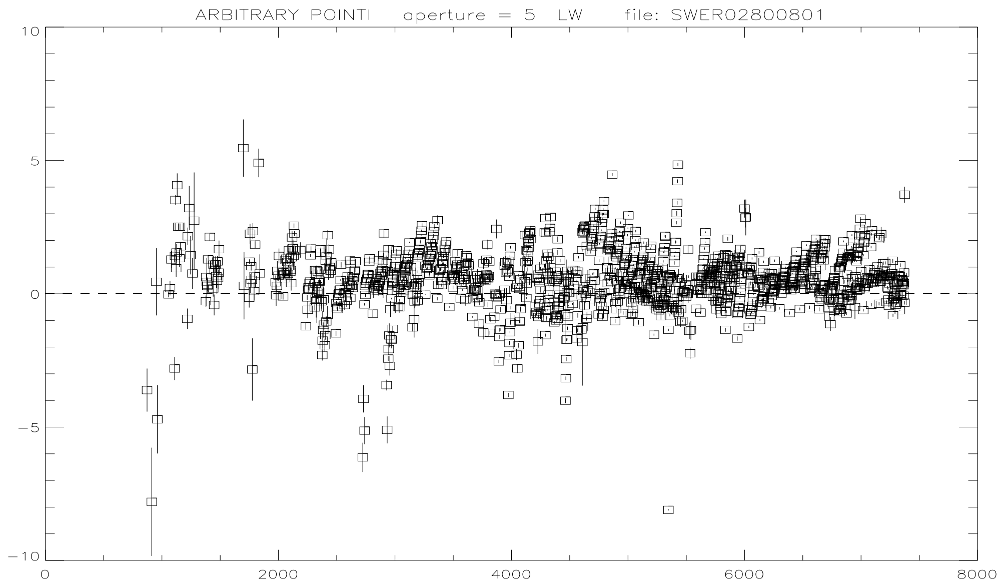

Figure 3: Misalignment of the peaks (ΔLVDT) versus LVDT for the grating calibration scan in revolution number 28.

For the lines in NGC 7027 this effect is absent as can be seen in figure **??**, which shows the shifts in 11 lines in N032. The average shift here is a mere 0.2 LVDT.

The second thing conspicuous in figure **??** is the large spread and the structure in the deviations. When this plot appeared on the screen it became clear that the points shift up with the detectors.

In figure **??** the Δ LVDT are shown for the detectors in band 3 and 4. Indeed there is a clear trend within each band. It is clear from figure **??** that no such thing can be the case for the NGC 7027; the spread is just not large enough. Obviously the pitch between the detectors is OK. What is different in the case of G028 is the CAL08 from which the wavelengths of the fringes are obtained. This CAL08 dates from an ILT where the peaks of the fringes were measured and associated with external measurements on vapour lines, lasers etc. From these measurements a wavelength calibration was made, which was used to transform the fringe peaks into fringe wavelengths. And this was stored into CAL08. Here something might have gone wrong in the sense that a different pitch between the detectors was used to calculate the wavelengths of the fringes.

Superficially seen, CAL08 could have only *one* list of fringe wavelengths per band in stead of one per detector, but subtle effects like fringes in band 3 shift the wavelengths in different detectors of the same band slightly but noticeably.

Thirdly, the structure in the deviations, most clearly seen at high LVDTs, could signal that some manipulations eg. filtering that for some undoubtedly good reason were done on the

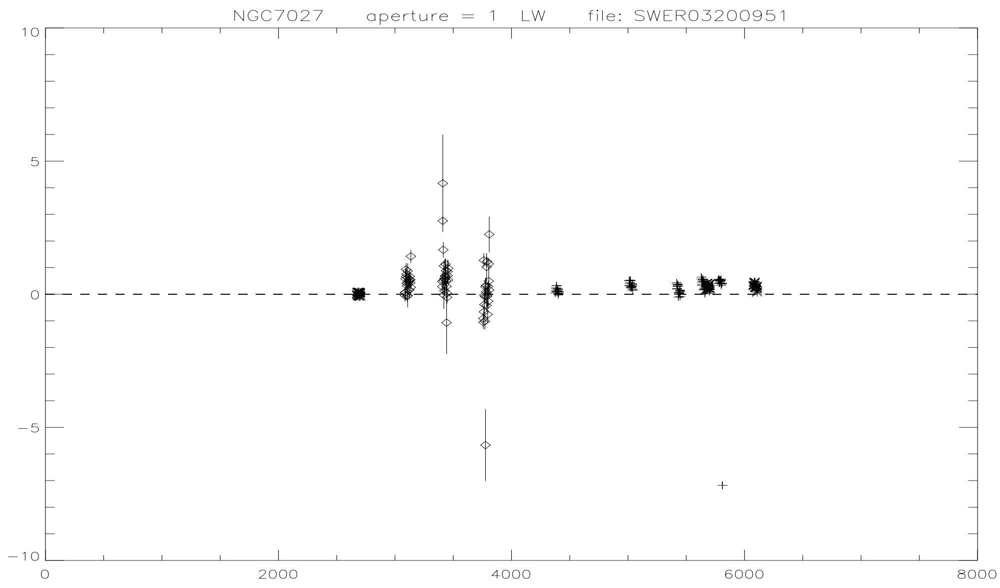

Figure 4: Misalignment of the lines of NGC 7027 in revolution number 32.

