MARS EXPRESS

PLANETARY FOURIER SPECTROMETER

INSTRUMENT CALIBRATION REPORT

VOLUME III

PFS SPACE CALIBRATION

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1 – GENERALITIES

We whish to report here about the activity done in the Near Earth Verification with PFS on board the Mars Express Mission.
MEX was successfully launched on June 2 2003, and was sent to Mars according the predicted trajectory.
On June 23 the NEV activity for PFS started. We had prepared a program of activity so that we could test first the thermal environment, then the mechanical functionality, finally optical alignment, and then, with all the PFS parts tested, we were planning to perform a number of tests more or less standard : test the data telemetry modes, test the unobstructed field of view for the different position of the scanner, test the capability to heat the detector, and so on.
Reality went a different way. The unexpected occurred.
PFS was successfully switched on. Thermal studies were performed, and everything looked in agreement with the predictions. Details will be given in the following. The block unblock system worked perfectly, and to this moment we have blocked and unblocked the pendulum many times, and always the time needed for the operation has been 10 minutes. The double pendulum moves and the experiment is in good conditions : we have reasons to believe that the optical alignment has been kept in both channels .
We have identified two problems : A partial failure of the internal calibration lamp, and a mechanical disturbance generated by the spacecraft and entering PFS interferometer.
The calibration lamp is in the Scanner, and, by means of a parabolic mirror focuses the lamp on the PFS SW detector. On ground the intensity of the lamp radiation was rather high, and from the studies performed we could predict saturation in space, when the detector temperature would be 200-210 K, and the responsivity would increase consequently. In space on the contrary the signal was smaller than on Earth, and very noisy. Most likely the lamp has lost the optical alignement with the Interferometer SW detector, and is focussed just outside of the detector. We need, therefore, to find a procedure to calibrate in space the SW channel, or to check the validity of the calibrations performed in the Lab.
The second problem is mechanical disturbances coming from the spacecraft to the experiment. There are at least 2 frequencies 100 Hz and 600 Hz of relatively large amplitude generated on board MEX and entering the interferometer. They are clearly seen in the autotest when we study the speed of the pendulum. The mechanical disturbances changed, but did not disappear when the X band transmitter was switched off. The effect of the mechanical disturbances has been studied by changing the speed of the pendulum, and we have a way to minimise its negative effects.
Overall, therefore, we may say that PFS in space is working very well and should not suffer much from these two minor problems.
It is important to add that we have proven we can work during slew manouvres (as it will be at Mars) and even during wheels offloading, as in July 11 nev5 tests. Furthermore PFS survived without any effect the “MEX safe mode” which occurred during star calibrations. In this mode the spacecraft performs manuvres at a rate 20 times higher than during the slew manuvres. PFS was switched off unblocked and it went trough the manouvres as such. It occurred on July 13, while it was switched on and blocked on July 22, 2003.
In terms of disturbances from other experiments we have seen an effect from the switch off of Omega cooler only.

2 - THERMAL STUDY

The thermal environment of the experiment is more or less what it was expected from modelling the experiment. I report here about the activity on July 11, which is the longest implemented up to now.

2.1 INTERFEROMETER TEMPERATURES

8 termometers in IB show the behaviour shown in figure 1 : during the very long activity the temperature increased from 280 to 286 K, which is normal and OK. Note that after 350 measurements ASTRA it went off, and we see immediately some cooling, which is than recovered by the trend to warm up, being the experiment on. The different temperatures are not necessarily evidence of a thermal gradient, but rather we should improve the understanding by inter calibrating the values, which has not yet been done.

2.2 LASER DIODES TEMPERATURES

The SW laser diode temperature is shown in figure 2. This temperature is very important for the good functionality of the double pendulum, as the SW laser diode zero crossings are used to sample the interferogram and to control the motion. After 100 measurements (1000 sec = 16 minutes) the temperature has reached the value that has been fixed, and it is stable to hundreds of a degree from that moment on. Note that the same was true for the temperature of the LW laser diode, which in less than 50 measurements reaches the controlled temperature (see figure 3). By mistake a command was given after 600 measurements, to increase the temperature of the LW laser diode to 297 K (was actually intended to be heating of the SW detector, but a mistake was in the parameter of the telecommand). The Laser diode went on worming up, but at the end of 1700 measurements had not yet reached the fixed temperature.
The effective control of the laser diodes temperature was never achieved in the ground testing.

2.3 LW DETECTOR TEMPERATURE

The LW channel measures the temperature difference between the detector / instrument and the source. In order for the measurements to be reliable and of sure interpretation, it is important that the LW detector is stabilised to high accuracy. The circuitry controlling the LW channel detector temperature should, in theory ensure the temperature fixed, with an accuracy of 0.01 K. In Figure 4 we see that the fixed temperature is achieved after 40 measurements: the temperature is then stable between 286.9 and 287.0 i.e. 286.95+- 0.005 K. A blow up of the initial part is given in figure 4b.

2.4 SW DETECTOR TEMPERATURE.

The SW detector temperature is shown in figure 5. The temperature at the switch on is of the order of 210 K. This temperature is OK and allows to increase the responsivity of the channel with respect to room temperatures. In order to compare measurements from space with laboratory ones we tried to heat the detector to 220 first and then to 250 K. The temperature of the detector keeps increasing and never reaches the 220 or the 250 K which were requested. It seems therefore that to keep the SW detector to a fixed temperature is essentially impossible : we are not able to heat it enough, so that we can keep a fixed temperature. The radiator provided by Astrium is not marginal, while the power we can indeed dissipate on the detector to increase its temperature, is very small.

This is not a problem, as we indeed need the detector cooled to increase its responsivity. The problem is that in the Lab we were not able to achieve the low temperature we have in space, therefore we have no overlap between measurements in space and in the Lab. Only fixing the SW temperature around 211 K we can hope to have it fixed, but this was not tested in the NEV.
WE NEVER TRIED TO HAVE IB AT STABLE TEMPERATURE!!!!

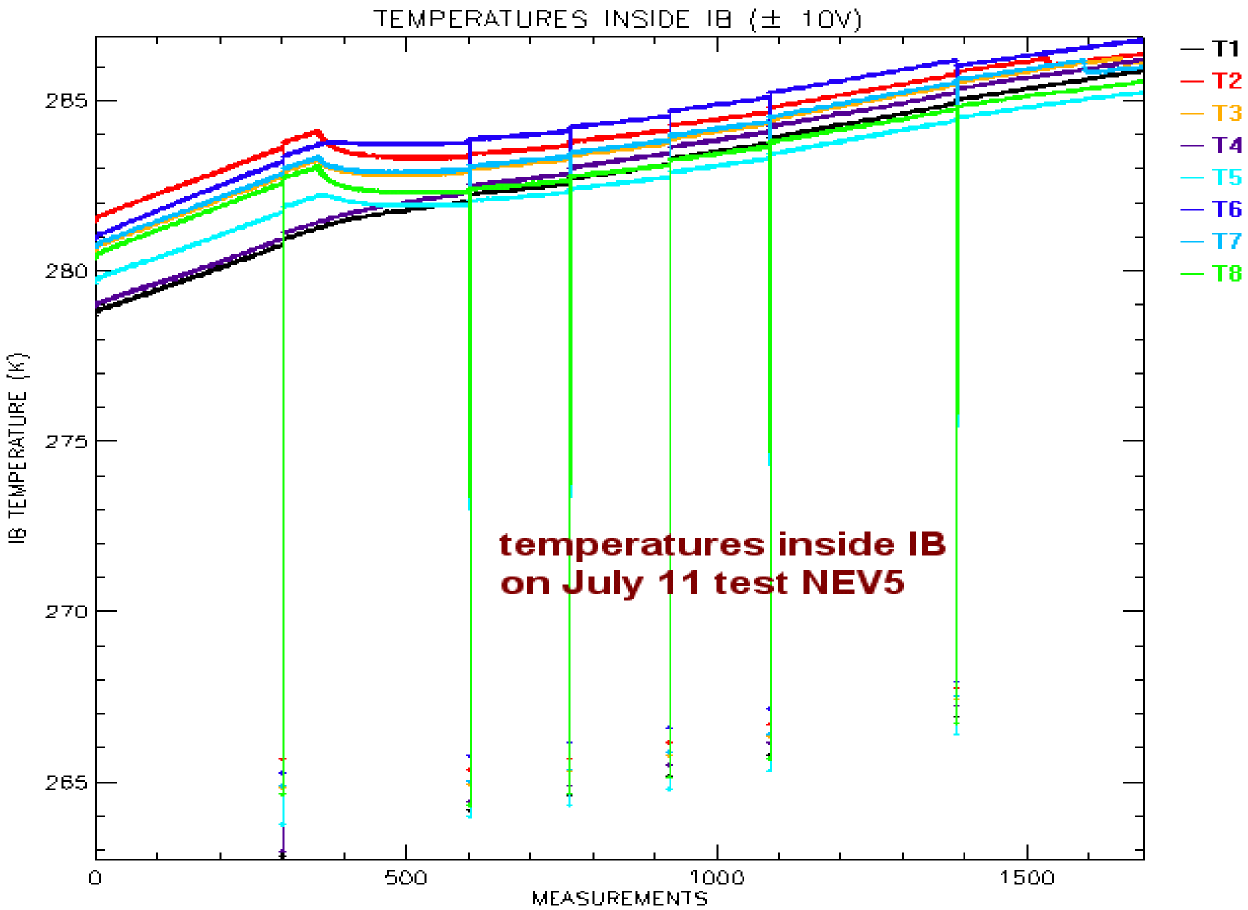


Figure 1 – temperatures inside IB during test NEV5. The temperature decrease after 360 measurements are due to ASTRA stwitch off. Note that the vertical lines identify the ending of one activity and beginning of another one. In the tests reported here the activity was :
Test 4 – Calibrations – DTM17 – N=100 – Speed 2000 – TempSW = 220 : BB, DS, CL
Test 4 – Calibrations – DTM17 – N=100 – Speed 3000 – TempSW = 220 : BB, DS, CL
Test 5 – Speed 3000 – TempSW= 250, CL, N=10
Test 5 – Speed 3000 – TempSW= 250, DS, N=10
Test 5 – Speed 3000 – TempSW= 250, BB, N=10
Test 4 – Calibrations – DTM17 – N=100 – Speed 2000 – TempSW = 250 : BB, DS, CL
Test 4 – Calibrations – DTM17 – N=100 – Speed 3000 – TempSW = 250 : BB, DS, CL
Each vertical line is indicating autotest.

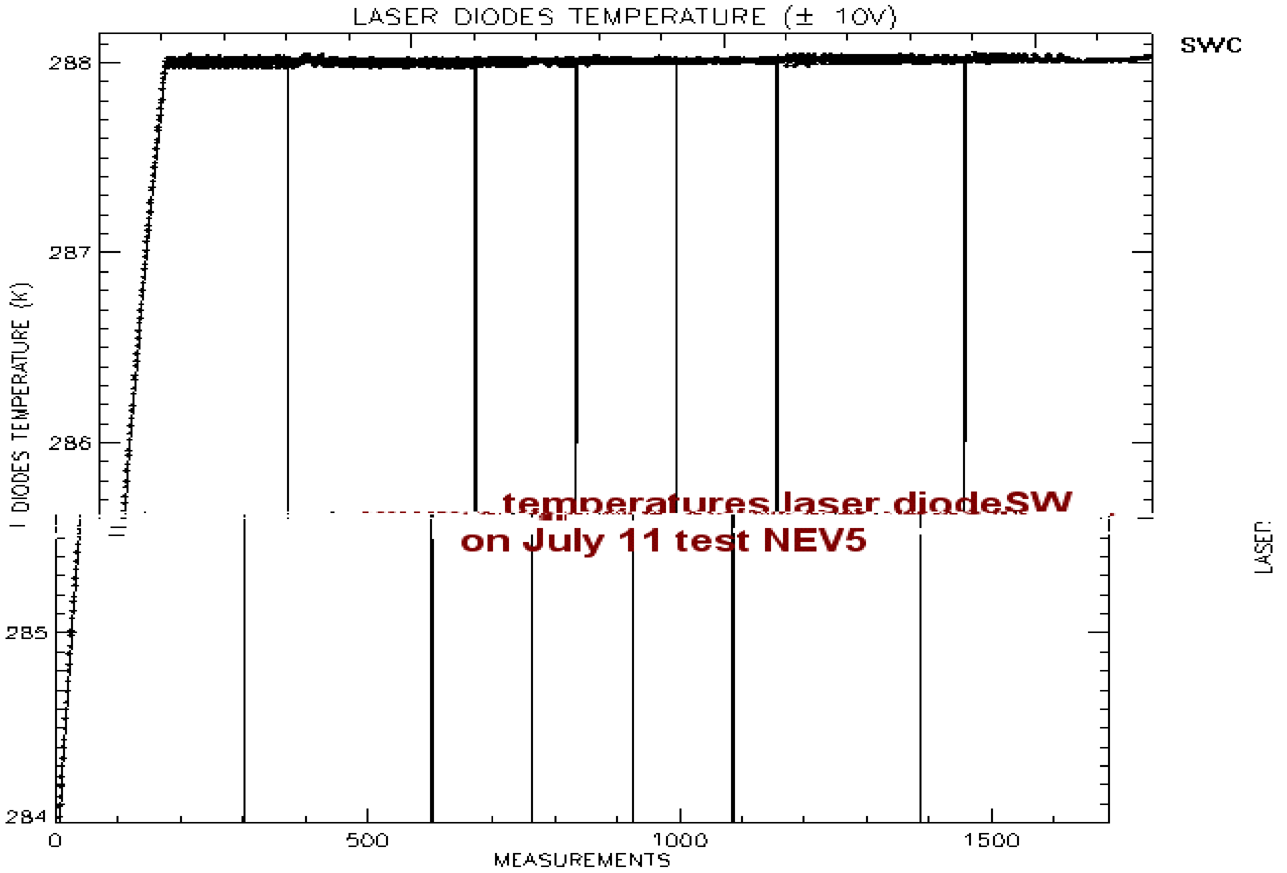


Figure 2 – SW Lased diode temperature. Note the heating in 100 measurements, 15 minutes.

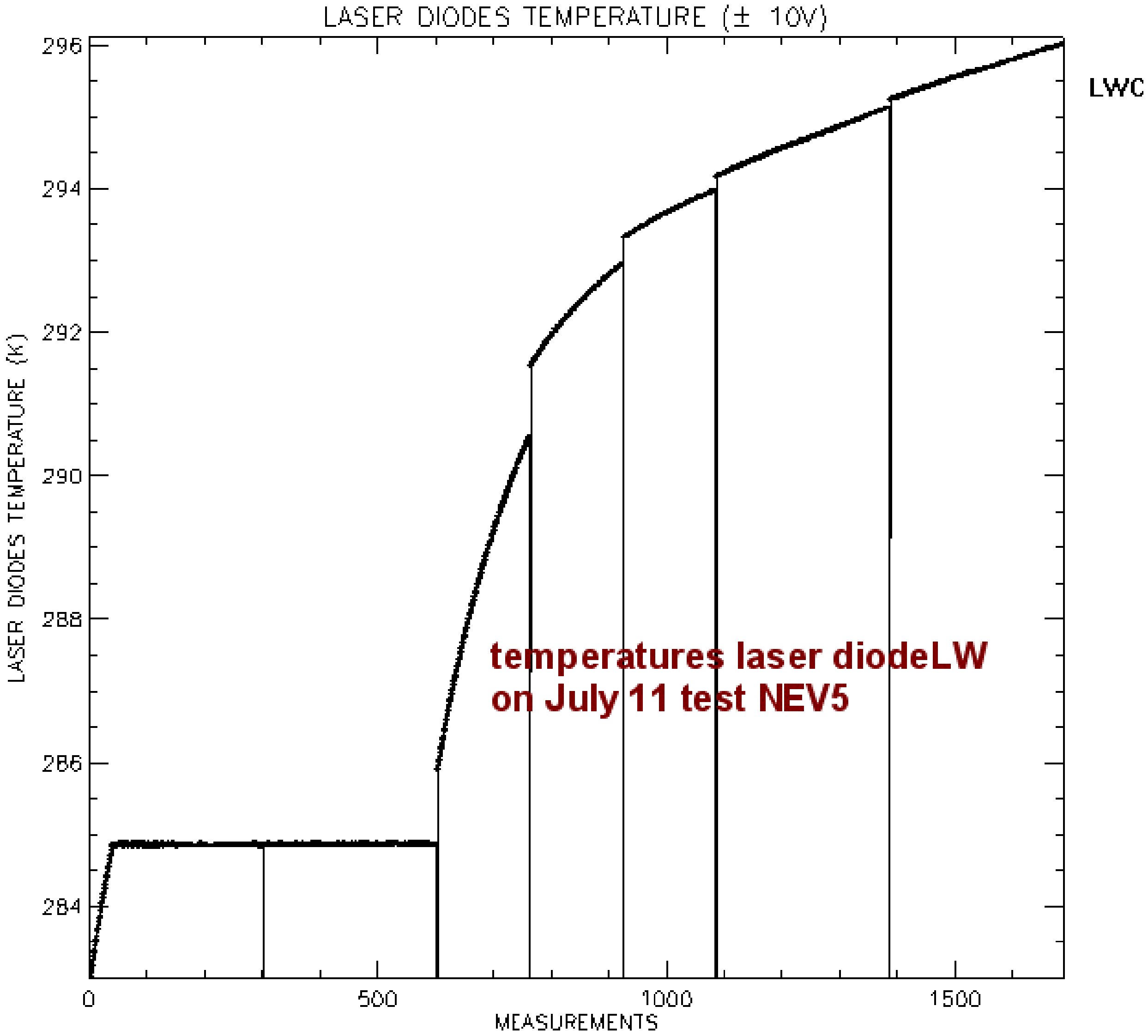


Figure 3 – Laser diode temperature LW. The temperature stabilization was achieved in less than 50 measurements (6-7 minutes). After 600 measurements it was given by mistake the command to heat the laser diode to 298 K. At the end of the measurement sequence that value was not yet reached.

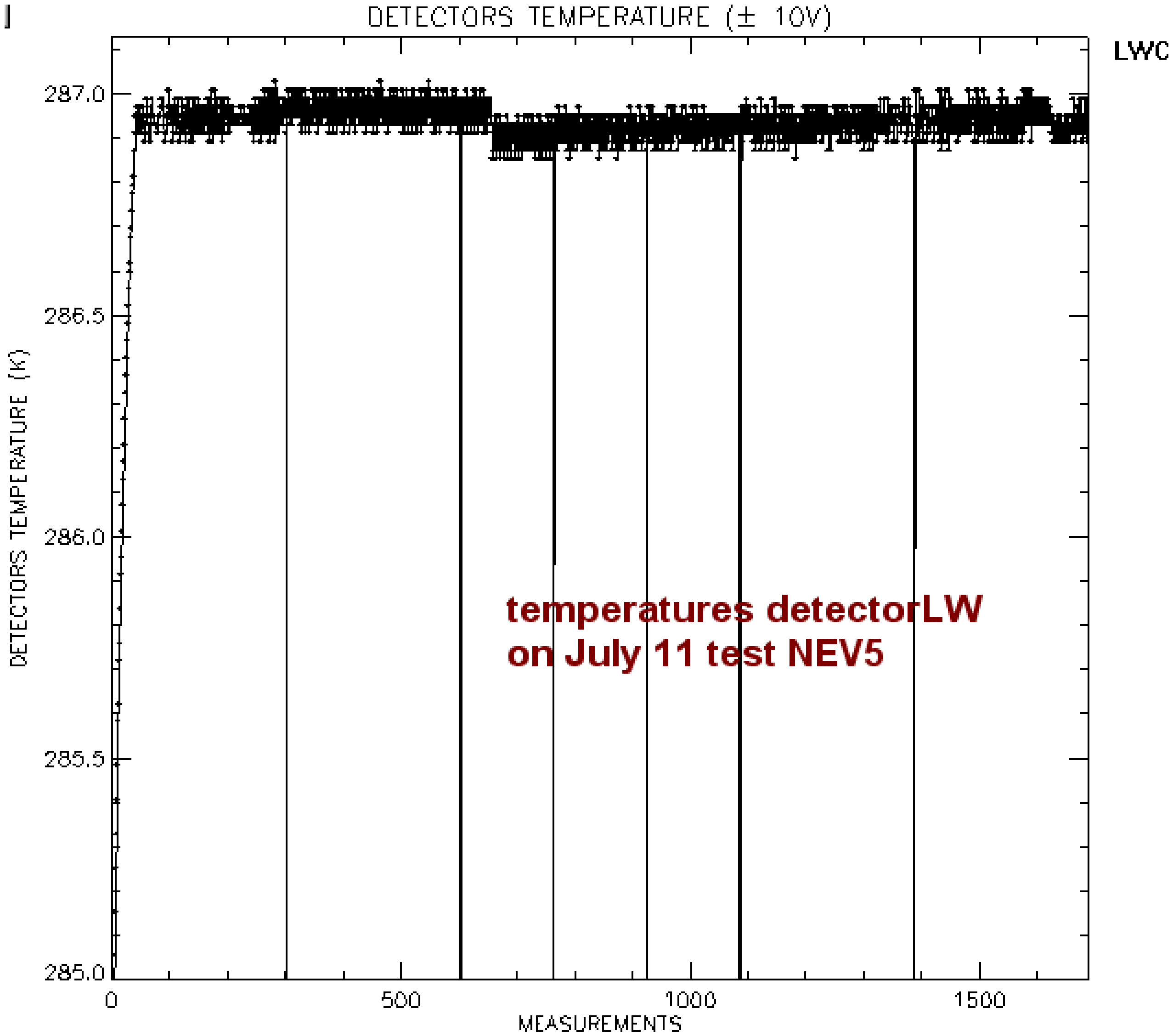


Figure 4 – Temperature of the detector LW. In about 50 measurements the detector working temperature is reached and stabilised.