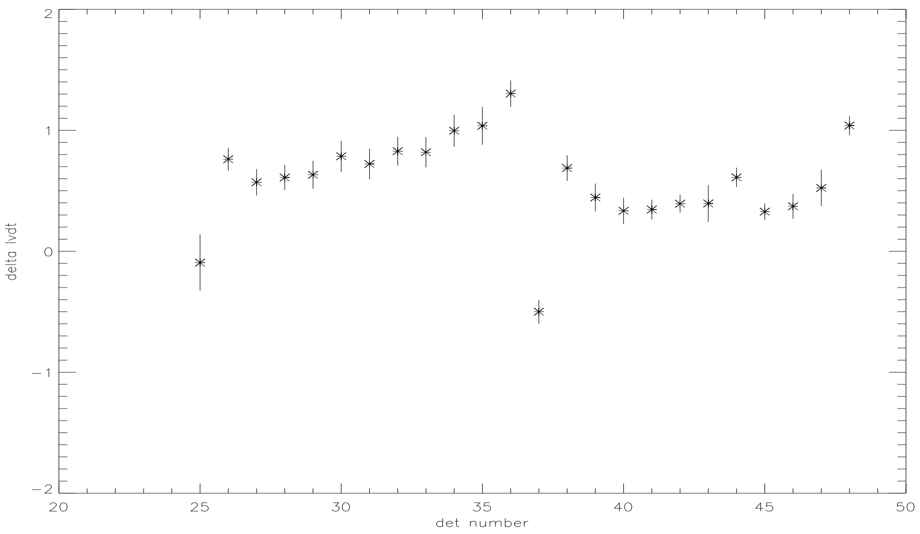

Figure 5: The shift in Δ LVDT, averaged per detector.

ILT measurements, are not any more performed on the present grating scan.

B.2 New CAL08

These reasons, although by themselves certainly not serious enough to disable a proper wavelength calibration, convinced us to make a new CAL08. This actually should have been done earlier but was postponed as its only use is for the wavelength calibration, which was deemed utterly stable. A linelist was constructed for all detectors in bands 3 and 4 made with c331_linelist on G028. Some adaptations in the peak finding software had to be made to collect a larger percentage of the fringes present in the full grating scan. Then it was assumed that the wavelength calibration at the beginning of 1996 was 'true'. Using this calibration, wavelengths were calculated for all fringe peaks found. Herewith 3 effects were nullified: the overall shift of 0.5 LVDT, the structure in the deviates and the differences between the detectors. On the down side is that using full grating scans only shifts can be discovered with respect to the 'true' calibration at the beginning of the mission. On the other hand, the old CAL08 had a 'true' calibration too i.e. the ILT calibration that it was based on.

The linelist thus made is used to update the CAL08 file, using the procedure update_cal08.

B.3 Shifts

The full grating scan of revolution number 356 was compared against the new CAL08, again using c331_linelist. The result is shown in figure ??. The benefits of the new calfile are obvious, a very tightly bound linear shift becomes present. With the old CAL08 a constant shift was seen, but the linear part was completely hidden in the superfluous noise from the old CAL08. The deviations are larger at short LVDTs because the fringes are much broader over there and consequently there are less fringes at short LVDTs.

For NGC 7027 measured in revolution number 356 a similar plot was made, using c341_linelist. With some fantasy the linear shift is present here too, but without the information of grating scan it might as well be a constant shift. (figure ??)

B.4 Wavelength Calibration

Considering the two linelists available for updating the wavelength calibration and seeing that they both show a similar effect, we firstly decided to use G356 to update the first two coefficients of the grating polynome (CAL16E). By applying only a linear correction we made sure that the straying points at low LVDT could not play havoc with the polynome. The measurement on N356 was used to check the results. The fit entailed a very small adjustment.

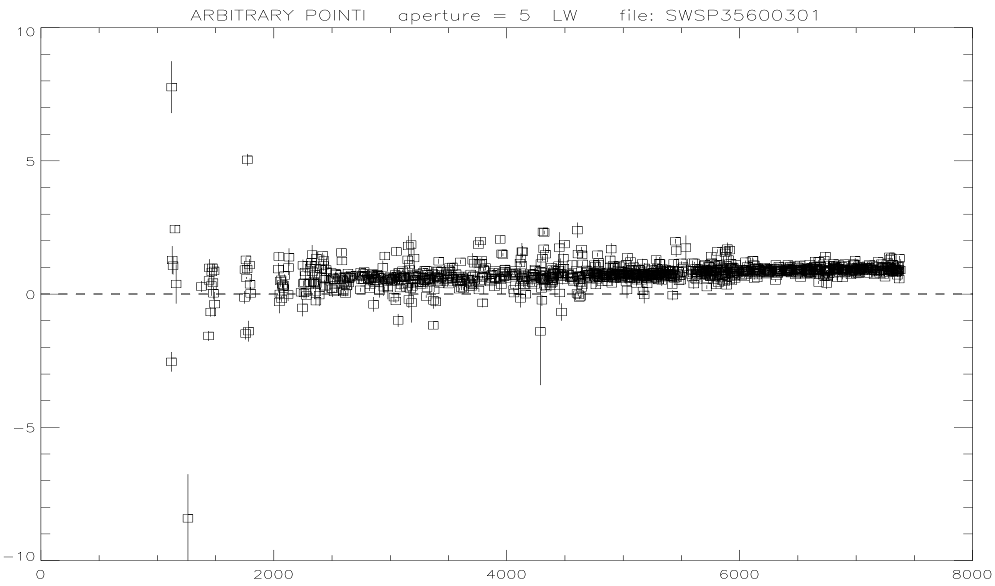

Figure 6: Deviation in ΔLVDT of revolution number 356 wrt. the wavelength calibration of revolution number 28.

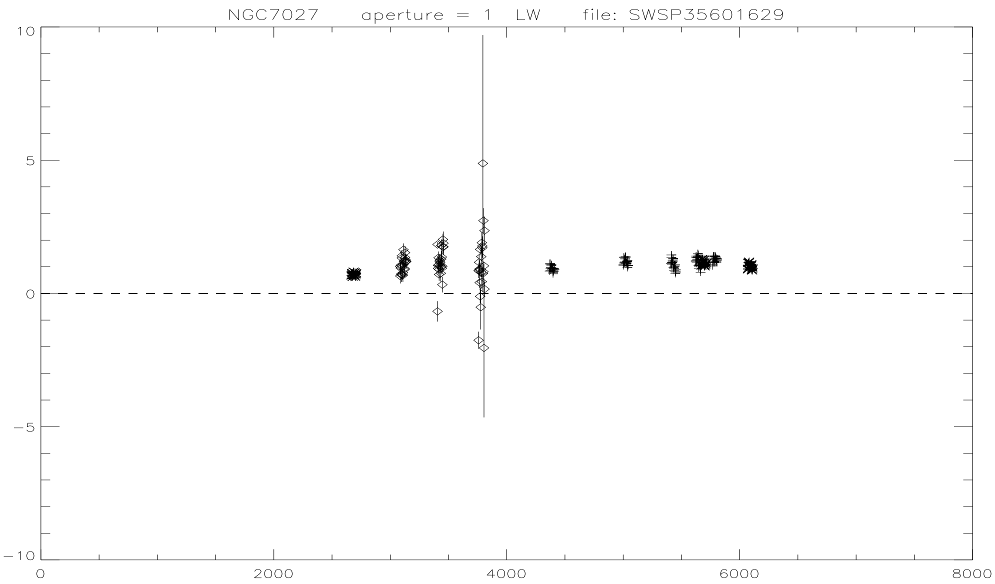

Figure 7: Shift in the lines of NGC7027 in revolution number 356 wrt. the calibration of revolution number 28.

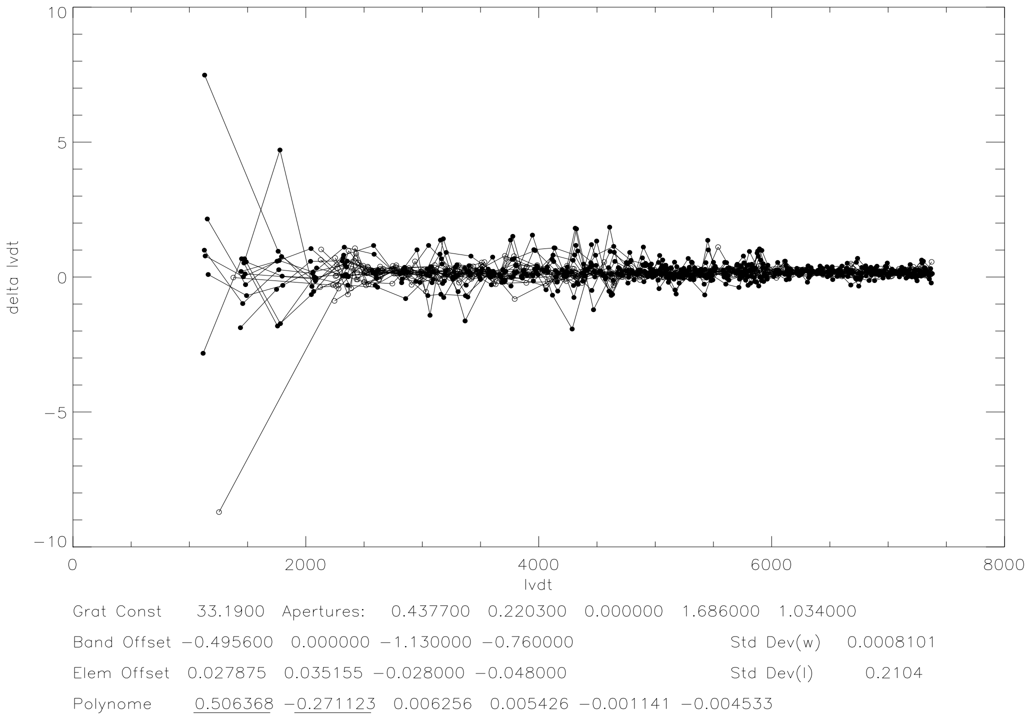

Figure 8: Deviations of the grating scan wrt. the new wavelength calibration.

coeff	old	new	stdev
0	0.506334	0.506368	0.000019
1	-0.271143	-0.271123	0.000039

The deviations from the fit are shown in figure **??**. The standard deviation of the fit is 0.2 LVDT. Figure **??** shows the application of the newly derived grating polynome on N356. Here we find a formal standard deviation of 0.5 LVDT. This result is a bit disappointing: of an error of about 1 LVDT we correct only 50 %. On the other hand figure **??** is not that much better.