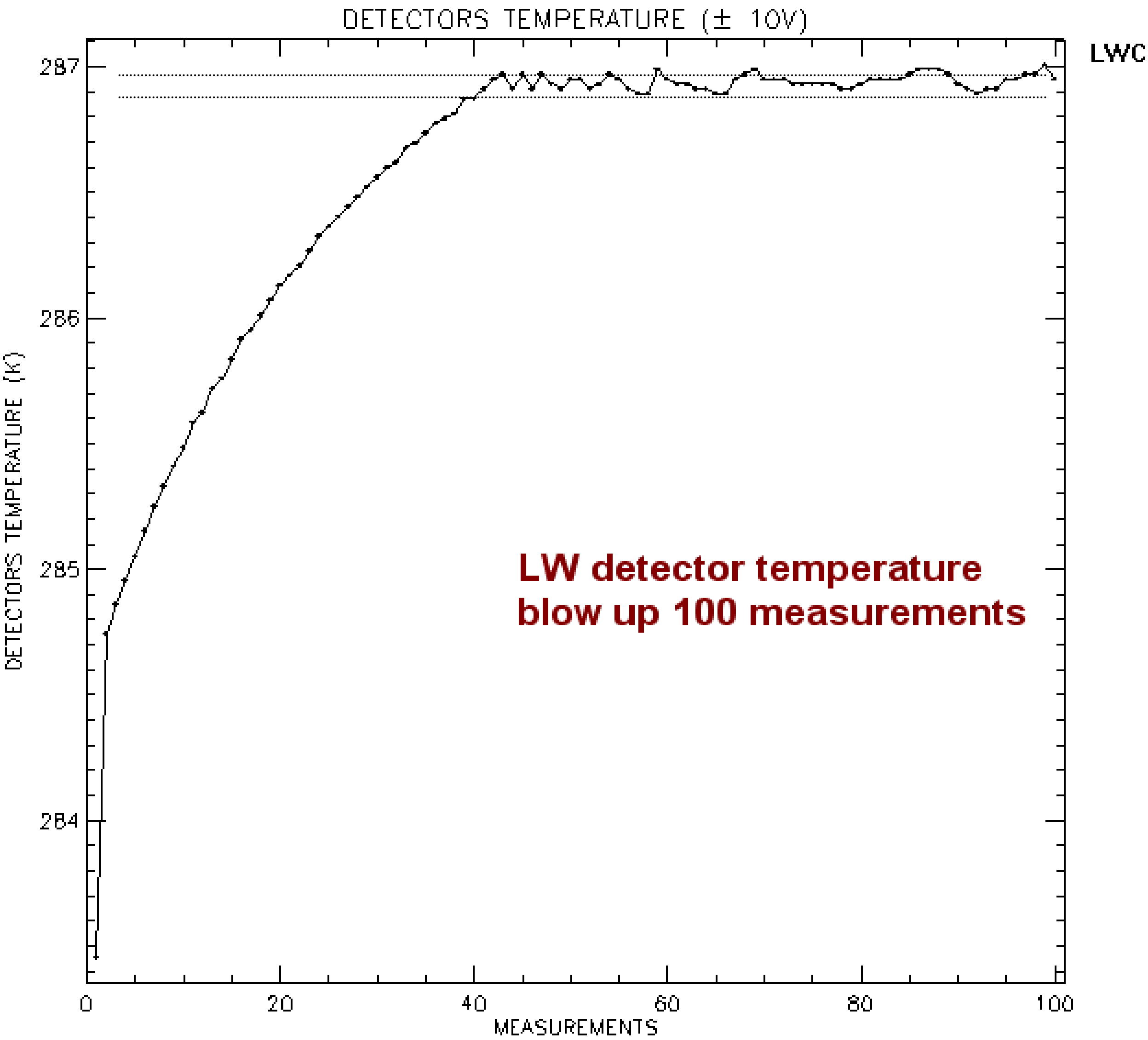


Figure 4a – Temperature of the detector LW. In about 40 measurements the detector working temperature is reached and stabilised to a value 286.95 +- 0.05 or less.

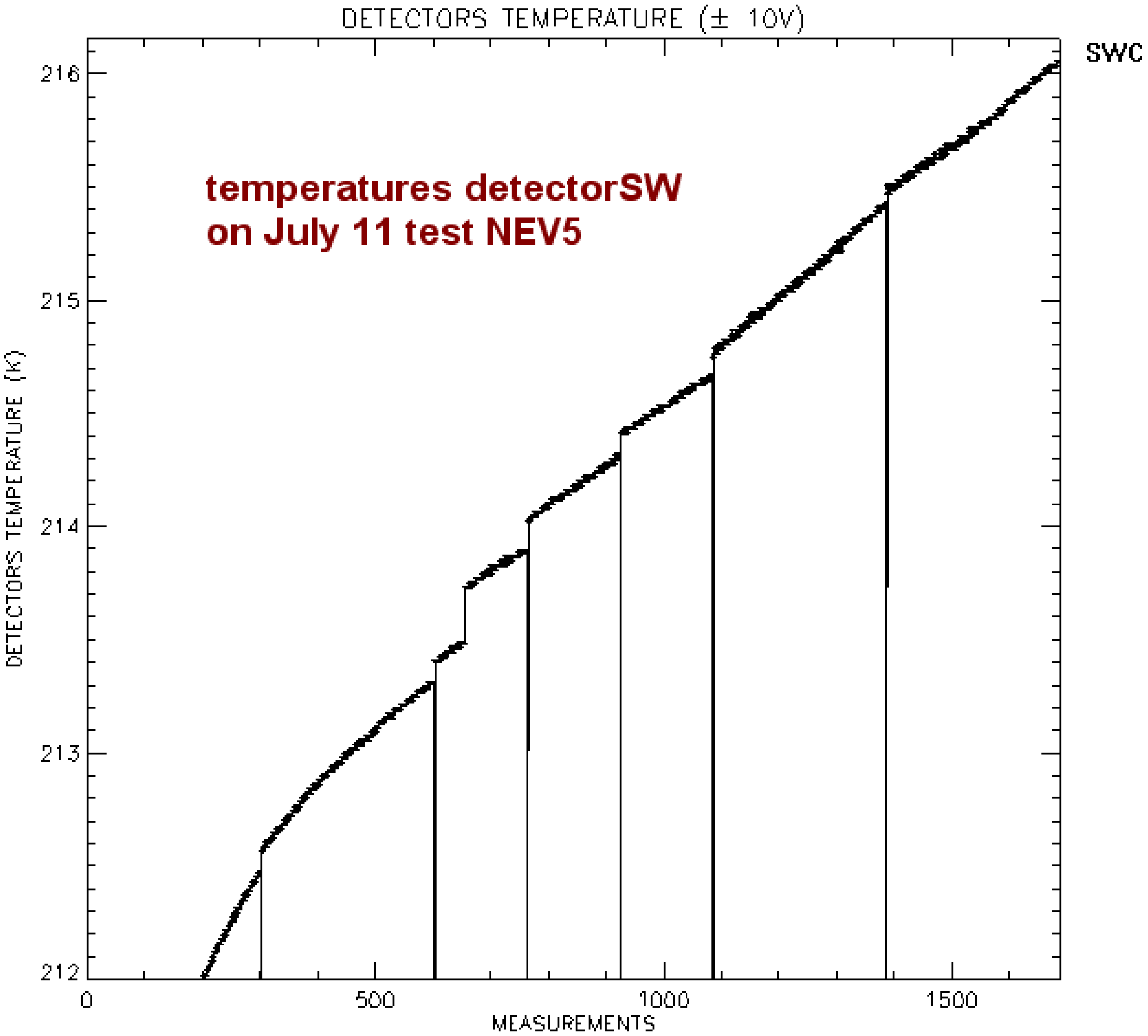


Figure 5 – SW detector temperature. In this test we first set a temperature of 220 K, then a temperature of 250 K. The detector was never able to reach even 220. The heater is not enough, while the radiator is very efficient.

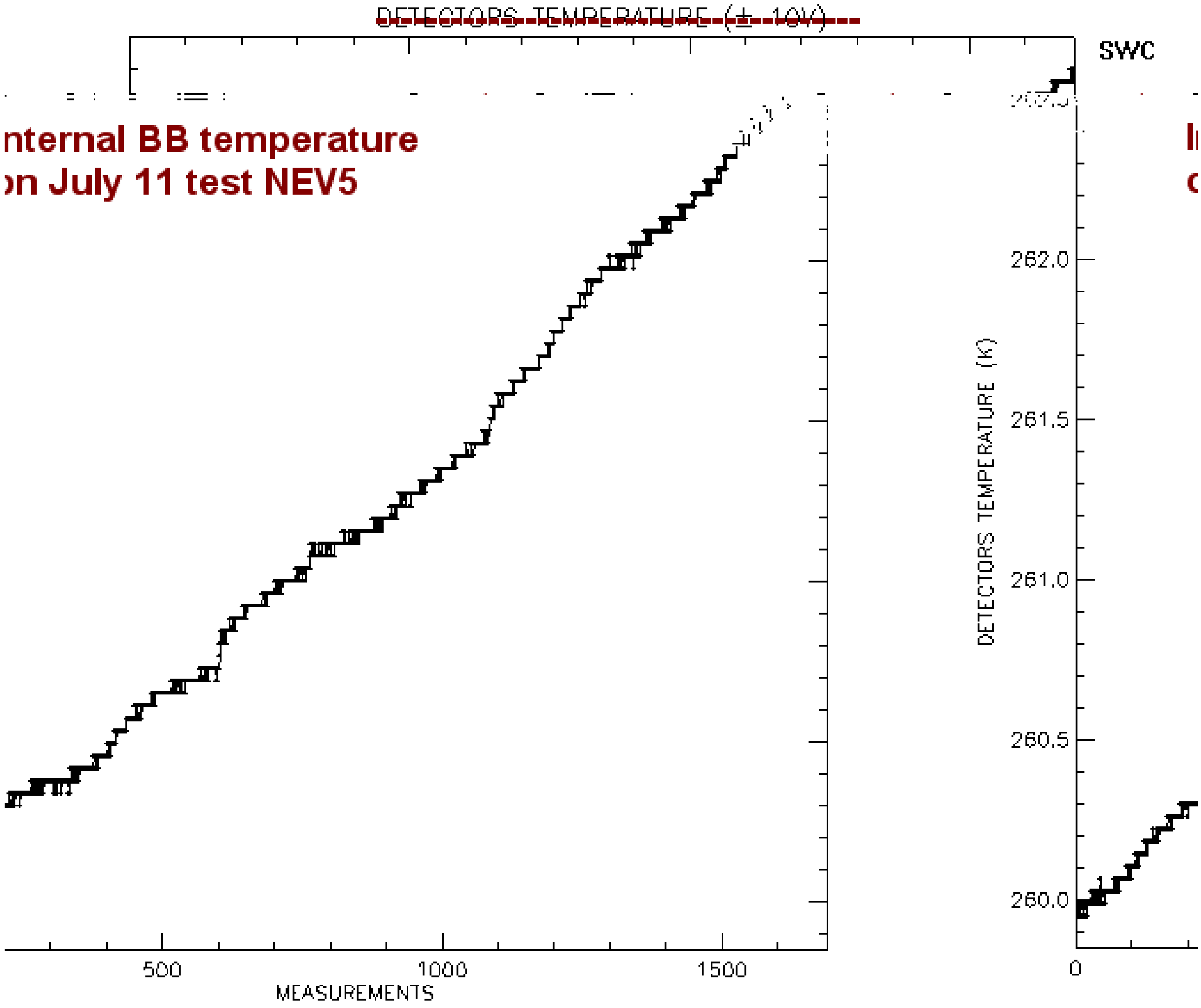


Figure 6 – Temperature of the internal BB during the measurements session. Note the heating of 2.5 deg in 7 hours.

2.5 INTERNAL BB TEMPERATURE

We conclude the study of the thermal behaviour of the experiment by noting that in general the Scanner was found to be at 10 degrees below zero (263 K). In the NEV5 study it was at 260 K when the test was started, and in 1700 measurements (roughly 17 000 sec) it increased by 2.5 Kelvin. Figure 6 shows how the temperature increased more or less linearly during the entire period of activity. At Mars we shall take only about 500 – 600 measurements per orbit, and although the thermal conditions are different, we do not expect the Internal BB to change its temperature by more than 0.6 K.

IN CONCLUSION THE THERMAL ENVIRONMENT ON MARS EXPRESS IS OK AND ALLOWS PFS TO WORK AT ITS BEST PERFORMANCE.

2.6 EFFECTS OF SOLAR ILLUMINATION

It is interesting to add the behaviour from thermal point of view, of the experiment during the last part of the star calibration slew, on July 13, when the spacecraft went in safe mode.
The geometry was such that in this last 15 minutes, solar light was being reflected by the back side of Beagle 2 and entering the aperture in which is located the scanner. The scanner was essentially closed at this time, as we were taking measurements of internal sources. Through the scanner the thermal radiation was entering the experiment and heating it at a rather high rate:

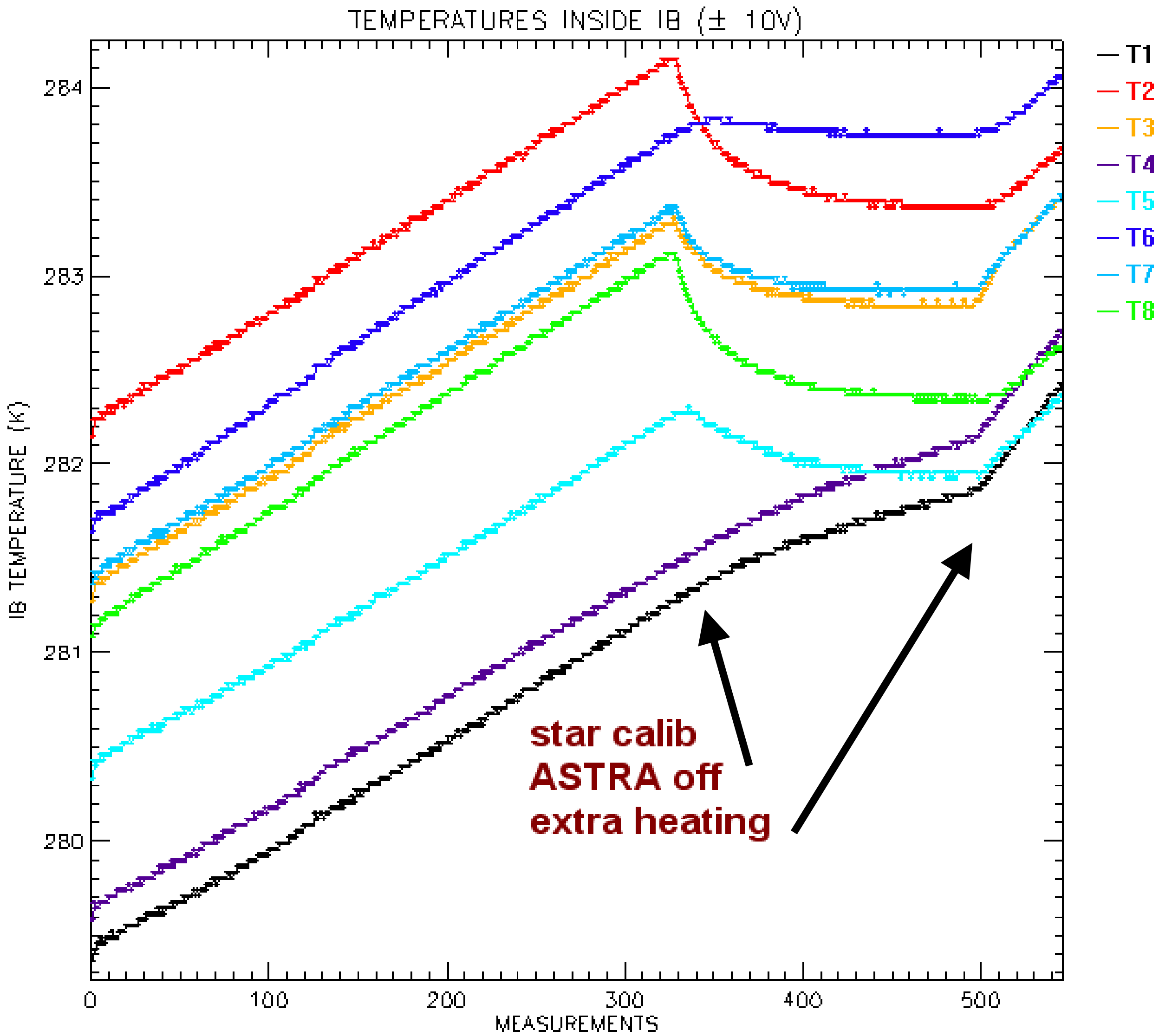


Figure 7 – Extraheating observed when solar light reflected by the back side of Beagle 2 (silver thermal blanket) entered the slot where is located the scanner. No other part of the satellite observed anything special at this time. In the last part the time for a single measurement went from 10 s to 40 seconds due to motion problems.

During this extra heating the motion was probably not good and all the measurements are bad, showing many spikes or collection of groups of spikes.

3 - MECHANICAL STUDY

The mechanical study of PFS includes testing of :Block-Unblock system.
Rotating mirror of the scanner
Motion of the double pendulum.

3.1 BLOCK- UNBLOCK SYSTEM .

The paraffine actuator of the block unblock system of the double pendulum has been activated many times (of the order of 10 in a sense and 10 in the opposite sense). It has never given any problem, and the time to do the operation has been, on average, 10 minutes.
We have also positively tested the possibility to leave the experiment in sleep mode for long time (one day) with no problem (pendulum left unblocked). During the safe mode of the satellite the experiment was switched off with the pendulum unblocked. MEX went through fast manuvres. When recovered the experiment was OK.

3.2 ROTATING MIRROR OF THE SCANNER.

The scanner has been rotated “manually” (by direct telecommands) and automatically many times: has never given any problem.
We have verified that the 5 positions around the Nadir (namely + 25, +12.5, 0, -12.5, -25 degrees) have all the same unobstructed field of view. In each position 40 measurements were taken, the spectra from all positions are shown in figure 7.1.

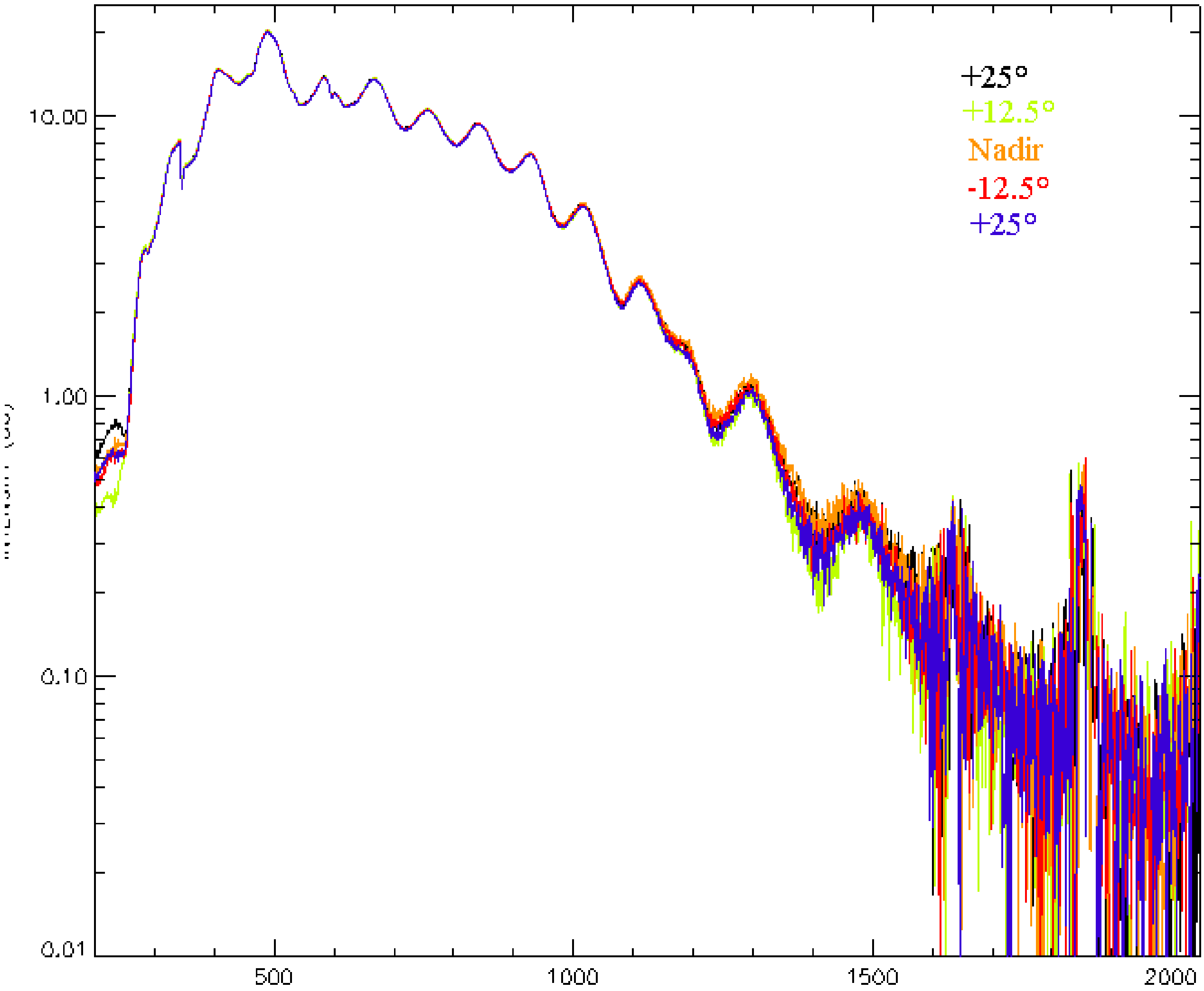


Figure 7.1 - Deep Space observations from +25, +12.5, +0, -12.5, -25 degrees. Small differences may be due to different detector temperatures. As first approximation the spectra are the same and coincide with the official deep space.

3.3 MOTION OF THE DOUBLE PENDULUM.

3.3.1 3AXIS STABILISED.

The motion of the double pendulum can be studied in 2 ways : autotest and test 1F. In the autotest we measure the speed of the double pendulum during one entire motion, by measuring the time between successive zero crossings. In the autotest we also measure the shape of the laser diode interferogram for a short run, the amplification of the photodiode signal and the current used in one motion. In the test 1F we measure the laser diode interferogram for the entire 16384 measurements to fill in the SW interferogram. This adds to the autotest the possibility to see the modulation of the laser diode interferogram. The low frequency modulation, occasionally observed in the Lab, it is generated by possible non monochromaticity of the laser diode, when its temperature is not correct. The low frequency modulation, when it becomes large, can generate bad pendulum motion, spikes in the interferograms, and other bad features.

A typical result from autotest performed in the laboratory is given in figure 9, while the first autotest done in space, with PFS only experiment on, it is shown in figure 8. The difference is clear and strong.
The autotest in space was showing strong modulations (see figure 8). These modulations, a priori, could be due also to bad motion caused by a non monochromatic laser diode. When we have that, usually because of wrong temperature, the laser diode shows many strong modulations. In order to verify the situation, we decided to perform test 1F in order to exclude that laser diode modulation was disturbing the motion. The result is shown in figure 10 : test 1F demonstrates that the laser diode has very little or no modulation. The modulated oscillations seen in the autotest, therefore are due to mechanical vibrations. The FFT of the 1F data, on the other hand, can give us the spectrum of the mechanical vibrations : indeed it shows that some mechanical vibrations are present. Figure 11 shows this spectrum : The scales are somewhat arbitrary, but the horizonthal scale becomes frequencies in Hz if multiplied by 4.25.
In figure 11 there is a central large peak which is due to the laser diode itself, which identifies the 2000 Hz of the motion. This is the frequency of the sine wave. This frequency appears to be modulated by others of much less intensity : These other frequencies appear as satellites around the main peak. We note about 5 peaks on each side of the main one. Note that the peaks at lower frequency than the main one may affect directely our measurements by having the relative zero crossings fluctuating around the real position. The frequencies above 2000 Hz may also affect the measurements, and they may appear as aliasing in the spectrum.
Figure 12 gives a blow up of the central part of figure 11. We see now that the situation is really rather complex, even the central peak having 2 small satellites. At low frequencies, therefore there seem to be several mechanical disturbances. For the moment we identify the following frequencies :
+- 19 Hz
+- 144 Hz
+- 293 Hz
+- 540 Hz
+- 651 Hz
We can interpret these results as 3 basic disturbances modulating the higher frequencies : a 19 Hz modulating the 111 Hz, which in turn is modulating the 595 Hz .