If we assume that NGC 7027 fills the slit completely with spatially unstructured flux as is stated in Valentijn etal. (1996) then this deviation cannot be due to pointing errors and we might be able to arrive at a better solution by combining the two linelists. As all lines of NGC 7027 show the same residual shift and they are seen through all 3 aperture slits, the most simple solution seems to be adjusting also the position of the grating calibrator source. Adjusting the first two coeffecients of the grating polynome and the position of the grating calibrator source, we get the following numbers.

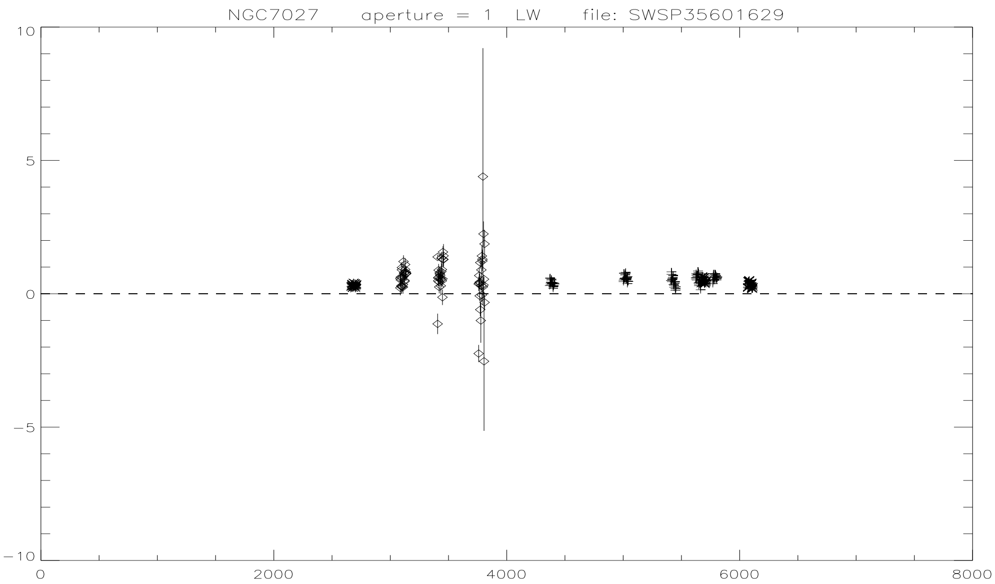

Figure 9: Deviations of NGC7027 wrt. the new wavelength calibration.

	old	new	stdev
coef 0	0.506334	0.506386	0.000059
coef 1	-0.271143	-0.271123	0.000040
aper 5	1.686000	1.683929	0.006744

The grating polynome is in radian while the other offset angles are in degrees. The first coefficient, 0.506386, corresponds to 29.01378 deg and the calculated shift is 0.002979 ($\approx$ 10.7 arcsec).

The overall standard deviation of this fit is 0.2 LVDT.

The notion of a slit-filling NGC 7027 was blown to pieces a measurement of the width of two of the stronger lines. Both were more appropriate for a point source of at most a few arcsec, than for an extended source filling the complete slit. This leaves open the possibility that a pointing error on NGC 7027 caused the deviation of 0.5 arcsec.

Weighting all evidence at hand we decided to only adjust the grating polynome, as we could find no good reason the do more.

C SW section

For the short wavelength section much the same story can be told.

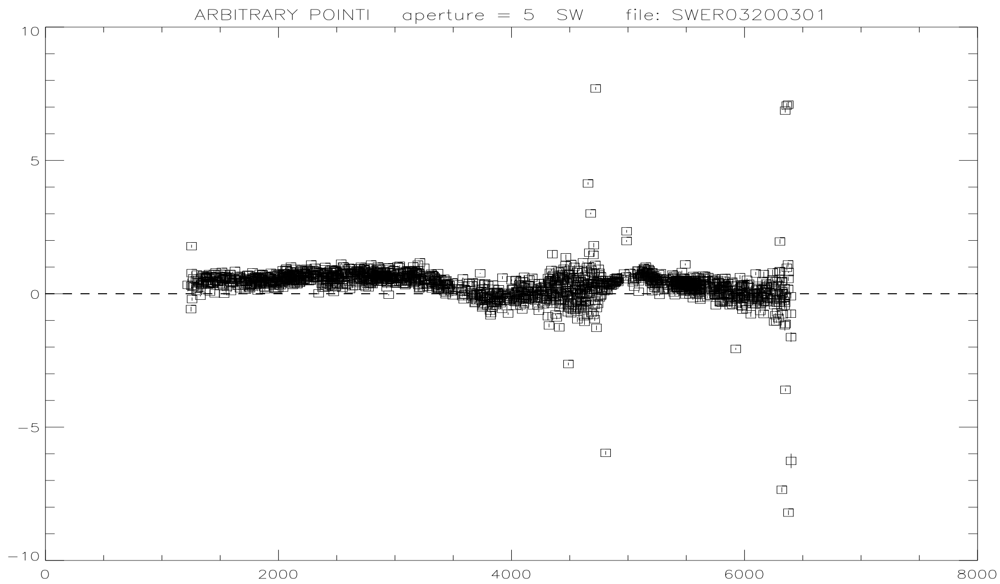

Figure 10: Misalignment of the peaks (ΔLVDT) of band 1 detectors versus LVDT for the grating calibration scan in revolution number 32.

C.1 Present Calibration

First we looked at the deviations of the full grating scan (high) in revolution number 32. They are shown in figure **??** for band 1 detectors and in figure **??** for band 2 detectors.

The band 2 detectors are nicely centered around zero while those in band 1 are slighly shifted by 0.5 LVDT. The latter were not used in the original wavelength calibration, because they are weaker in intensity and because the range in LVDTs where there are actually fringes present, is shorter. Both on the low LVDTs and on the high LVDTs.

To a (much) lesser extent the two effects described for the LW section, the displacements of the detectors and the residual structure, can be seen here too. Both effects reside in the CAL08 file as discussed above. A new CAL08 file was made, not only for bands 1 and 2 but also for bands 3 and 4. This CAL08 file is now valid for a grating calibration source setting high. The original CAL08 was a mixed version: setting high for bands 1, 2 and setting low for band 3, 4. We need this new version with setting high only as the quick check on the wavelength calibration is done with a high setting. And there is a difference. The calibration file CAL08 as derived above for the LW section with setting low is renamed to CAL08A.

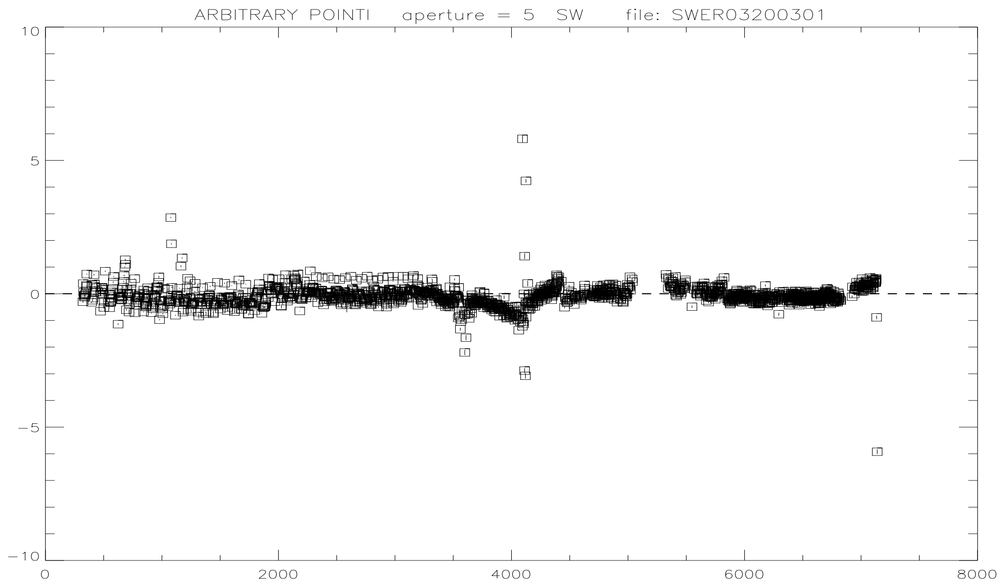

Figure 11: Misalignment of the peaks (ΔLVDT) of band 2 detectors versus LVDT for the grating calibration scan in revolution number 32.

C.2 Shifts

The grating scan of revolution number 370 was compared against the CAL08. The result, shown in figure **??**, displays the change between the beginning of the mission and November 1996. Contrary to the LW section, where the displacement was highly linear, for the SW section it is curved. The few highly deviating points are misidentifications in band 1 of fringe peaks which are very weak due to a nearby mylar absorption dip.

A very similar behaviour is seen in the displacement of the lines on NGC7027 (figure **??**). Most of the outliers have large error bars and are probably misidentifications. The well-defined points follow the grating scan curve nicely.

C.3 Wavelength Calibration

The curvature in the deviation of figure **??** forced us the derive a completely new grating polynome. Fortunately, we have a dense coverage of points over the complete LVDT range from 500 to 7000. Because of the outliers in band 1 we only used data from band 2 to derive the new grating polynome.

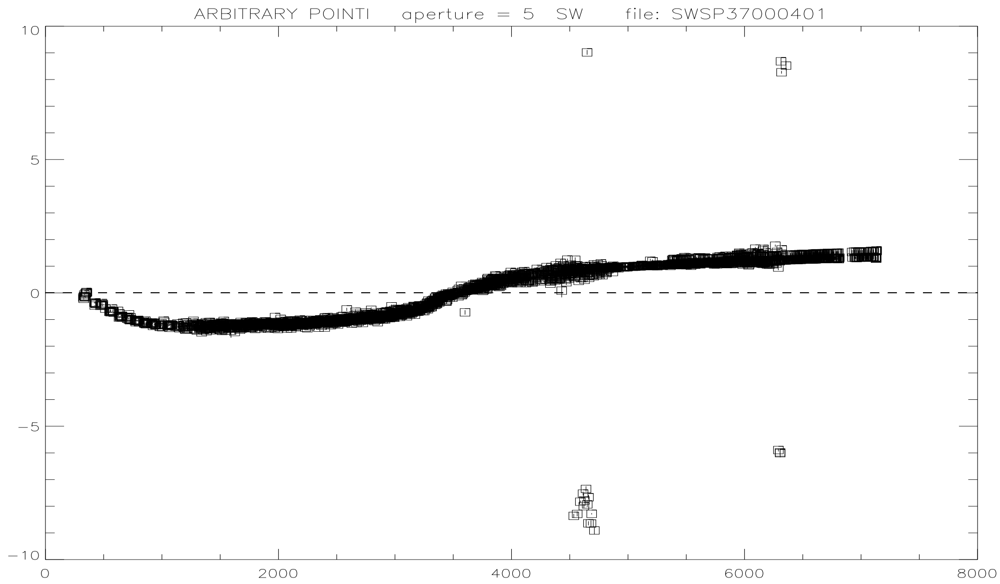

Figure 12: Displacement of the peaks (ΔLVDT) of SW detectors versus LVDT for the grating calibration scan in revolution number 370 wrt. the wavelength calibration of revolution number 32.