To better understand the frequencies of the disturbances present, we have studied the sine waveform sampled in each autotest, and doing the FFT we have done the necessary computations to have the final results in Hz.
We start with a typical spectrum in normal conditions : Fig 13 a, b, c shows the resulting spectrum in the 3 ranges 0-500 Hz, 500-700 Hz and 700 – 2000 Hz.

- 3 frequencies are observed around the 139-150 Hz interval .
- a number of other monochromatic lines appear in the low frequencies range.
- 3 large peaks appear in the intermediate range : at 595 Hz, at 544 and at 653 Hz
- At high frequencies a group of lines appear around 800 Hz, at 1200 Hz and at 1300 Hz. Note however the very different vertical scale, as these disturbances are of much smaller intensities.

All the frequencies identified above are "as seen by the interferometer ". In the spacecraft frame they have a different frequency value. We have been able to study the real value of the frequencies by studying the changes of these frequencies with the speed of the double pendulum. We have taken data with the speed at 1500 Hz, 2000 Hz, 2500 Hz, 3000 Hz. The default value was 2000Hz. The central peak in the 500 – 700 Hz interval moves from 587 Hz at speed 1500, to 614 Hz at speed 3000. If we assume we are dealing with a sort of Doppler effect, we see that at speed 0 we should have a disturbance of 587 – 27 = 560 Hz. Similarly the main disturbance in the low frequencies is at 142 Hz. However there is always another low frequency which is modulating the 587 Hz, and this is also directely seen in the spectrum and as modulation : the frequency is 113 (at speed 3000), at 108 (at speed 1500), at 103 (at speed zero).
All the previous results are for normal spacecraft conditions : 3 axis stabilised. They do not change, however when MEX is doing some slewing manuvre. A change has been observed in case of wheels offloading .

3.3.2- WHEELS OFFLOADING.

The NEV 3 test started immediately after a wheel offloading manuvre. The autotest presented immediately some unusual behaviour, which we can see in figure 14, as an extra high frequency disturbance. The FFT of the laser diode signal (shown in figure 15), in the high frequency part shows a very large noise level and some broad region enhanced : 800 Hz, 1200 Hz, 1400 Hz, 1600 Hz. In another case we used PFS during the wheels offloading activity, we saw the same high frequencies in the speed plot, but in the FFT of the laser diode (high frequency plot) the situation was rather different. Figure 16 a and b shows the FFT plot during the offloading activity done when the NEV5 test was performed. First the different vertical scale with the previous figure should be noted. The noise intensity is much lower now. The general aspect of the noise is also different, in the sense that single lines are now seen, rather than a general confused noise. In particular we see lines at 740, 850, 1205, 1500 Hz. In general the disturbances of the wheels offloading last for about 30 minutes (in any case less than 1 hour) and then disappear completely.

3.3.3- X BAND OFF.

It is not clear why the switch off of the X band for telecommunications should change the vibration environment on the satellite, but this is what has been observed during the test called star calibration : the X band was off, and we saw a different spectrum in the first autotest performed. The disturbance level was high at the beginning and we saw extra peaks in the LW channel spectrum. These peaks disappeared later from the measurements.
See figure 17.
In conclusion the double pendulum was able to move correctly with the spacecraft 3 axis stabilised, or in slew manuvres, or during wheels offloading, and survived intact the safe mode unblocked.

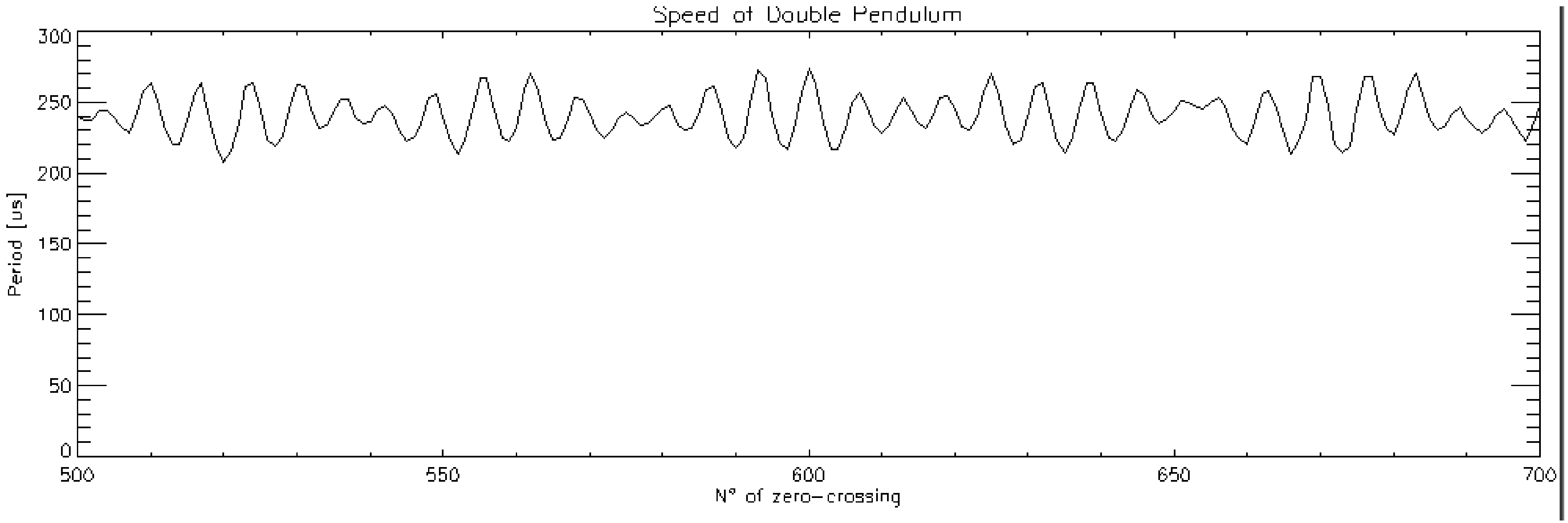


Figure 8 – The first autotest made in space : note 600 Hz oscillations, modulated by a 110 Hz. The quantity plotted is the time in microseconds between successive zero crossings, i.e. dividing 150 nm by the plotted quantity, we get the speed of the double pendulum.
Data are from NEV 1.

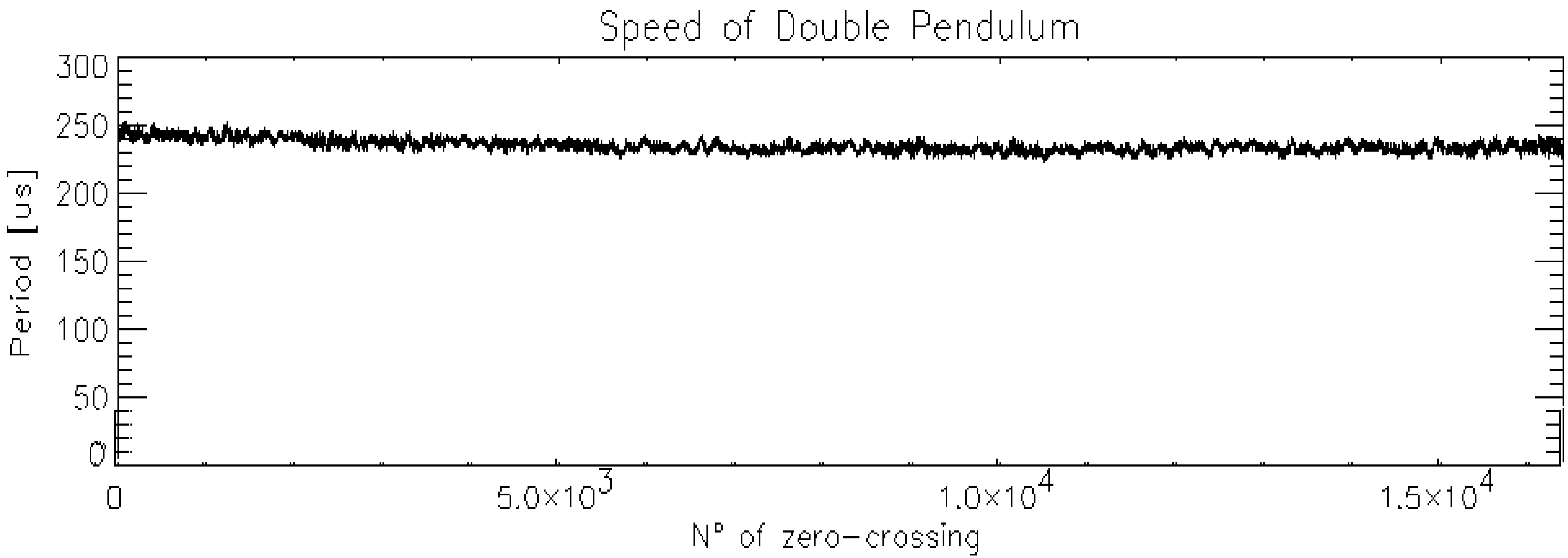


Figure 9 – Typical autotest results in the laboratory : Note that the time between zero crossings is very well constant at 245 micro seconds. This is needed for measuring well the interferograms.

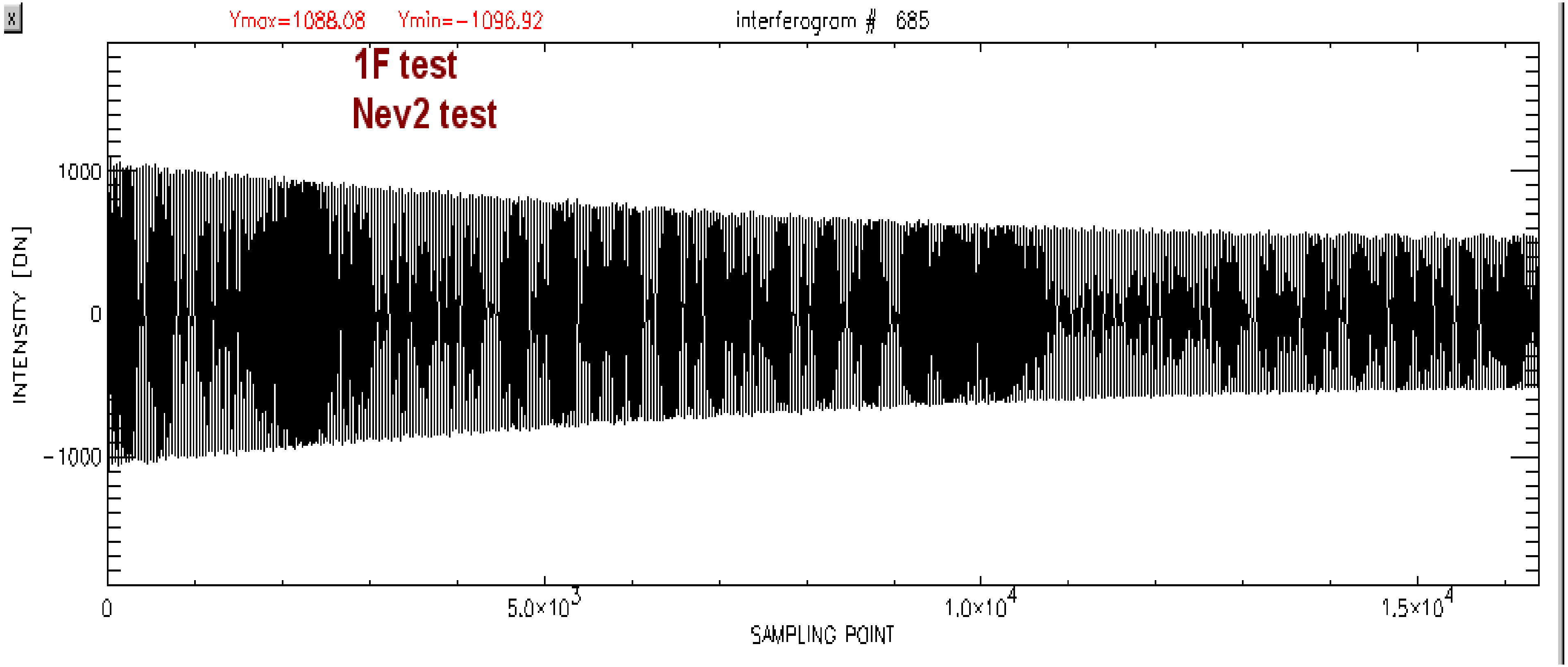


Figure 10 – The 1F test, showing no strong modulation of the laser diode interferogram, as it would be if the laser was not monochromatic.

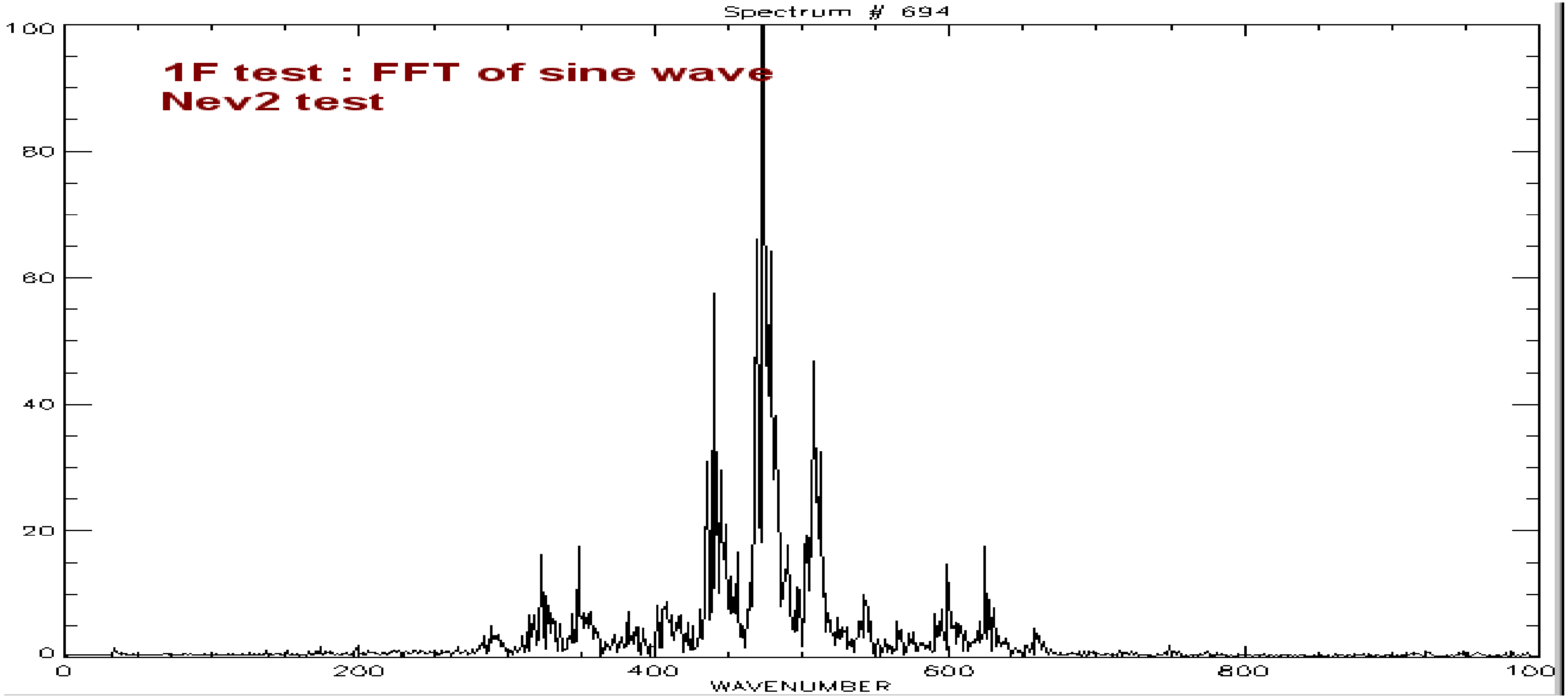


Figure 11 – FFT of the 1F test, showing the presence of modulating disturbing frequencies. Note that for cases like the one in figure 9, this FFT would be simply a delta function, like the central part only of this figure.

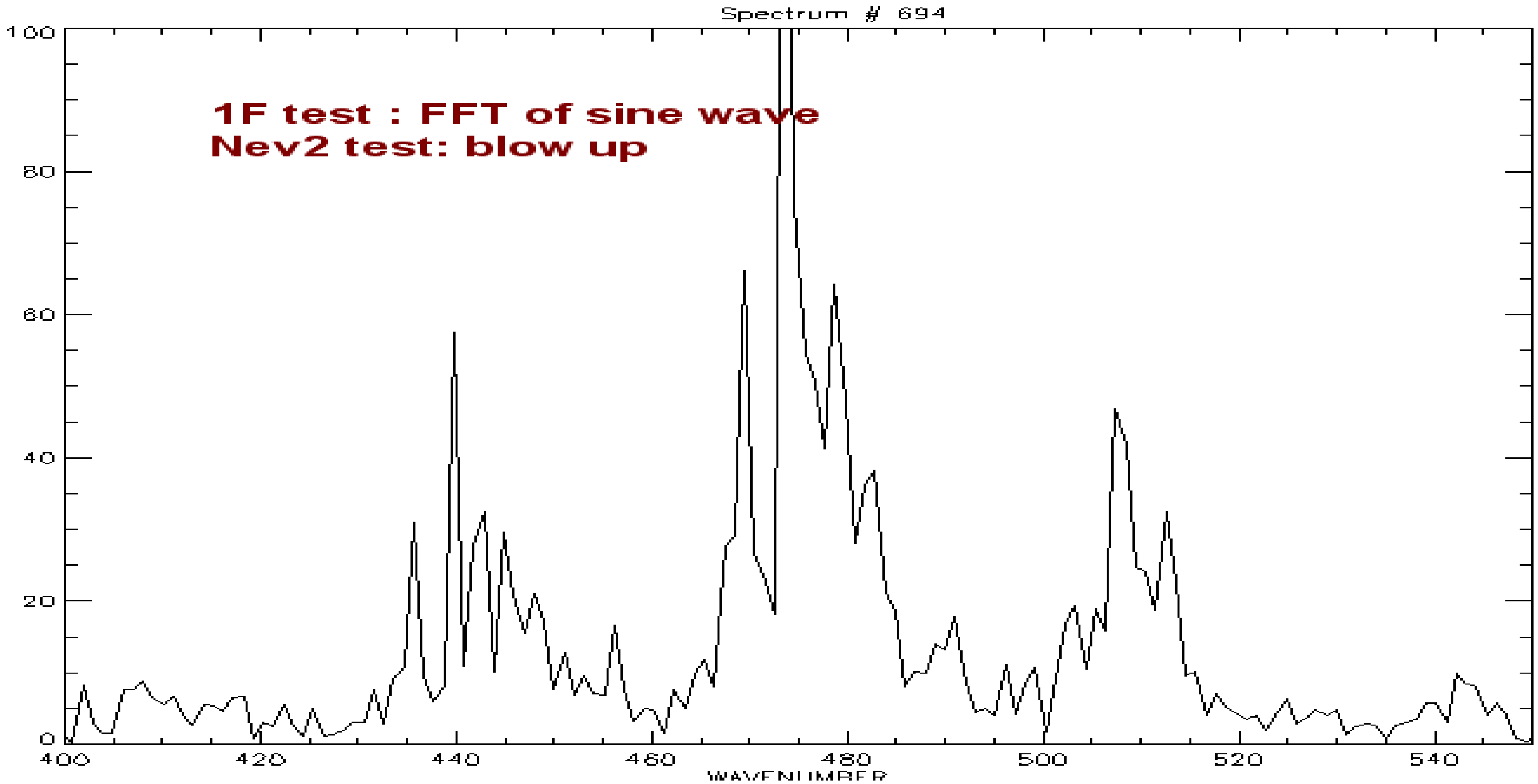


Figure 12 – Blow up of the central part of the previous figure .
Note that frequencies can be obtained by multiplying the abscissa number by 4.25. The large peak is the one that determines the double pendulum average speed at 2000 Hz.
Note that the central peak has satellites at +-19 Hz, +- 144 Hz, +- 293 Hz, +- 540 Hz, +- 651 Hz.
See text for explanations.

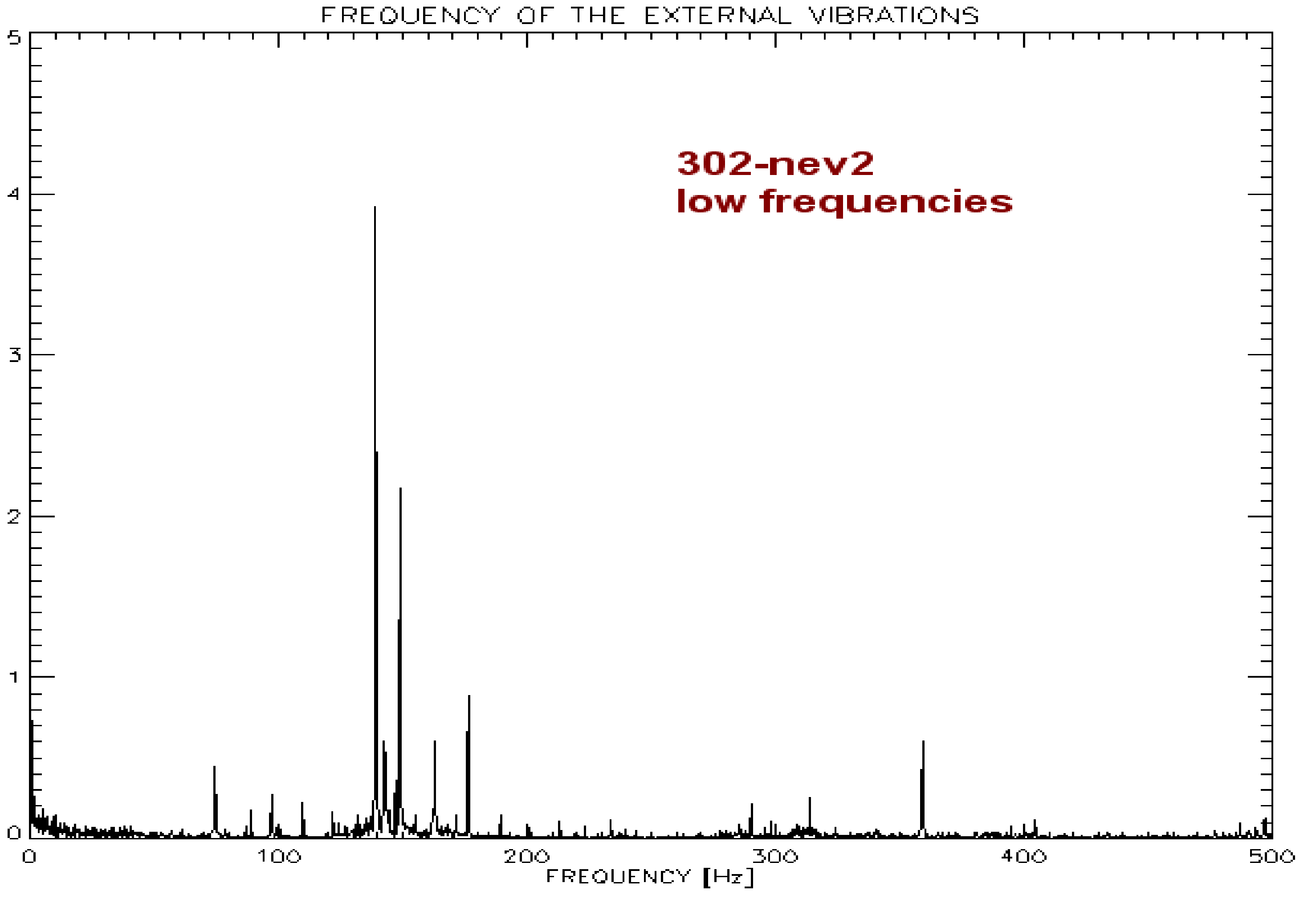


Figure 13 a – Autotest 302 – NEV 2. Low frequencies part.