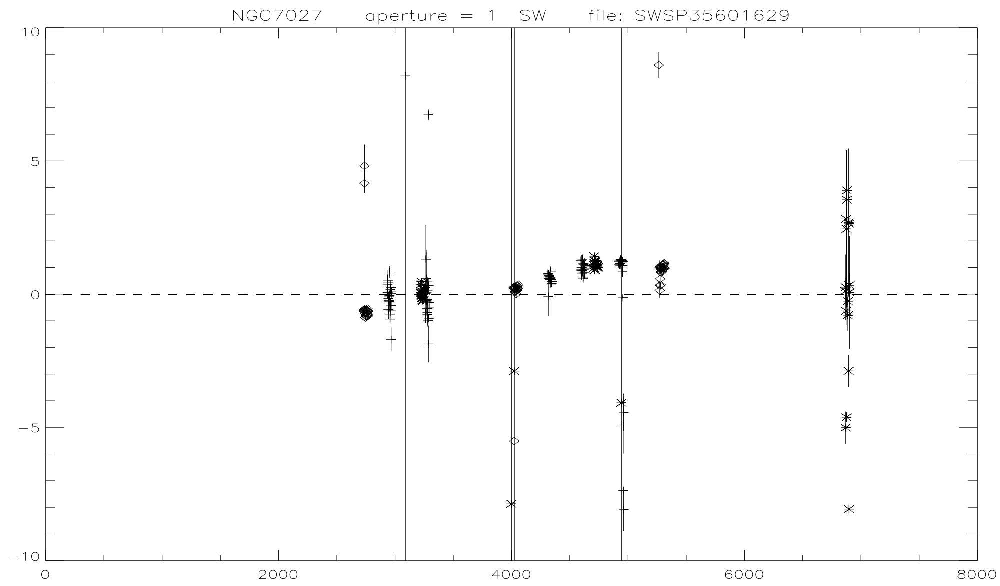

Figure 13: Displacement of the lines in NGC7027 in revolution number 356 versus LVDT wrt. the calibration of revolution number 32.

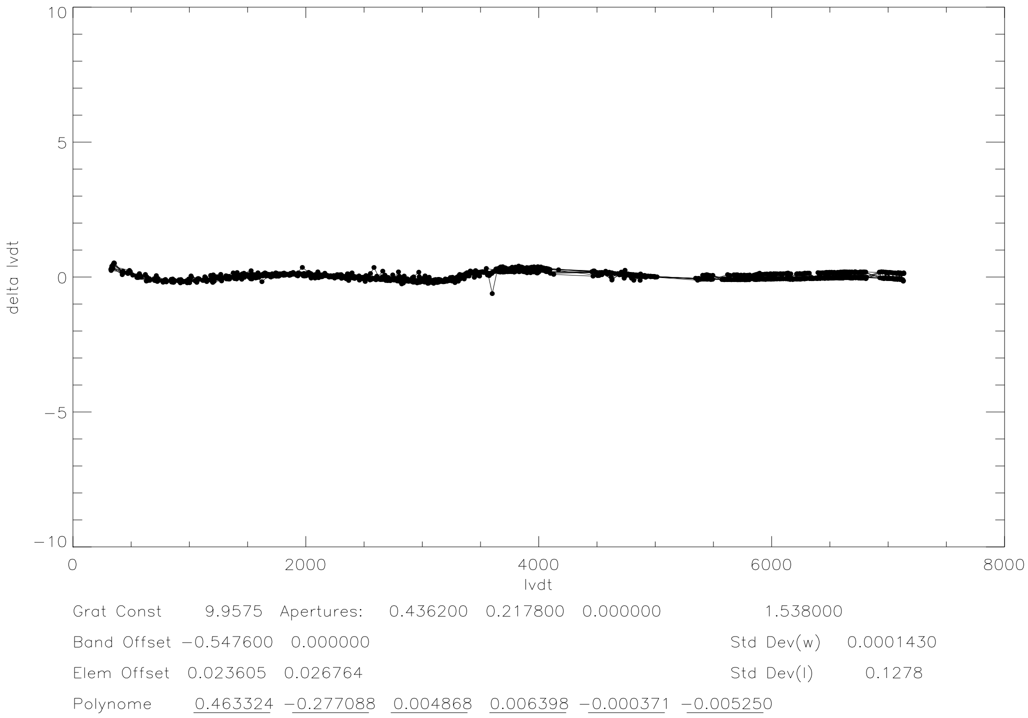

Figure 14: Deviations of band 2 detectors of the grating scan in revolution number 370 wrt. the new calibration.

coef	old	new	stdev
0	0.463302	0.463324	0.000061
1	-0.277327	-0.277088	0.000217
2	0.005015	0.004868	0.000659
3	0.006732	0.006398	0.001263
4	-0.000593	-0.000371	0.001372
5	-0.005443	-0.005250	0.001928

The deviations from the fit are shown in figure ??. The standard deviation of the fit is 0.13 LVDT. It is dominated by systematic effects, which means that the detection of the fringes is extremely stable, less than 0.1 LVDT. This can only be the case when all components ie. the grating calibration source, the fixed FP, the elements in the light path, the detectors, and the algoritms are extremely stable. Except, of course for the grating polynome, and even that part is changing very smoothly.

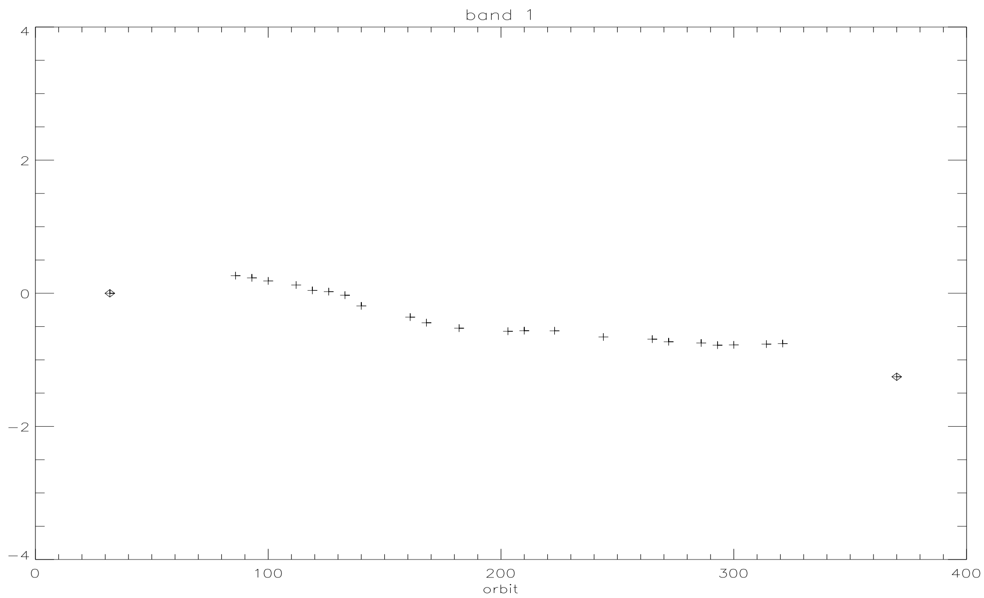

Figure 15: Trends in the grating shifts for band 1. Short LVDTs +, long LVDTs ∗. Full grating scan overplotted with ⋄.

D Trends

Between revolution number 80 and 320, 22 so called quick check grating scans were done. There are more Quick Checks both before revolution number 86 and after revolution number 321, but I do not have access to them in Groningen at this moment.

The quick checks consist of two short scans with the grating calibration source high. One scan from 1350 to 1750 LVDT (the short part) and the other from 6400 to 6600 LVDT (the long part). The two parts were analysed separately. The shifts in LVDT were plotted against revolution number number. In band 1 (figure **??**) there are fringes present only in the short part. Bands 2 to 4 are displayed in figures **??**, **??**, **??** resp. In each of these figures the short LVDTs are indicated with a + and the longer LVDTs with an ∗. The full grating scans, in revolution numbers 32 and 370, are also included with the same parts processed. These are overplotted with a ⋄. Note that in revolution number 32 the shift in LVDT is zero due to the way CAL08 is made.

In all bands the shifts in the longer part (∗) can be smoothly extrapolated to the values of the full grating scans in revolution numbers 32 and 370. For the short LVDTs it is different, extrapolation only succeeds when a constant is added to all quick check shifts. In band 4 (figure **??**) the shift in the short part is even larger that the one in the long part, the reverse of what is seen in the full grating scan. See also figure **??**. Only band 3 behaves more or less as expected. The puzzling behaviour of the short parts can be understood as being caused

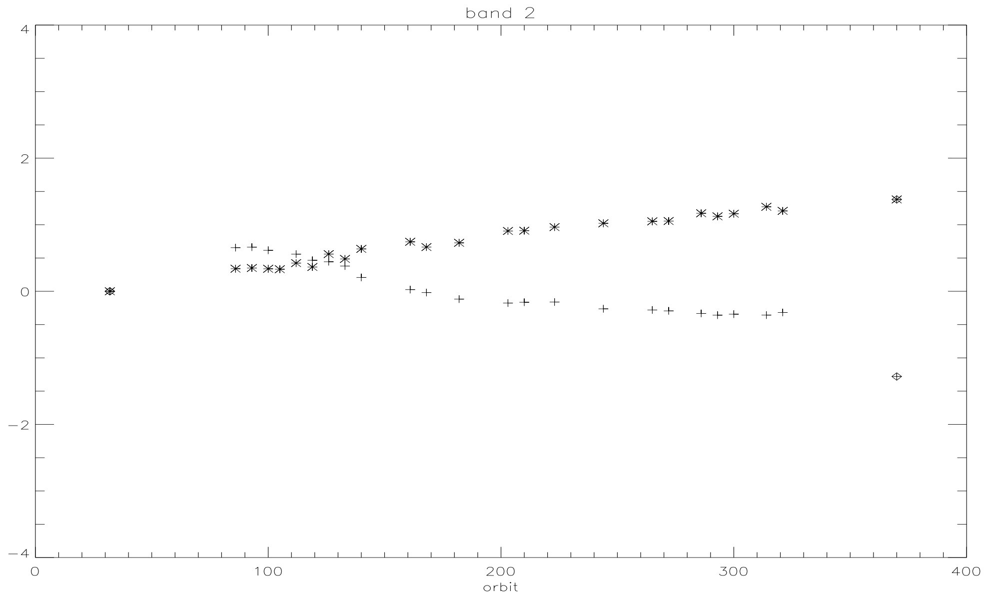

Figure 16: Trends in the grating shifts for band 2. Short LVDTs +, long LVDTs $*$. Full grating scan overplotted with $\diamond$.