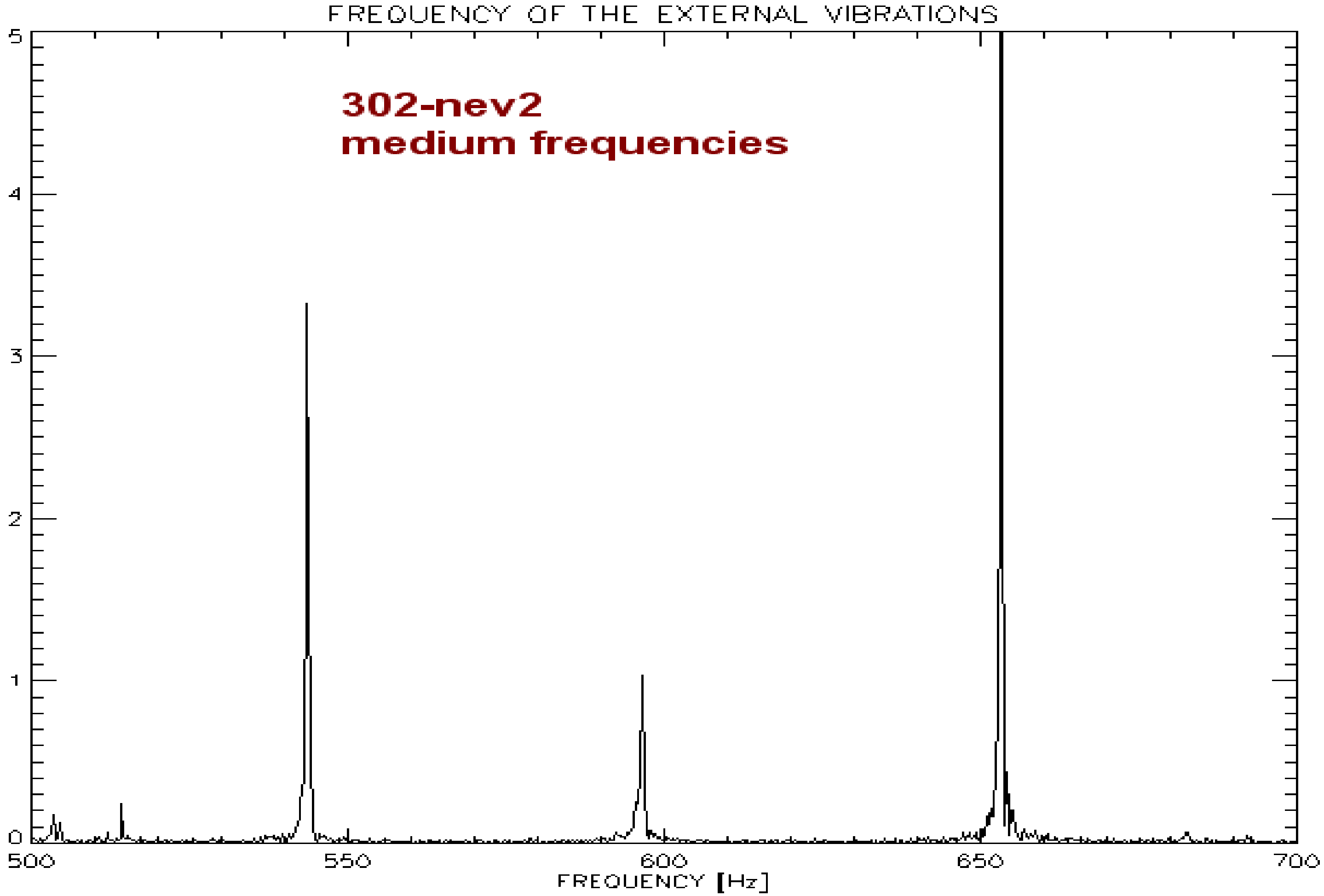


Figure 13 b – Autotest 302 – NEV 2. Medium frequencies part.

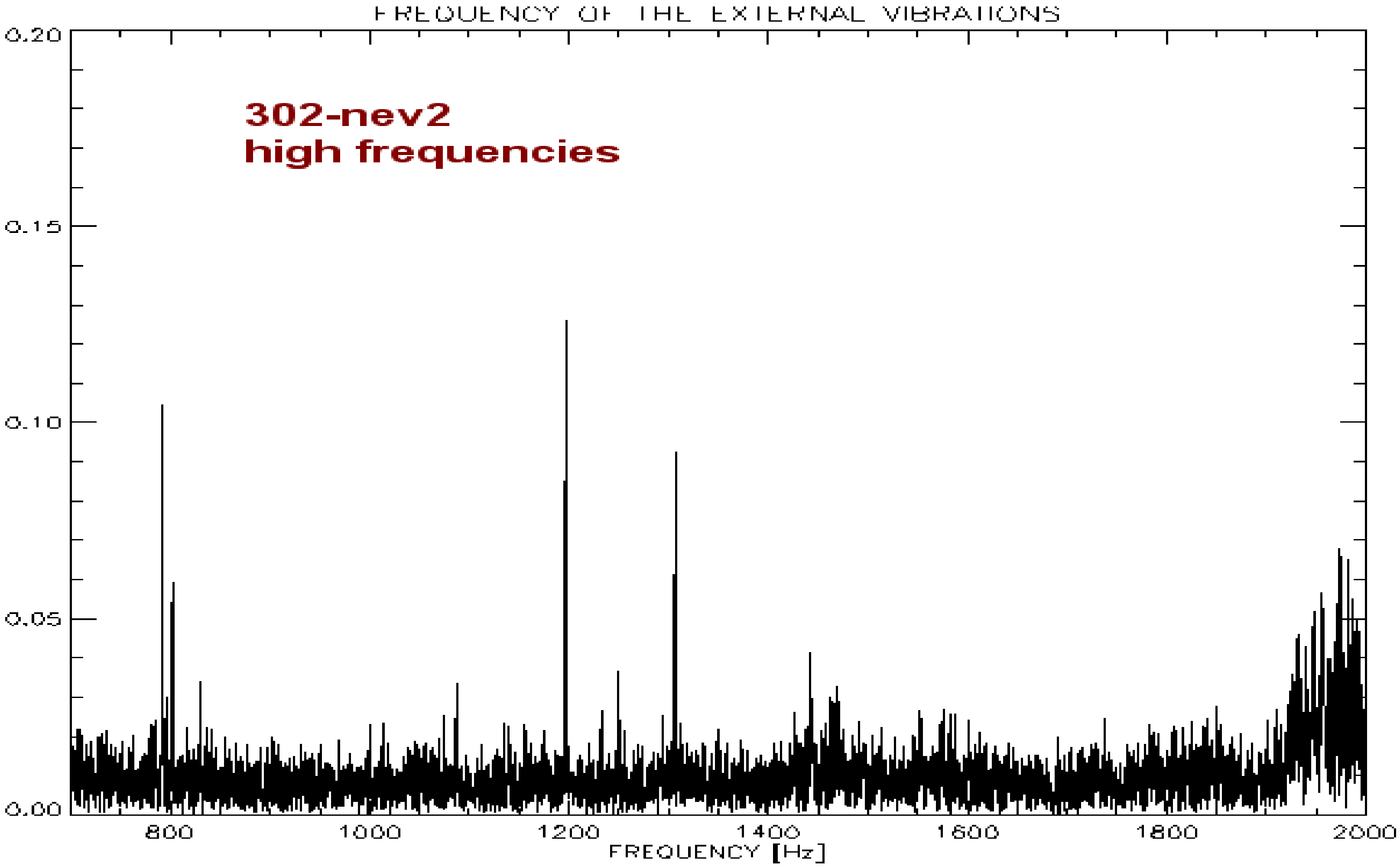
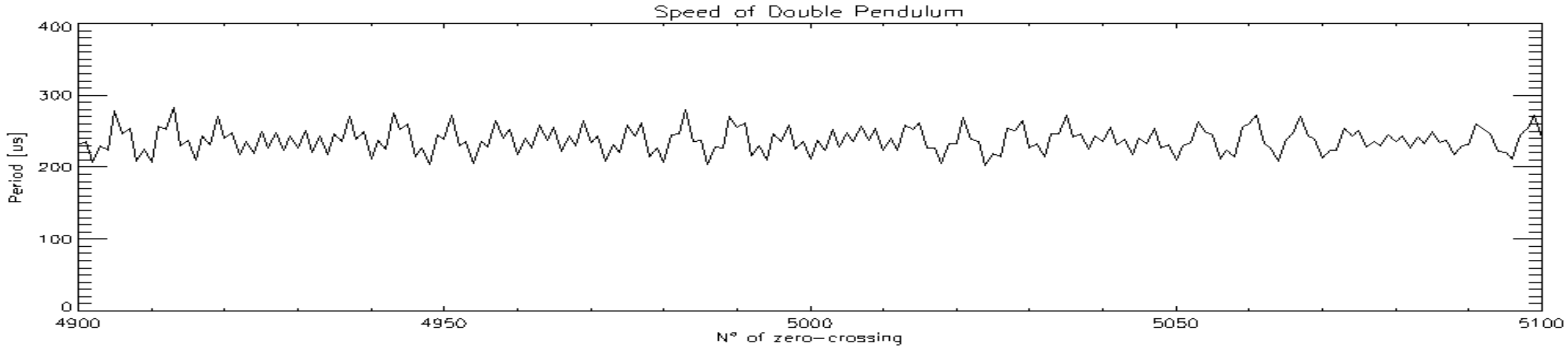


Figure 13 c – Autotest 302 – NEV 2. High frequencies part.

First Autotest During NEV 3



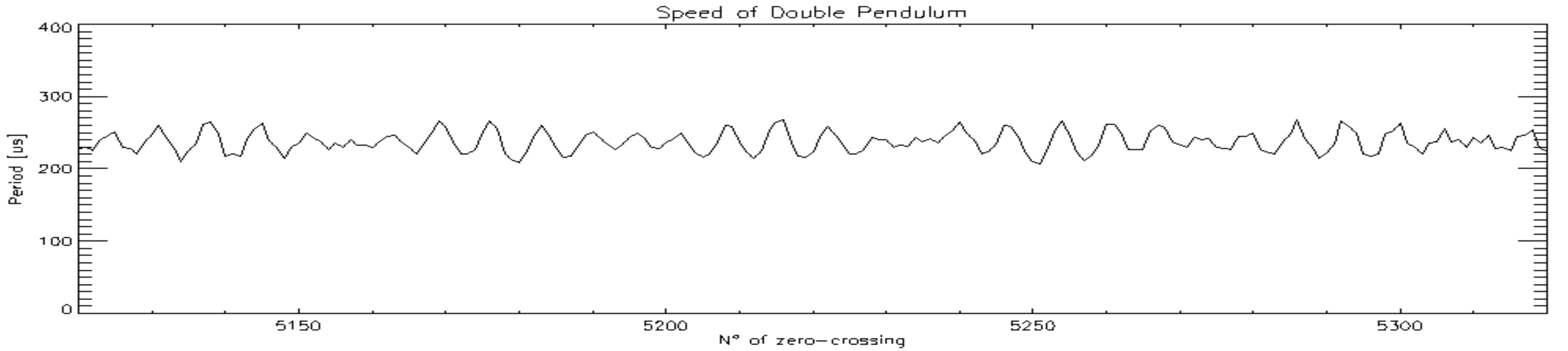


Figure 14 – Top panel Autotest motion just after the wheels offloading (note the high frequencies present). Bottom panel, autotest motion during normal conditions.

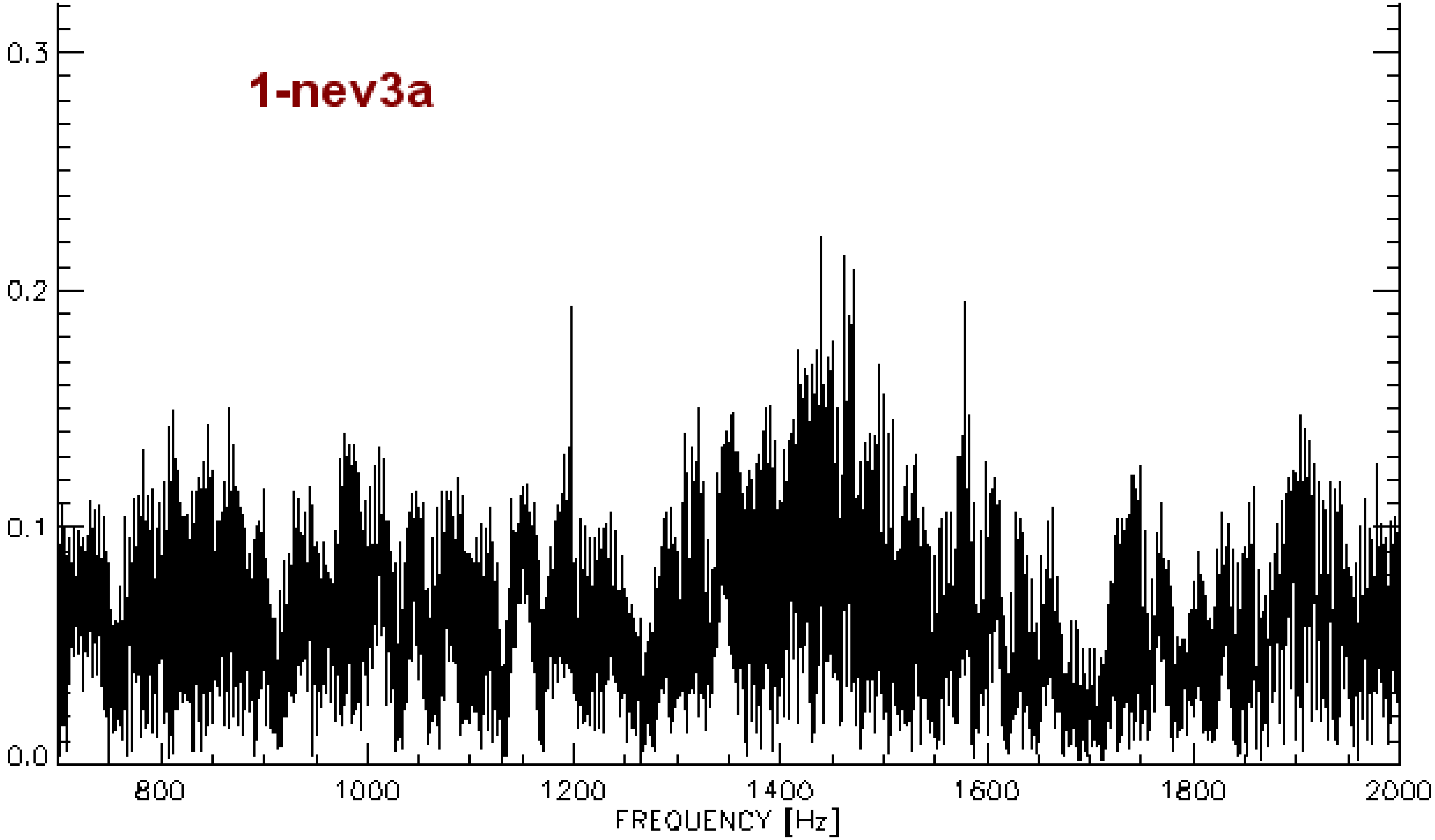


Figure 15 – FFT, high frequencies of the NEV3 test immediately after wheels offloading.

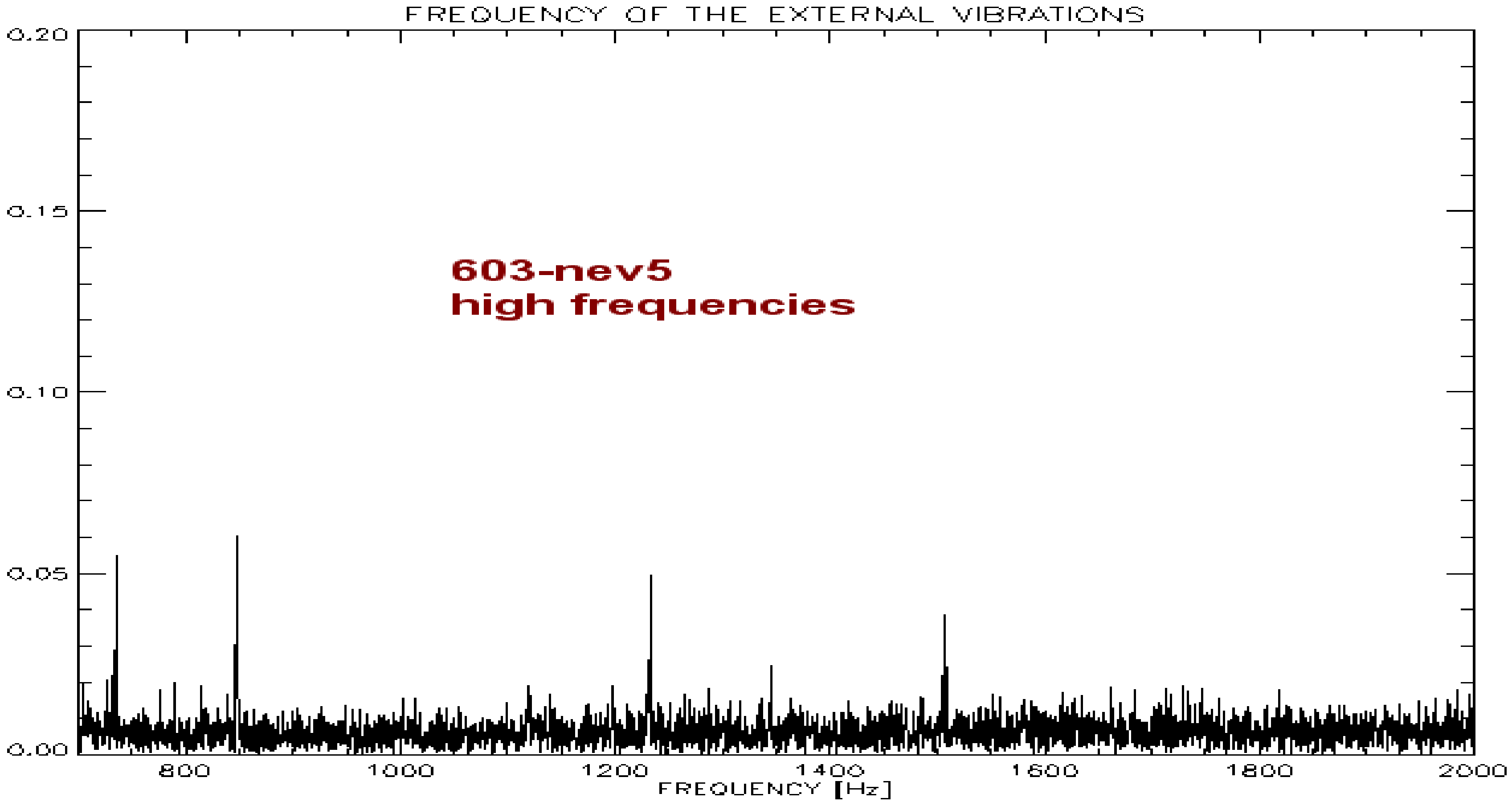


Figure 16 - FFT, high frequencies of the NEV5 test immediately before wheels offloading.

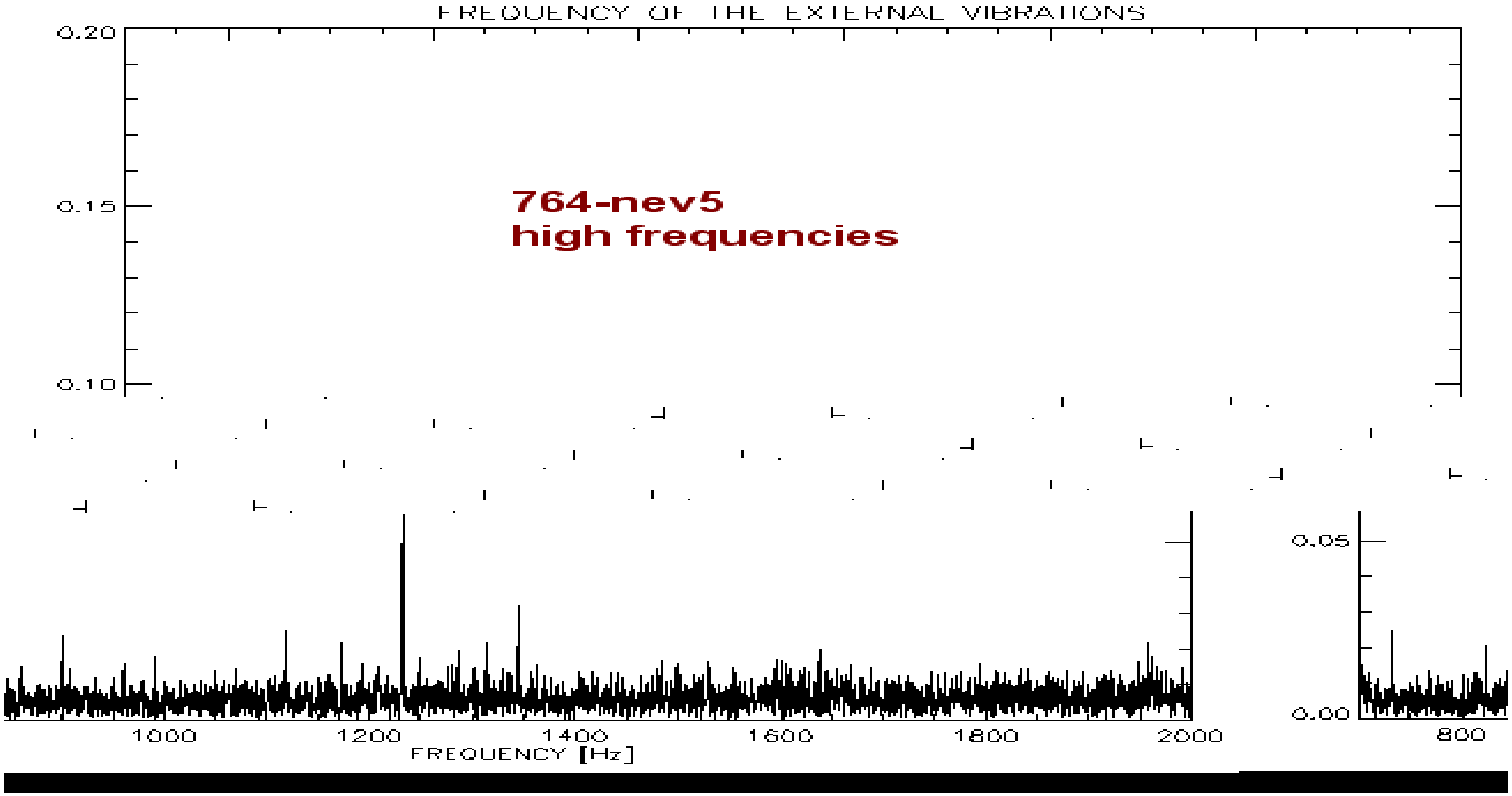


Figure 16 a - FFT, high frequencies of the NEV5 test immediately after wheels offloading.

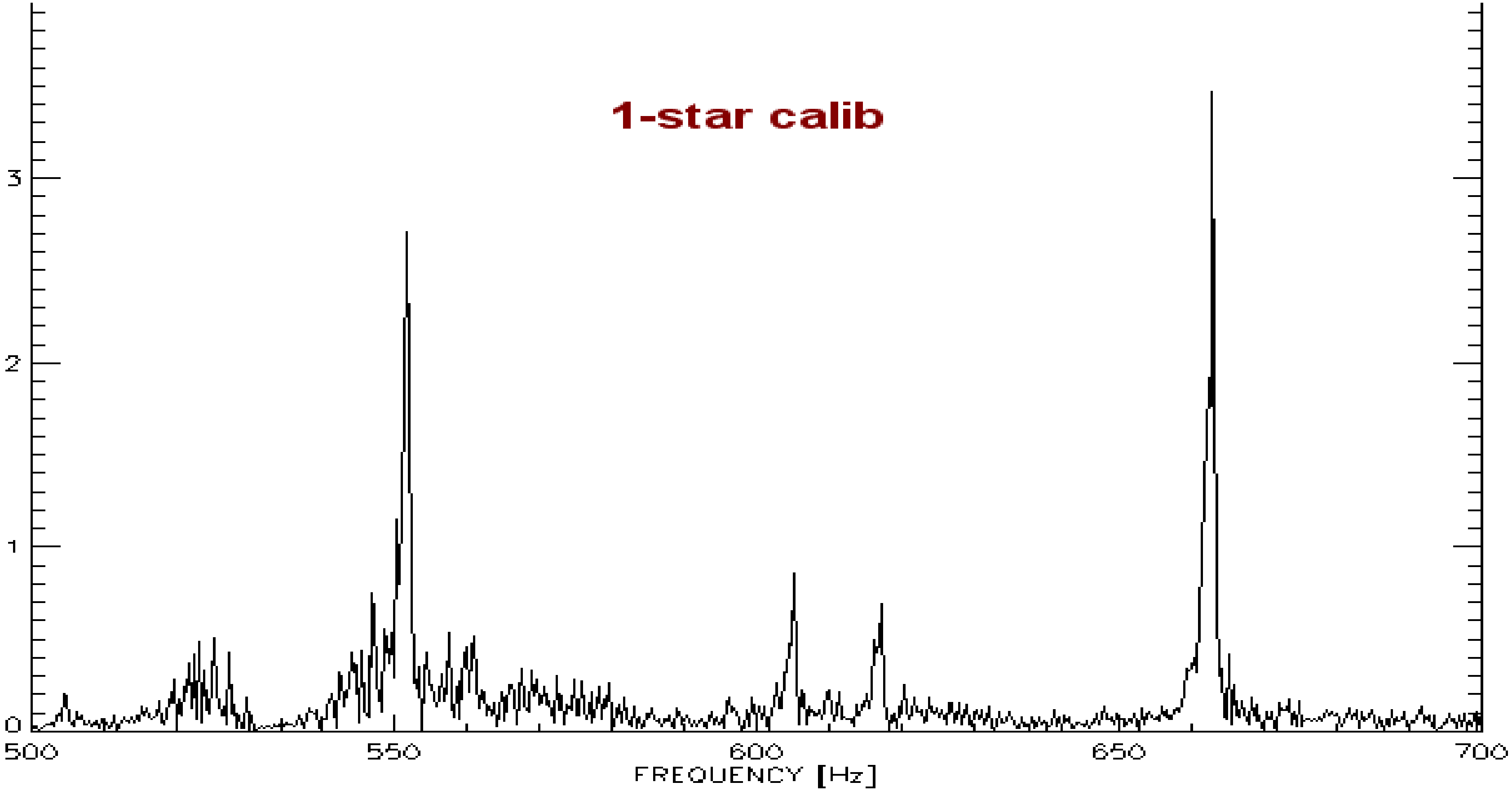


Figure 17 - Extra noise is observed during a period (40 minutes?) when the X band is switched off. Note extra frequencies also present.

4. LONG WAVELENGTH CHANNEL CALIBRATION

4.1- THE EFFECT OF MECHANICAL DISTURBANCES.

The two PFS channels have a band pass filter which is related to the speed of the pendulum and the sampling frequency. The band pass frequency for the LW channel is 50 – 500Hz and for the SW channel is 500 to 2000 Hz. This is valid for the default speed of the pendulum. The frequencies of the mechanical disturbances described previously are all within the band pass of one of the 2 channels. It is clear that the effect will be seen in the spectrum .

It should be noted that in any Fourier spectrometer measuring an interferogram, the mechanical disturbance seen previously would destroy completely the measurements. Indeed in the interferogram each point contributes to all the wavenumbers of the spectrum. A few bad points would destroy completely the measurements of the spectral radiance. The effect of the mechanical disturbance normally would be to force the experiment to take a measurement at an optical path difference randomly placed, instead of having measurements at precisely the same optical path difference increments. The mechanical displacement of the double pendulum for the SW channel is 150 nm, for the LW channel is 4 times that. It is clear that even small mechanical vibrations can destroy the measurements. PFS has been designed so to be “robust” against mechanical vibrations. The reference source (laser diode) used for controlling the motion of the pendulum and at the same time for timing the sampling of the signal, undergoes an optical path similar to the one of the real signal, therefore the mechanical vibrations are felt similarly by the reference channel and by the measured radiation. The result is that the radiance is still measured, and the effect of the vibrations is mostly in increasing the noise at certain frequencies, because the integration time of the signal measured is fluctuating. It is clear that changing the speed of the pendulum, therefore changing the bandpass frequencies range, can move the vibration disturbances in a portion or another of the spectrum, leaving the rest clean and uncontaminated.

Figure 18 shows average and standard deviation (sigma) of a set of measurements taken in the NEV1 test looking at Deep Space. Sigma has values between 0.06 and 0.08 almost everywhere. Three peaks go up to 0.4 (a factor 5 higher). These peaks are at 1660, 1880 and 2050 cm-1. The last peak is out of the LW range. In frequencies they are at : 415, 470. Note that there is also a small peak at 400 cm-1 which is equivalent to 100 Hz. The first frequencies 415 and 470 are actually aliasing from the frequencies at 530 and 585 Hz which are out of the LW range. The same frequencies are seen when looking at Internal BB or at the calibration Lamp with the LW channel (see figure 19 and 20) .

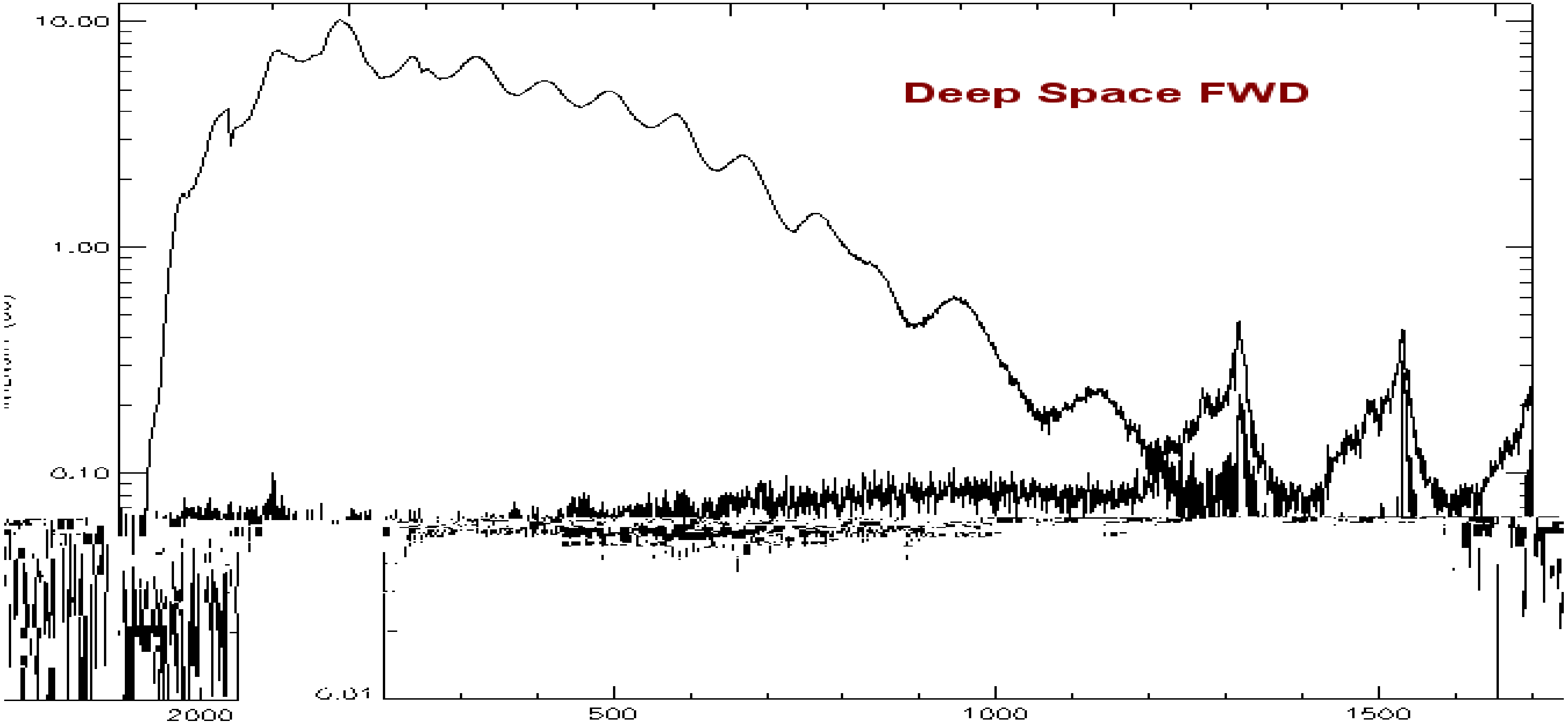


Figure 18 – Deep space observation. Average spectrum and sigma in the LW channel. Note the full coverage from 200 to 2000 cm-1. Note the presence of 2 or 3 peaks at 1650, 1870 and 2050 cm-1 caused by mechanical disturbances. In the last part of the spectrum the signal is below the noise.

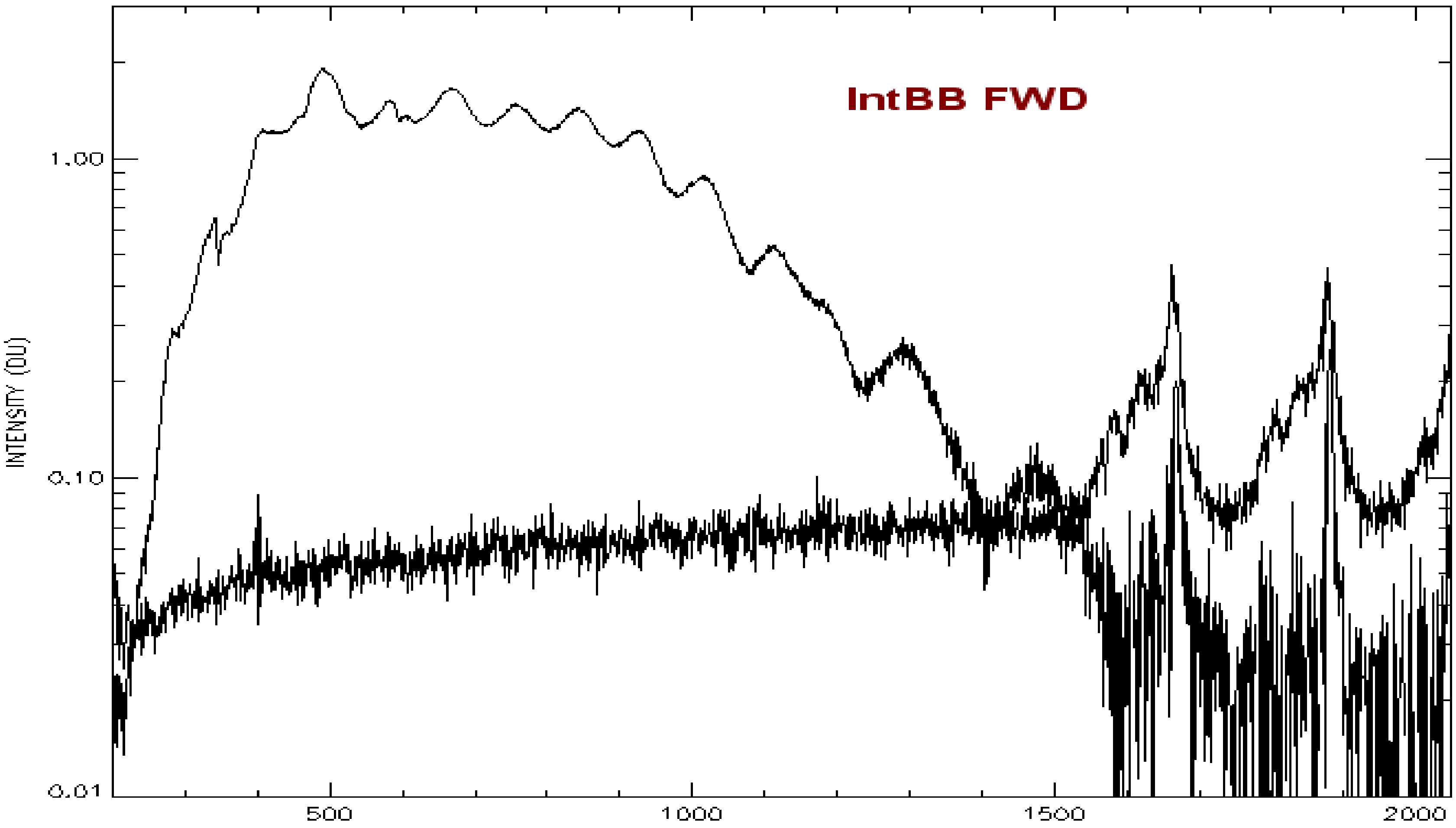


Figure 19 – Internal BB observation. Average spectrum and sigma in the LW channel.

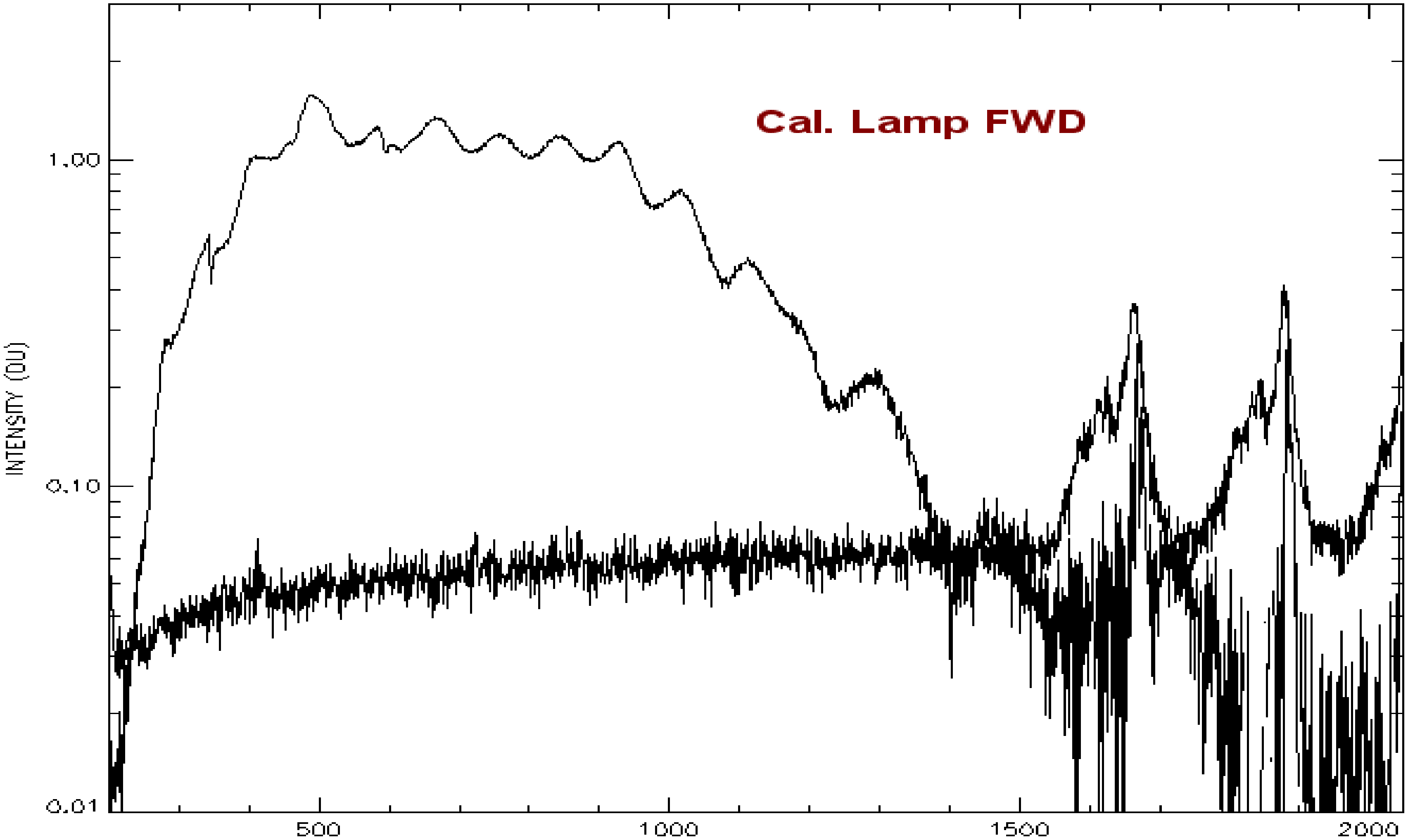


Figure 20 – Internal calibration lamp observation. Average spectrum and sigma in the SW channel.

4.2 THE EFFECT OF CHANGING THE SPEED.

We have been able to change the speed of the double pendulum and study the effect on the spectrum of the mechanical vibrations present. The changes were up to +- 50%, and in particular the upper frequencies were 1500, 2000, 2500 and 3000 Hz.
The resulting average spectrum and standard deviation for the deep space observations are shown in figure 21, 22, 23, 24 .
We note the apparent absence of major disturbances due to mechanical vibrations when the speed was 1500 Hz, while for higher speed we see 2 or 3 peaks in the noise, which may be reflected in artefacts in the signal also. The location of these peaks is changing with the speed : they seem to enter from right side and move toward the centre of the figure. Note also that the actual intensity of the disturbances is increasing with increasing speed.
These results are understood in terms of the effects caused by a changing speed : at low speed the disturbing frequencies may be out of the frequency range of the channel, and the disturbances present in the channel (if any) cause only a smaller jtter of the optical path difference increment.
In order to select the best speed for the experiment, it is not enough to look only at the LW channel, we have to consider also the SW channel. Here we note that from 1500 to 2000 cm-1 the wavenumber range is of lower scientific interest, at least compared to 400- 800 cm-1 or 800 – 1300 cm-1. Disturbances below the 1500 cm-1 should be avoided. This implies that speed 3000 should be avoided.
From the SW channel we shall conclude that speed 2500 is probably the best.

In conclusion we also show the result of a Test 5 obtained during NEV2 : The average spectrum and noise (sigma) is amplified by the well known factors, as we expected. (see figure 25).

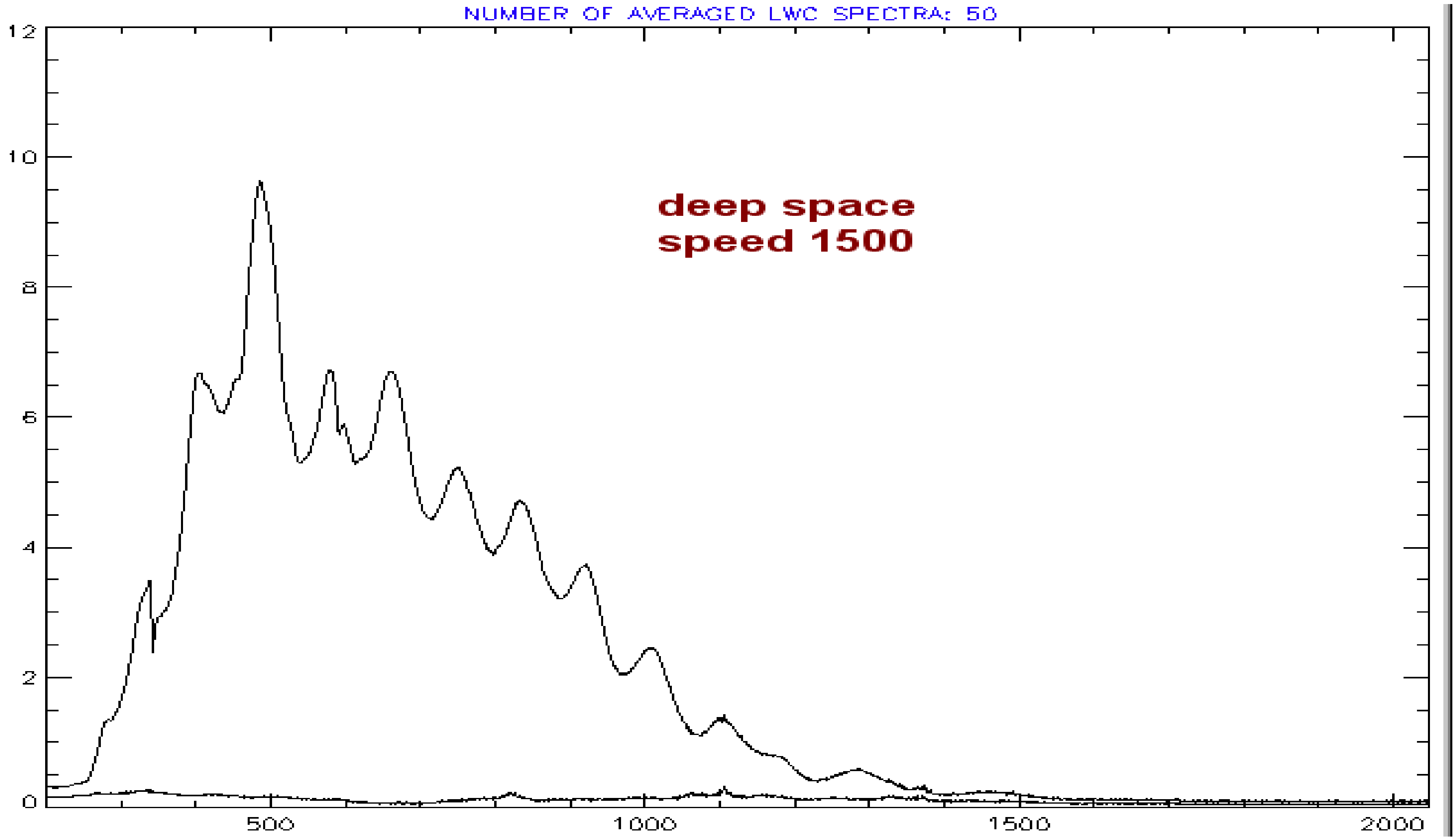


Figure 21 – LW channel on deep space at speed 1500 Hz. No strong disturbance is observed.