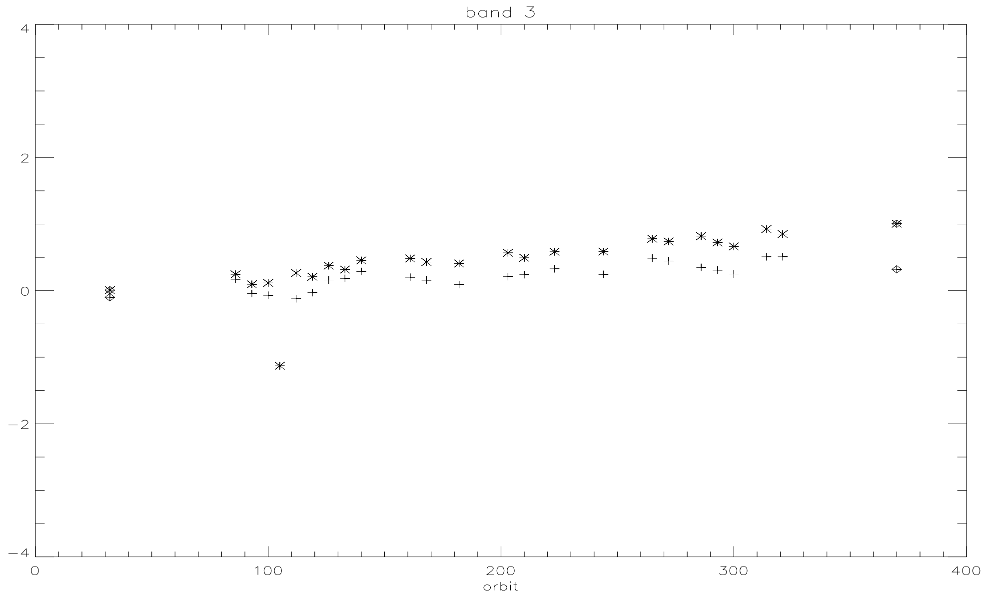

Figure 17: Trends in the grating shifts for band 3. Short LVDTs +, long LVDTs $*$. Full grating scan overplotted with $\diamond$.

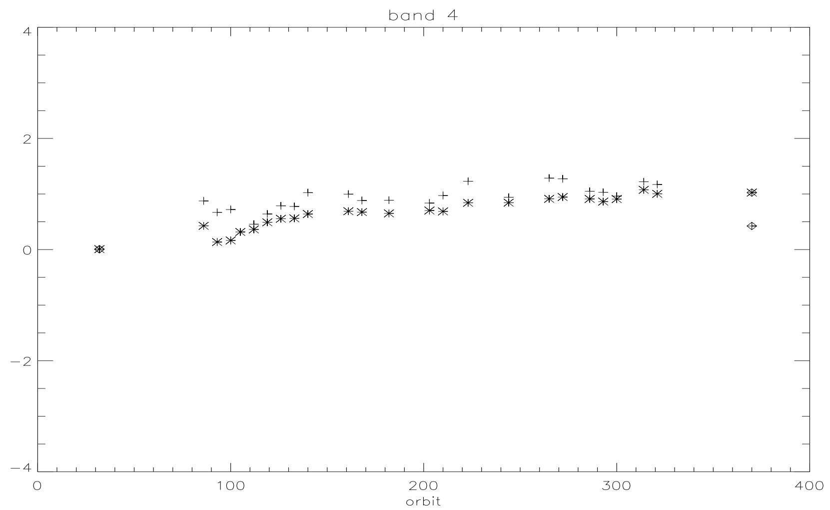

Figure 18: Trends in the grating shifts for band 4. Short LVDTs +, long LVDTs ∗. Full grating scan overplotted with ⋄.

by detector memory. In a full grating scan there has been flux on the detector for about 800 second before the part from 1350 to 1750 LVDT is done, while in the quick checks the shutter was closed before the start of the measurement. After 400 seconds, scanning from 1350 to 1750, the detectors are 'warmed' enough to obtain the same memory history as in a full scan. That explains why the longer parts are more or less OK.

It should be noticed however how much the same, even in detail, the behaviour is in bands 1 and 2 on the one hand and in bands 3 and 4 on the other. It strengthens my remarks at the end of the previous section on the internal stability of the instrument.

The slightly curved trends in band 1 and 2 suggest that the new wavelength calibration for the SW section should be applied since revolution number 150. The much straighter trends in especially in band 3 suggest for the LW section that the new wavelength calibration is valid since revolution number 200.

The here derived wavelength calibration is made valid within IA since revolution number 200.