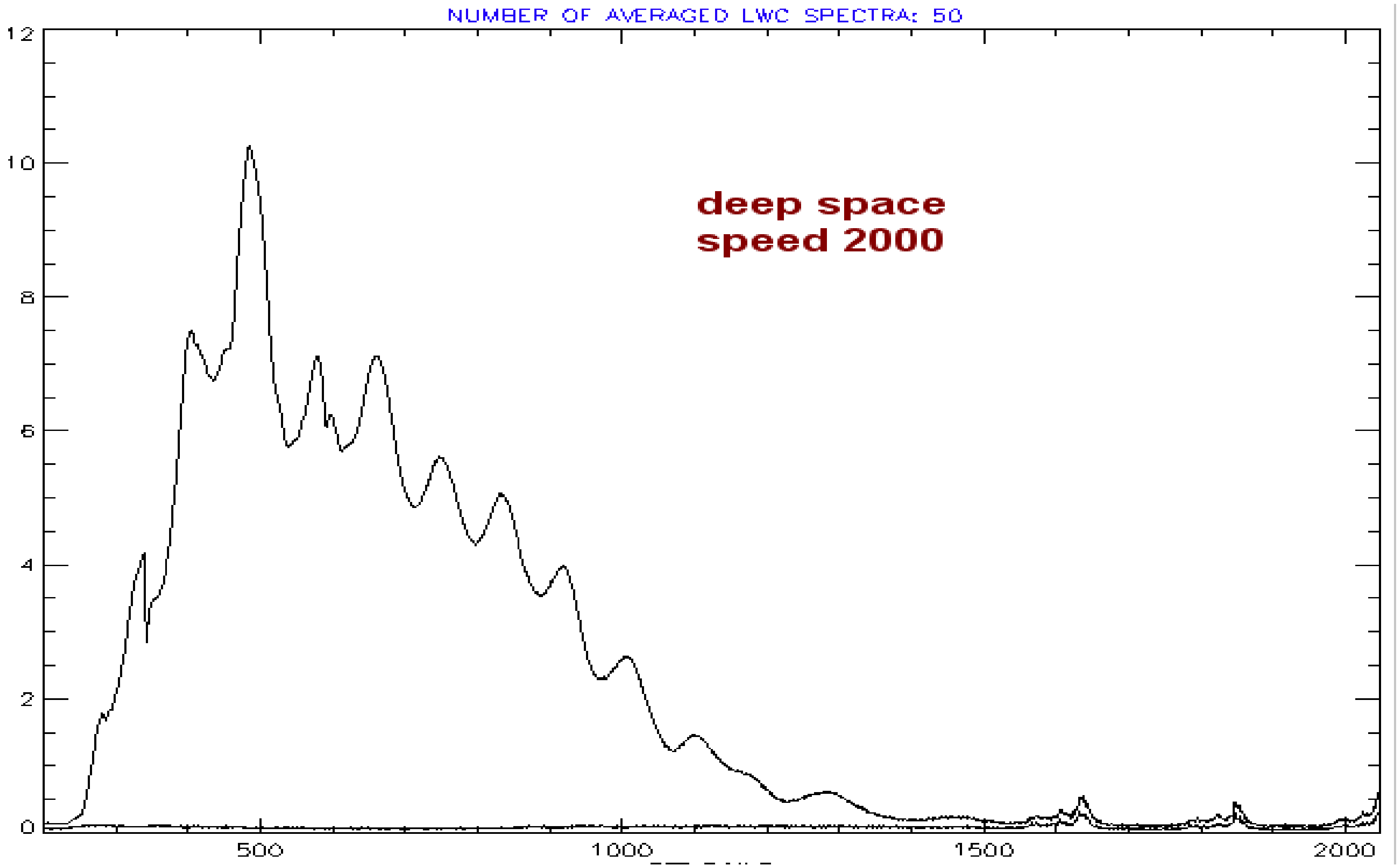


Figure 22 – LW channel on deep space at speed 2000 Hz. Strong disturbance are observed at 1630 and 1830 cm-1.

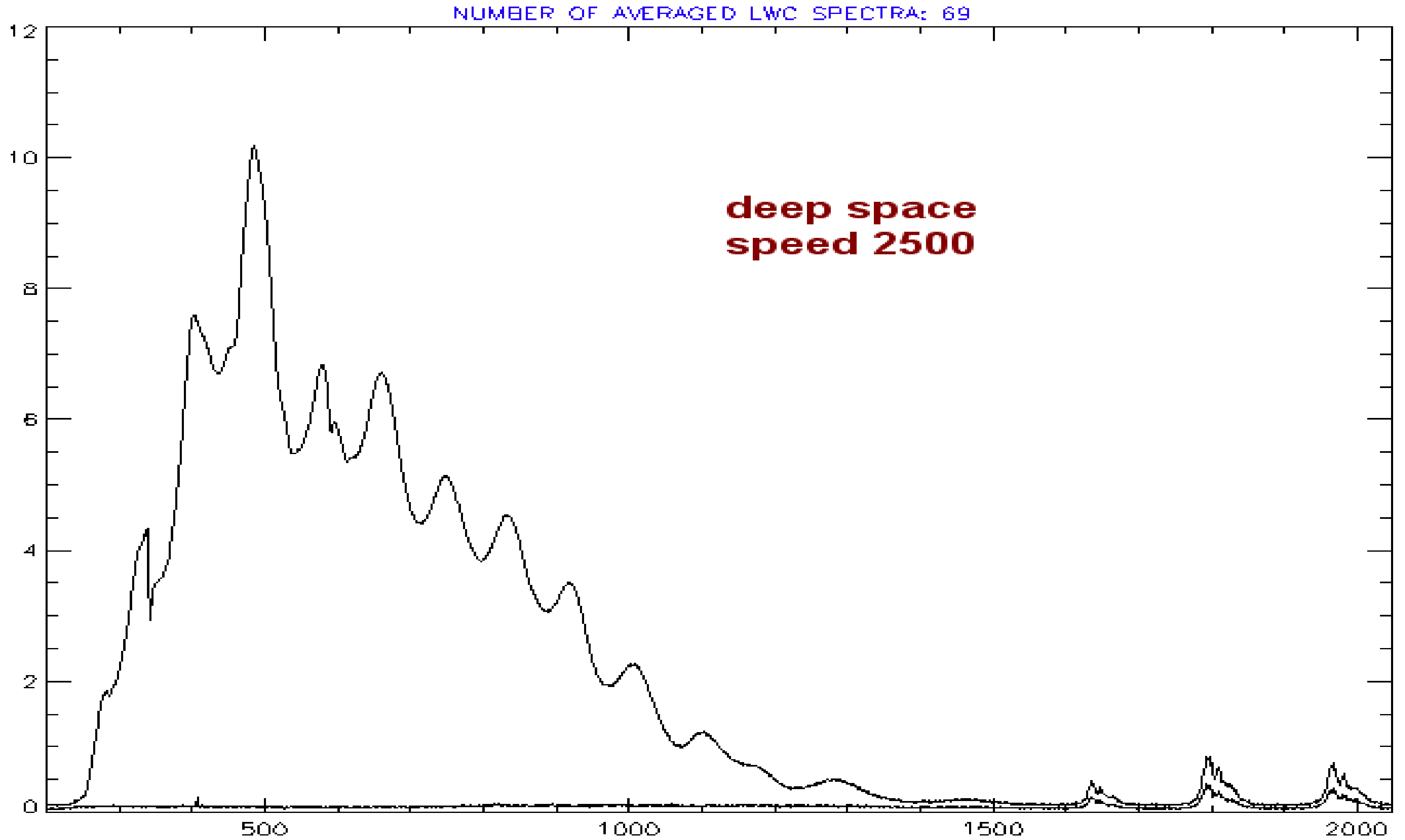


Figure 23 – LW channel on deep space at speed 2500 Hz. Strong disturbance are observed at 1630 ,1800 and 1960 cm-1.

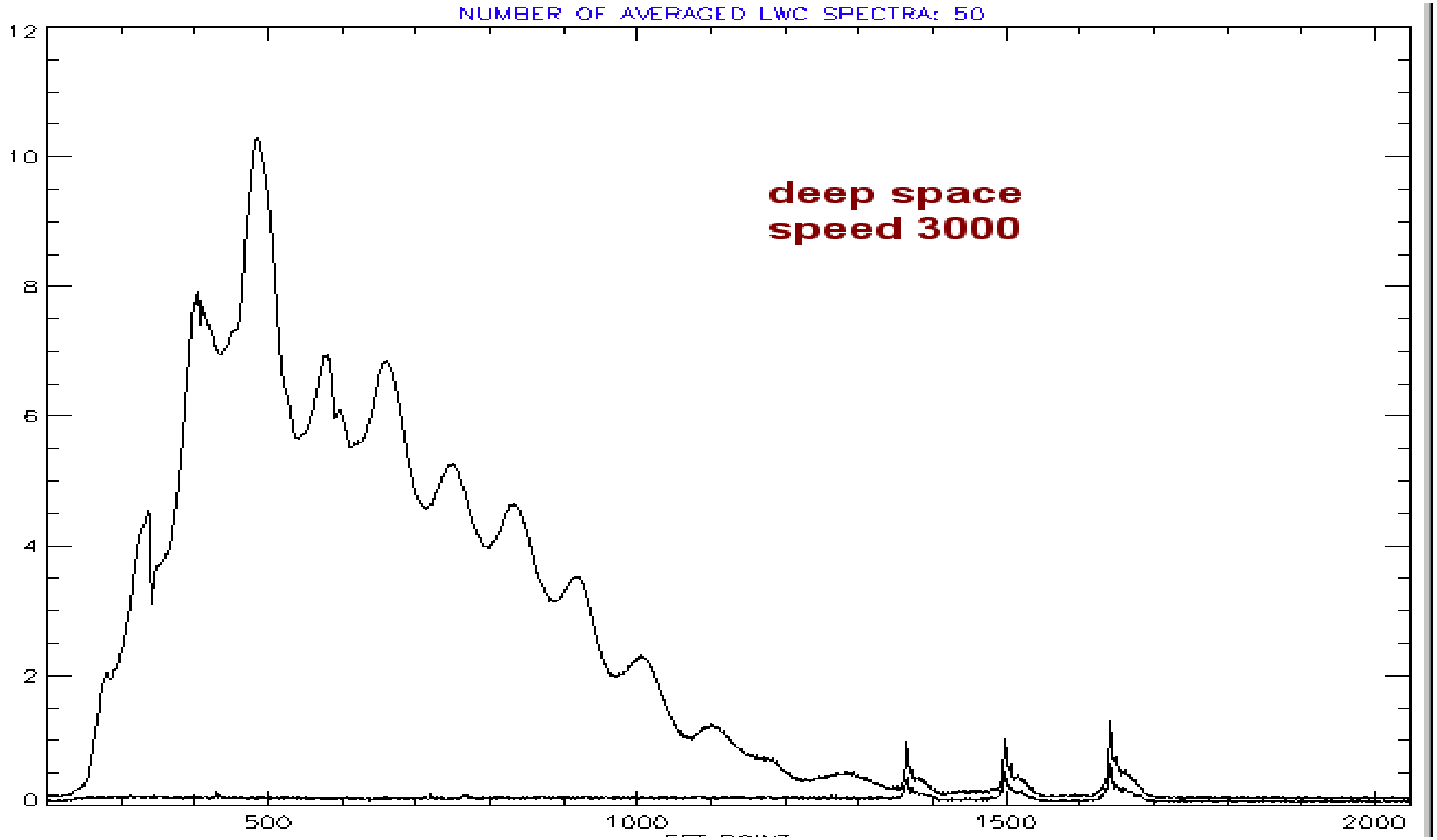


Figure 24 – LW channel on deep space at speed 3000 Hz. Strong disturbance are observed at 1370 ,1500 and 1630 cm-1.

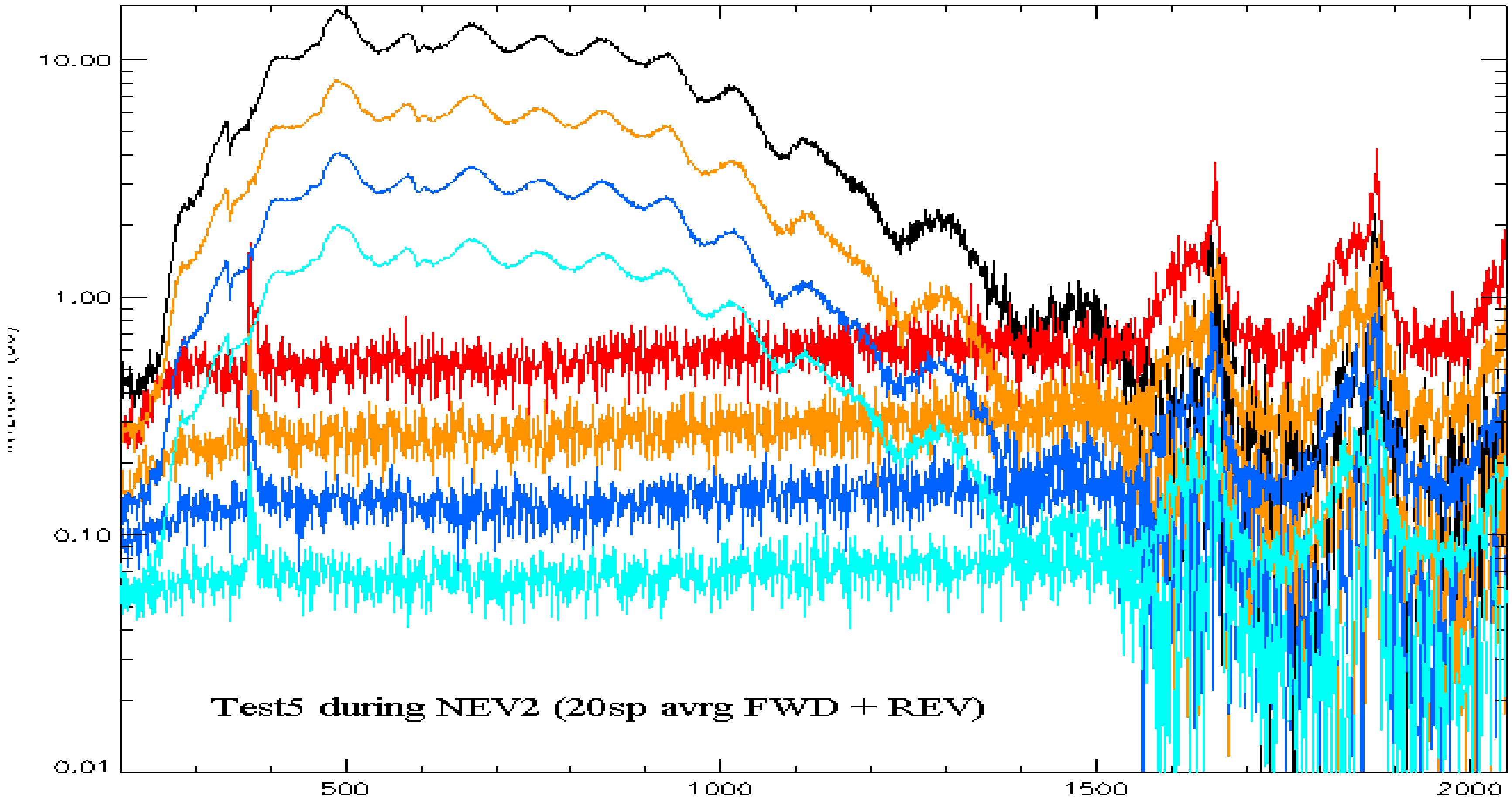


Figure 25 – Variations of signal and sigma with increasing gain factor. Internal BB source. Max amplification is 8 .

4.3 MODELLING THE SOURCE-DETECTOR-INSTRUMENT INTERACTION

The LW channel measures the temperature differences between the source and the instrument. The instrument thermal conditions are therefore very important, and should be conveniently described/ modelled.
In IRIS Mariner 9 The instrument – detector was kept at a constant temperature (251 K), and the instrument was described as a Planckian B(Teff) emitted with an effective temperature Teff. This Teff was a mixture of instrument Ti and detector Td

(1) $B(Teff) = \alpha B(Td) + (1-\alpha)\, B(T_i)$

The measured spectrum is then

(2) $S(v) = Res\,(I(v) - B(Teff))$

Res is the responsivity of the instrument, and α is an unknown parameter to be determined. Hanel has shown that with 3 measurements it is possible to calibrate in radiance the Martian measurements. The 3 measurements should be to Deep Space (a source of zero radiance), to an internal BB of known temperature, and finally to Mars or to the source that we want to measure.
The previous approach was determined mostly by the thermal conditions of the experiment, with IRIS fixed at 251 K, and the detector almost at the same temperature, but not exactly the same.
With PFS we had in the Laboratory measurements a different approach :detector and instrument were essentially at the same temperature, but in equation (2) the planckian of the instrument had an effective emissivity of 0.97. In the Lab, therefore we had :

(3) $S(v) = Res\,(I(v) - 0.97\,B(Ti))$

The temperature of the instrument was working better than the temperature of the detector, when any temperature difference was present.
In space this approach has not worked. We have seen that a better description of the interaction is obtained by using the temperature of the detector. Therefore we have used :

(4) $S(v) = Res\,(I(v) - 0.97\,B(Td))$

However from theoretical point of view there is another approach, which is more consistent and that takes into account the fact that in space the detector temperature and the instrument temperature are substantially different (see the previous study). In this case we have

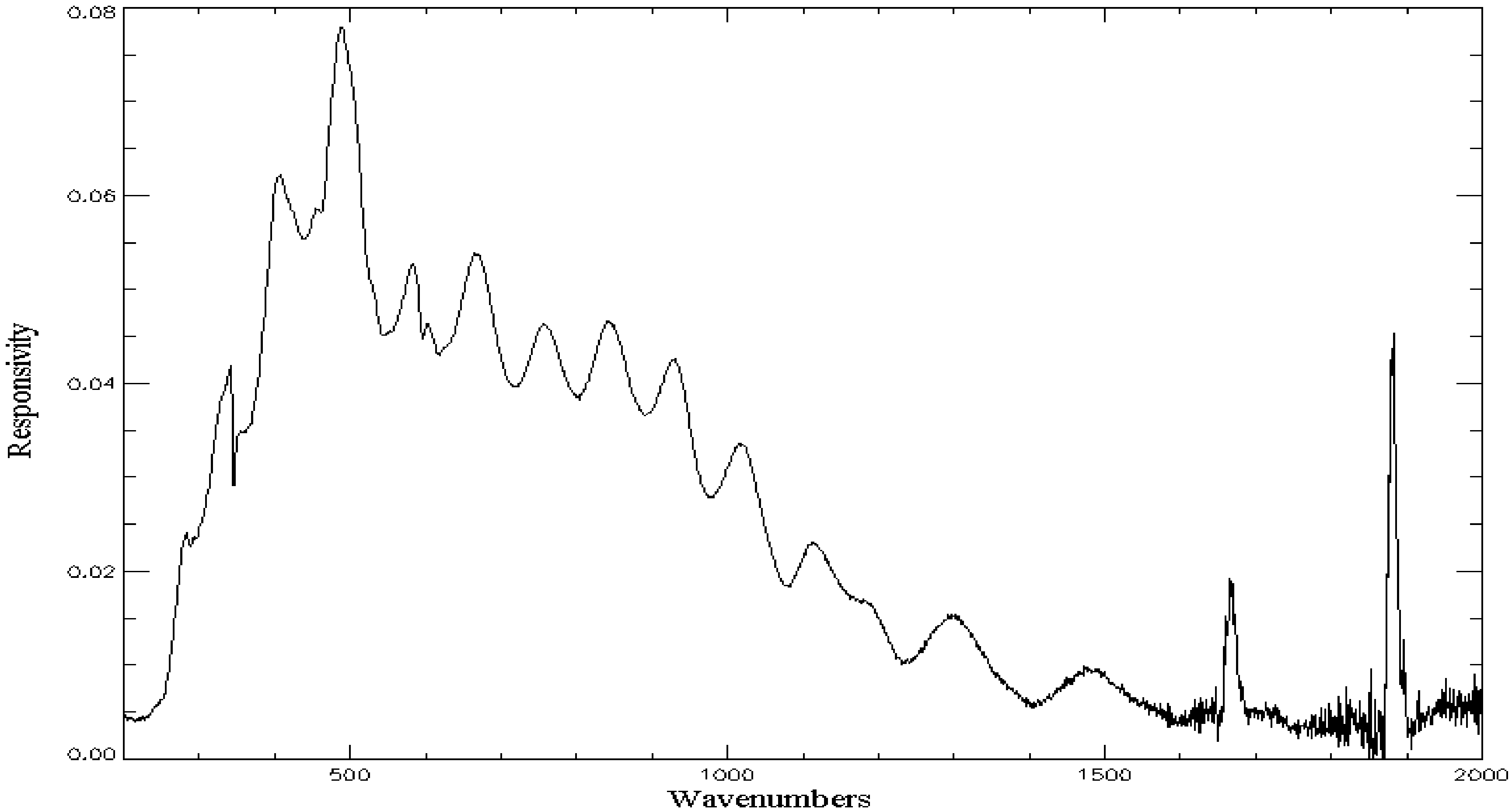
(5) $S(v) = Res\,(I(v) - (\alpha_i B(Ti) + \alpha_d * B(Td))$

Assuming Ti and Td known, we need to determine α_i and α_d possibly from different instrument – detector thermal status. With this approach however, we need 4 measurements to be able to calibrate the Martian radiation (one of the four). At Mars we are going to have a complete set of calibrations at the start of the session, and another at the end of the session. A priori these two sets could be equal, but we know by experience, that while the detector temperature will be constant over the 2 hours, the instrument temperature will not be constant, and therefore we can, at every pass, get the needed 4 measurements.
In conclusion must be recognised that the instrument responsivity obtained in the different ways are very close one another, therefore one methode or another will not change very much the results.

4.4 CALIBRATION AT SPEED 2000 HZ.

We have first performed the calibrations (computation of responsivity and NER) using equation 4 above, and later we have repeated the computations with equation 5 above.
Figure 26 shows the average of 8 different responsivities obtained from NEV 1 and NEV2, Deep Space and Internal BB. Forward and Reverse motions have been handled separately. The double pendulum speed was 2000. The responsivity is between 0.005 and 0.08 over the entire wavenumber range 200 – 2000 cm-1 .
In figure 27 the same responsivity is compared, on a log scale, with the one obtained in the Lab from the IFSI BB. The space responsivity is certainly higher than the Lab one obtained from the IFSI BB.
In figure 28 the same responsivity is compared with the IKI BB responsivity. The agreement with the IKI BB responsivity is almost perfect, with some differences in the 200-400 cm-1 part and also in the 1600 – 2000 cm-1 range, where the IKI BB responsivity was not well defined. The 2 peaks in this range for the responsivity are clearly due to mechanical disturbances.
Figure 29 shows the NER computed in space observations, compared with the laboratory NER from IFSI BB data. The two NER curves are very close, and only in the range 1700 – 2000 cm-1 seem to be substantially different, the space one being lower.
The responsivity obtained has been used to calibrate measurements from the internal BB. Figure 30 shows one single measurement of the BB calibrated. Fifty measurements have been averaged in the spectrum shown in figure 31, and are compared with the Planckian of the same temperature. In Figure 32, finally, the average calibrated spectrum has been smoothed over 11 points to better show the comparison with the theoretical curve. It appears that the instrument is able to measure radiance in the entire range 200 – 2000 cm-1. The mechanical vibrations disturb the measurements by increasing the noise in the range of frequencies affected by them.
We have also used equation 5 to calibrate PFS. We need now 4 sets of measurements, 2 on deep space and 2 on internal BB, but with some temperature differences between the 2 pairs. This conditions have been satisfied in the NEV 5 test. We have computed first the 4 average spectra, then from the first 3 measurement we computed the emissivity of the instrument and the emissivity of the detector. Figure 33 shows the emissivity of the detector, while figure 34 shows the emissivity of the instrument. Note that the relative temperature appears as sign of the emissivity : in other words the instrument is colder than the detector, as it is also true for the Internal BB and Deep Space (the detector is the hottest component). The instrument emits toward the detector, which is, in turn, emitting toward space. The curves are shown only in the interval 300 – 1500 cm-1, which are the parts less affected by noise. The use of equation 5 is strongly affected by noise, therefore we limit our results between 300 and 1500 cm-1.
Figure 35 shows the comparison between all the responsivities : on the scale of the plot the differences can hardly be seen. We are comparing the responsivity obtained with the emissivity description of instrument and detector, with the responsivity obtained in the Lab with IKI BB, with the previous description (0.97 times the detector planckian) and other similar results. The responsivity of the LWC of PFS, obtained with experiment and detector emissivity has been used to obtain the radiance from the fourth set of measurements in the NEV 5 test. The resulting radiance is compared with a planckian in figure 36. The agreement is good, but spectral features due to optical elements are still visible. Overall the responsivity obtained with 0.97 B(Td) is still relatively good, and the others, although formally more reasonable and physically correct, are not really different.

4.5 CALIBRATION B



.
Figure 26 – LW channel responsivity computed from measurements of internal BB and deep space. Note: the responsivity does not go to zero at the extreme 200 and 2000 cm-1. Note the 2 peaks at 1680 and 1880 cm-1 caused by mechanical vibrations.
Units are DU/ (ergs/s sr cm^-2 cm^-1) .

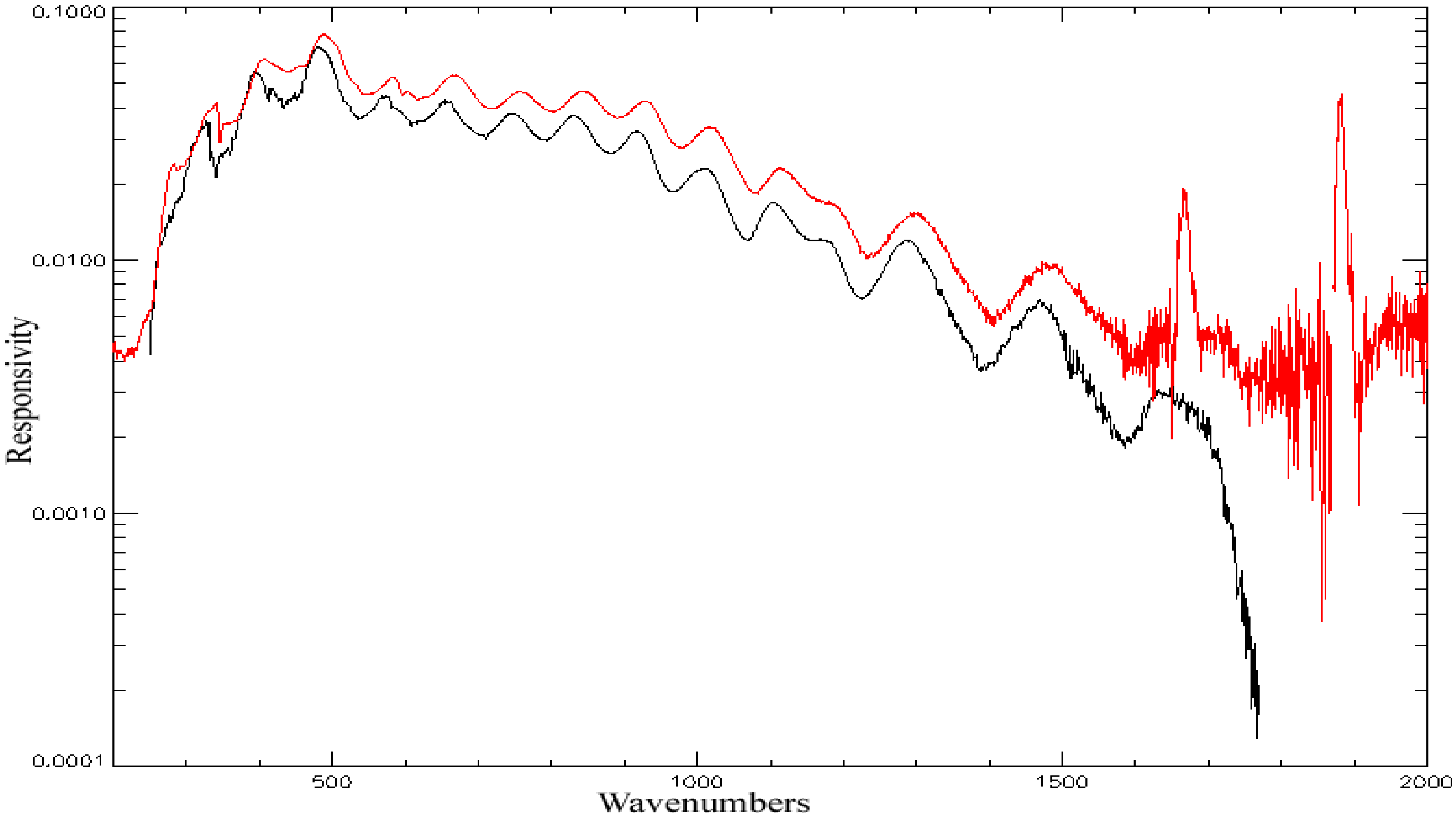


Figure 27- Responsivity of the LW channel in space (red curve) and in the Lab (black curve). Units are DU/ (ergs/s sr cm^-2 cm^-1) .

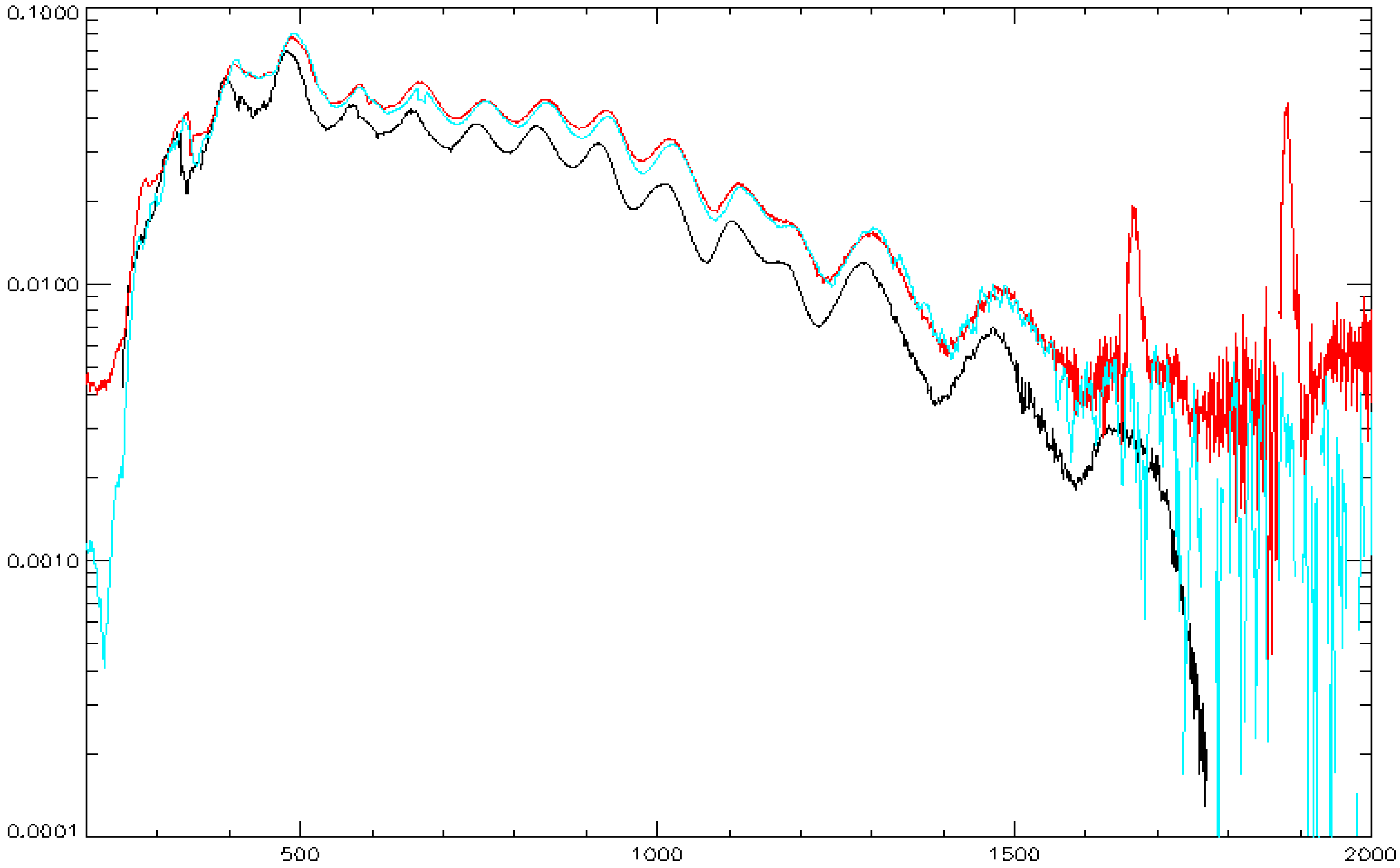


Figure 28 – Comparison between space responsivity (red curve), Laboratory responsivity (bleu curve) with IKI BB, and laboratory responsivity (black curve) with IFSI BB. Units are DU/ (ergs/s sr cm^-2 cm^-1) .

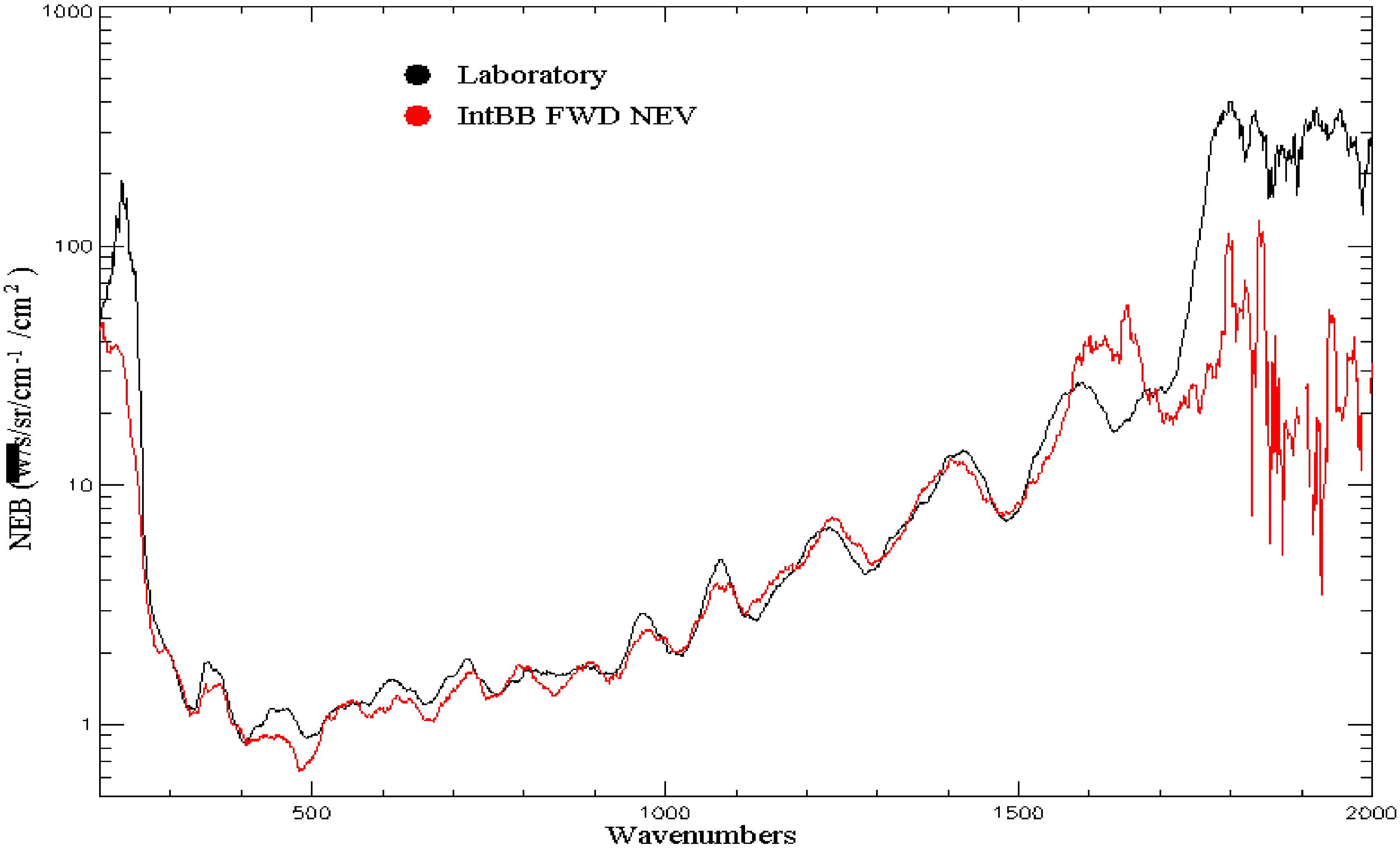


Figure 29 – Noise Equivalent Radiance obtained as sigma/ responsivity. Units are (ergs/s sr cm^-2 cm^-1) .

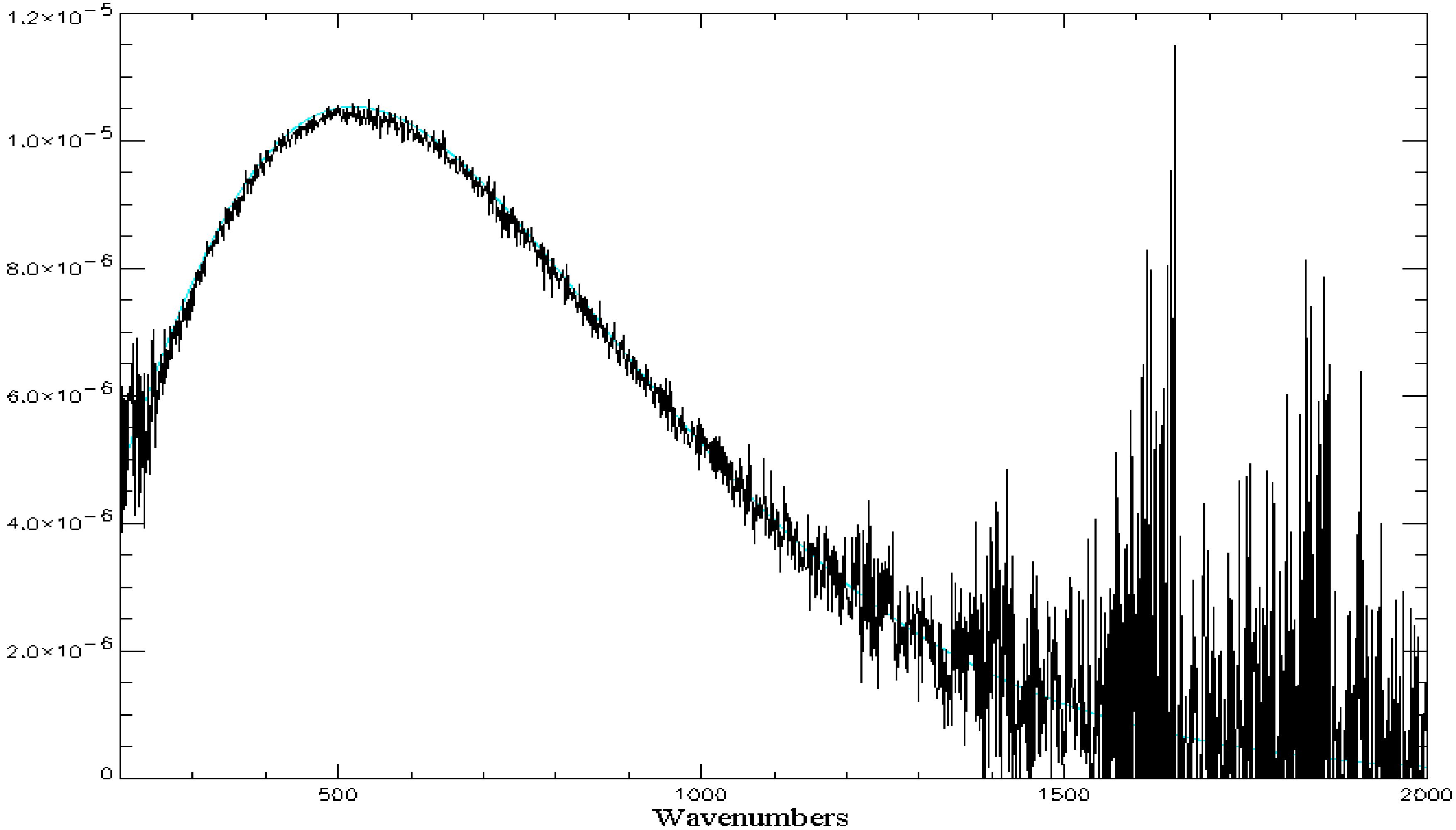


Figure 30 – Radiance from the internal BB measurement. Single measurement to show the actual noise level. Between 1500 and 2000 cm-1 the noise is generated by mechanical vibrations.

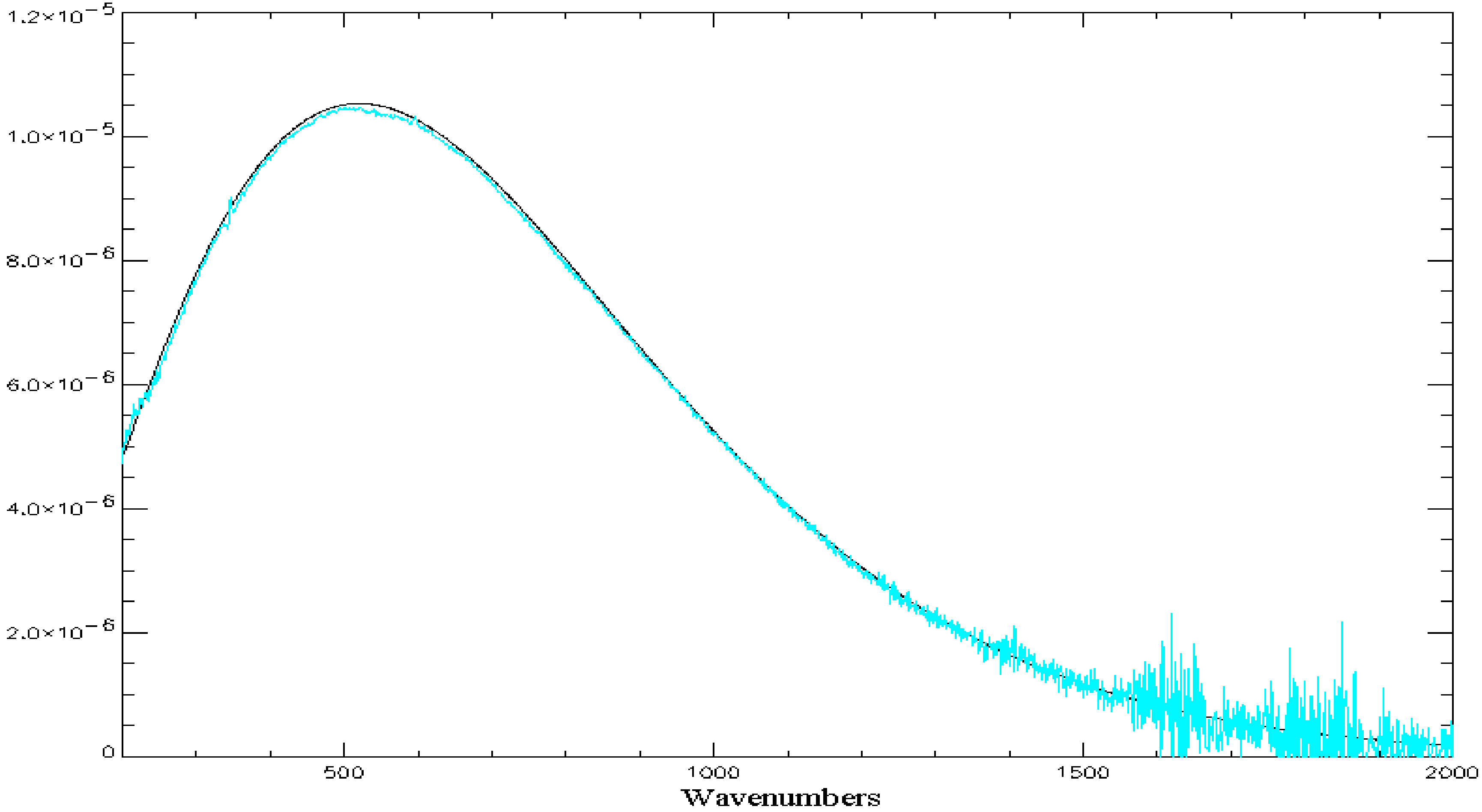


Figure 31 – average over 50 measurements of the radiance from the internal BB with a temperature difference of 20 K. Note the perfect matching over the entire range, disturbed only by the noisy tail in the spectrum.

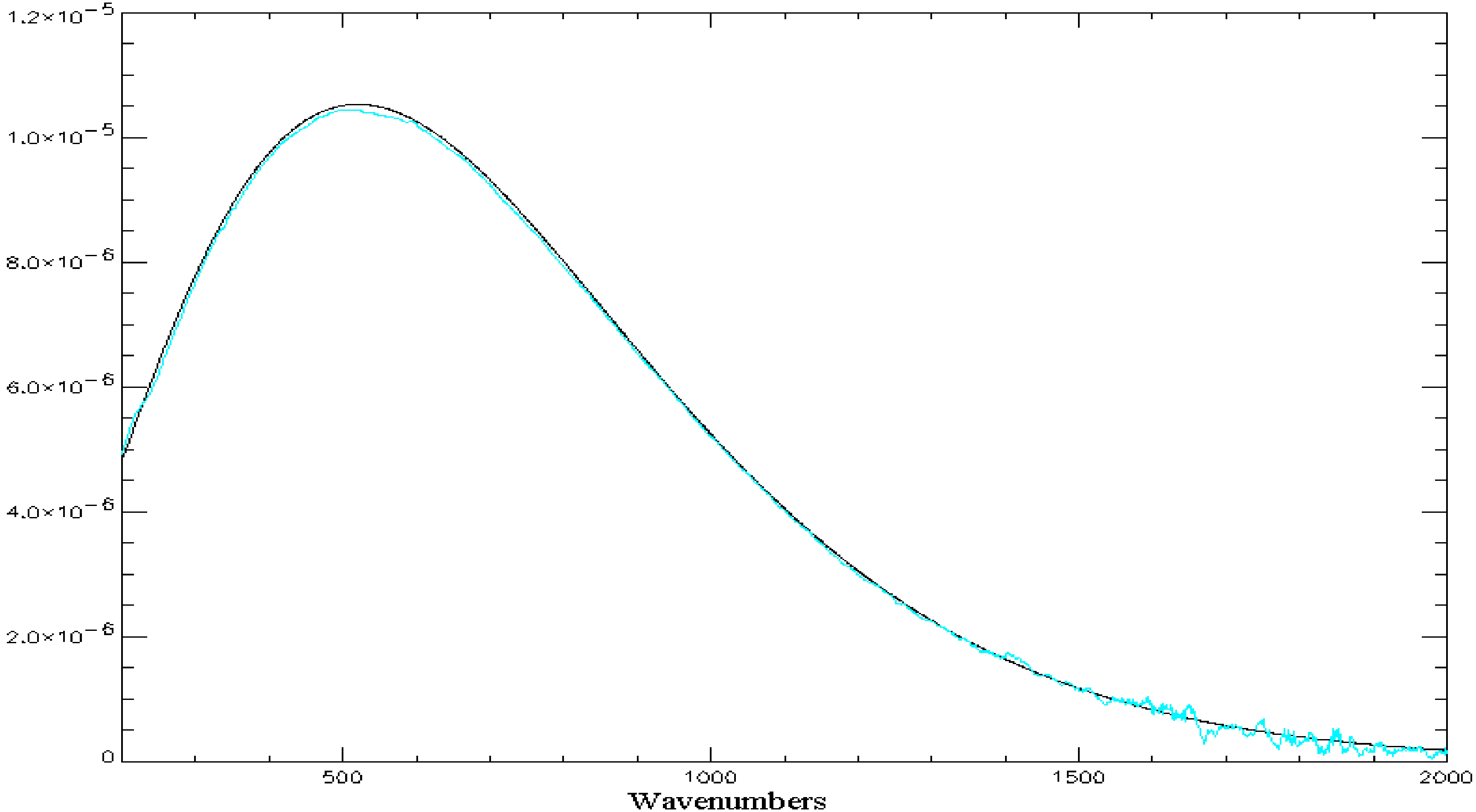


Figure 32 – average over 50 measurements of the radiance from the internal BB with a temperature difference of 20 K. The spectrum has been smoothed over 11 points. Note the perfect matching over the entire range .

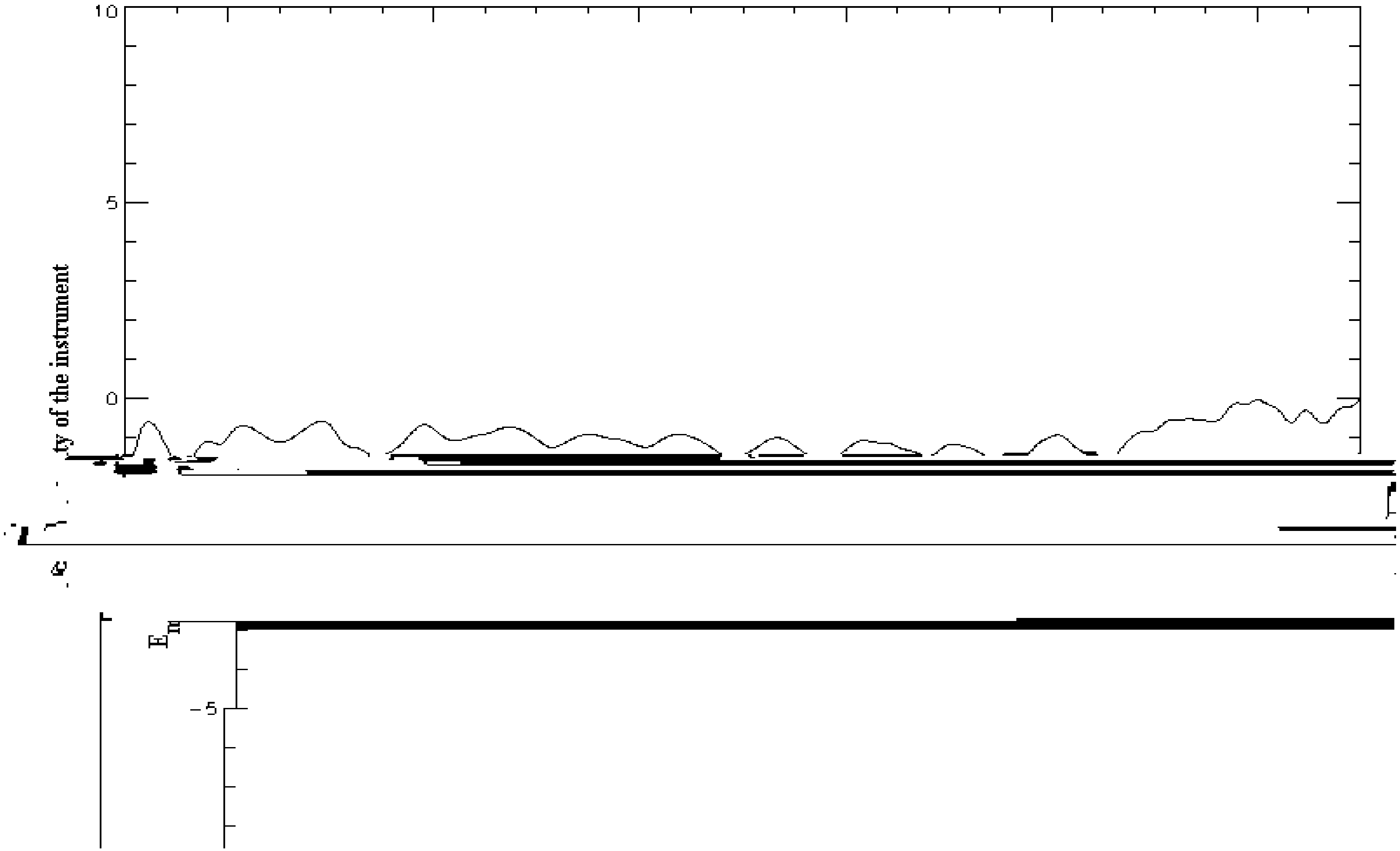


Figure 34 – Emissivity of the LW C instrument.

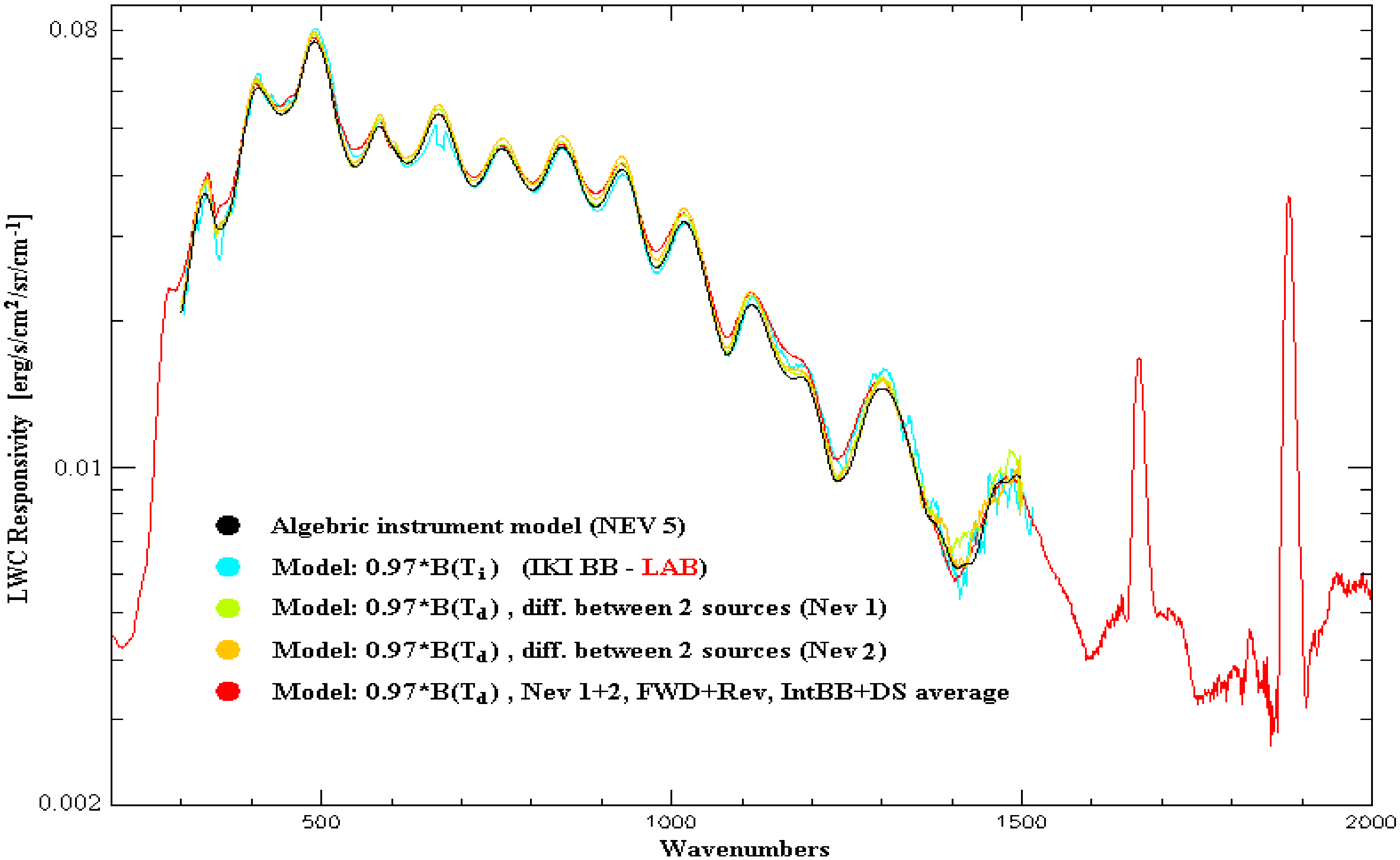


Figure 35 – Comparison between all the computed responsivities.

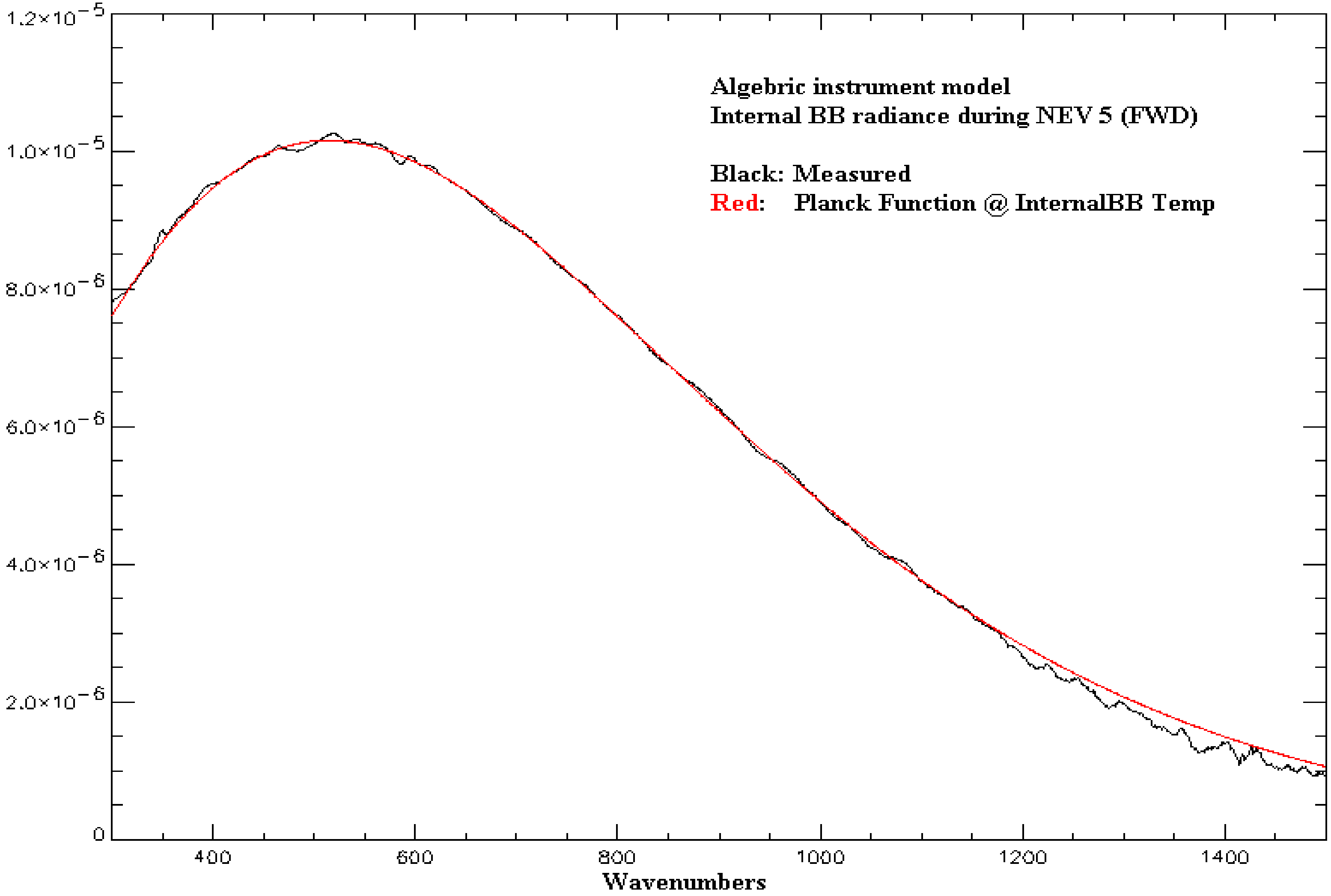


Figure 36 – Radiance of the internal BB obtained using the so called algebraic model of the instrument.

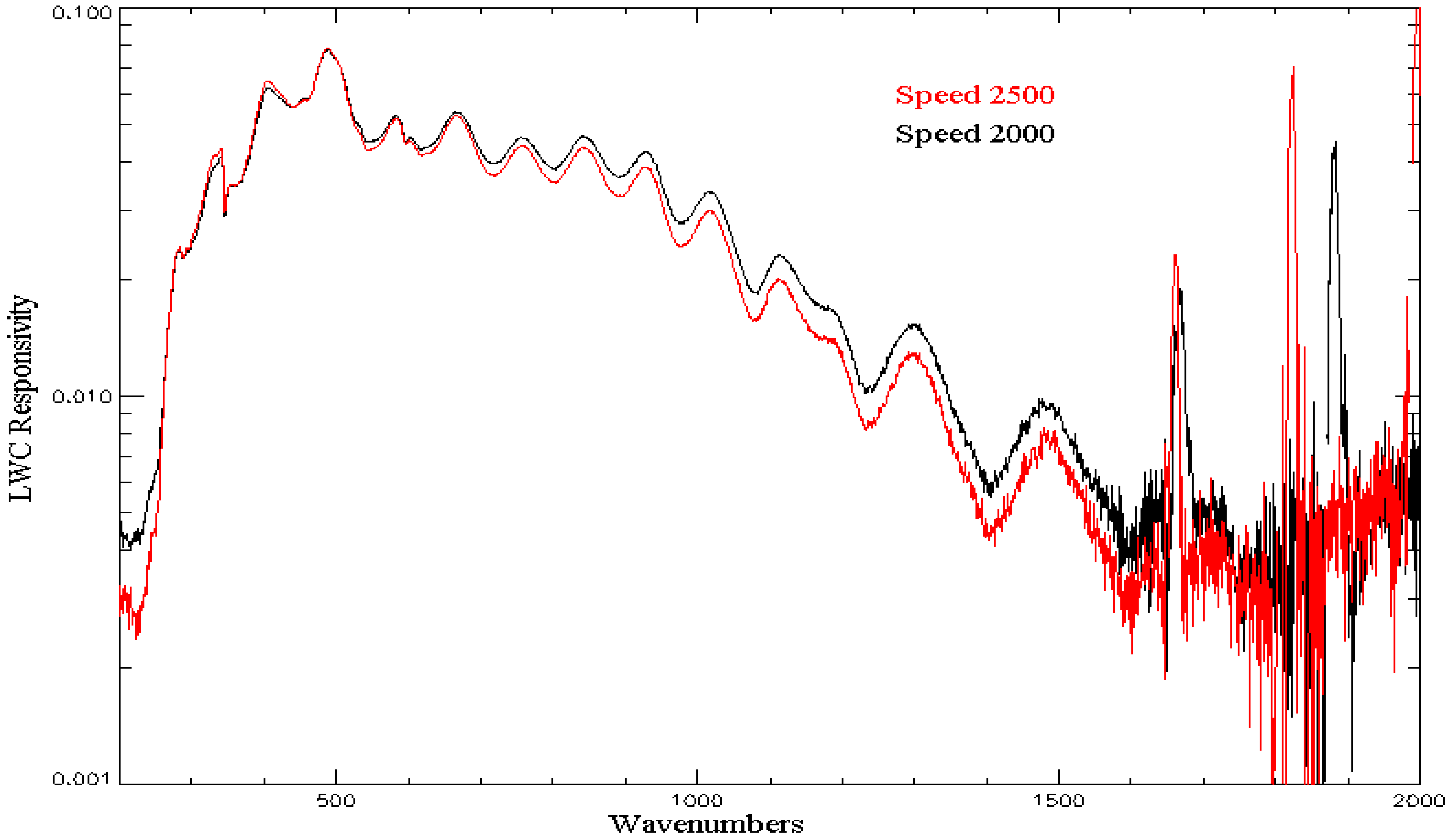


Figure 37 – LWC responsivity at speed 2000 and speed 2500. In the future this will be the used speed.

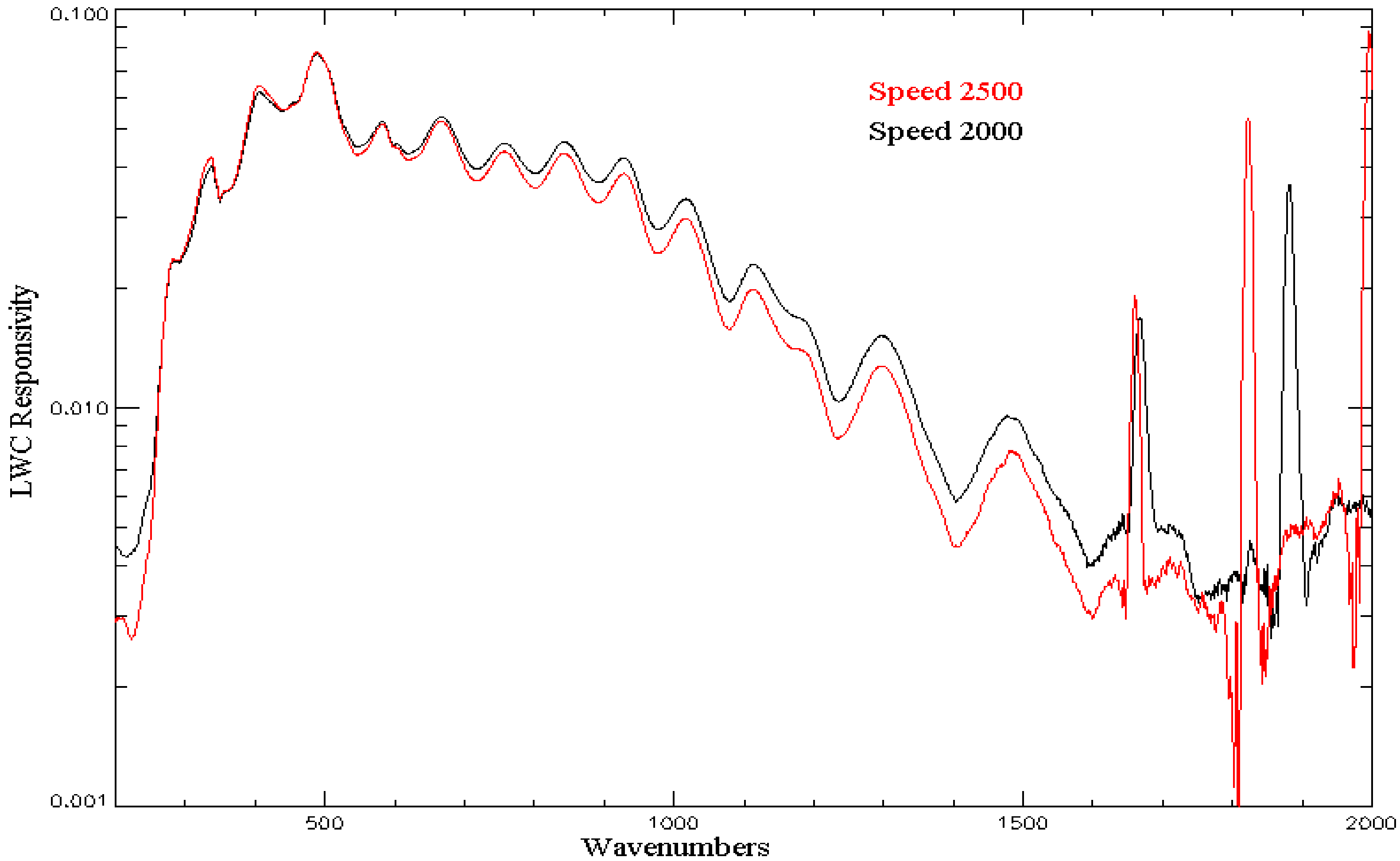


Figure 38 – The same responsivity as in the previous figure, but smoothed over 11 points. Note the variations due to the band pass filter.

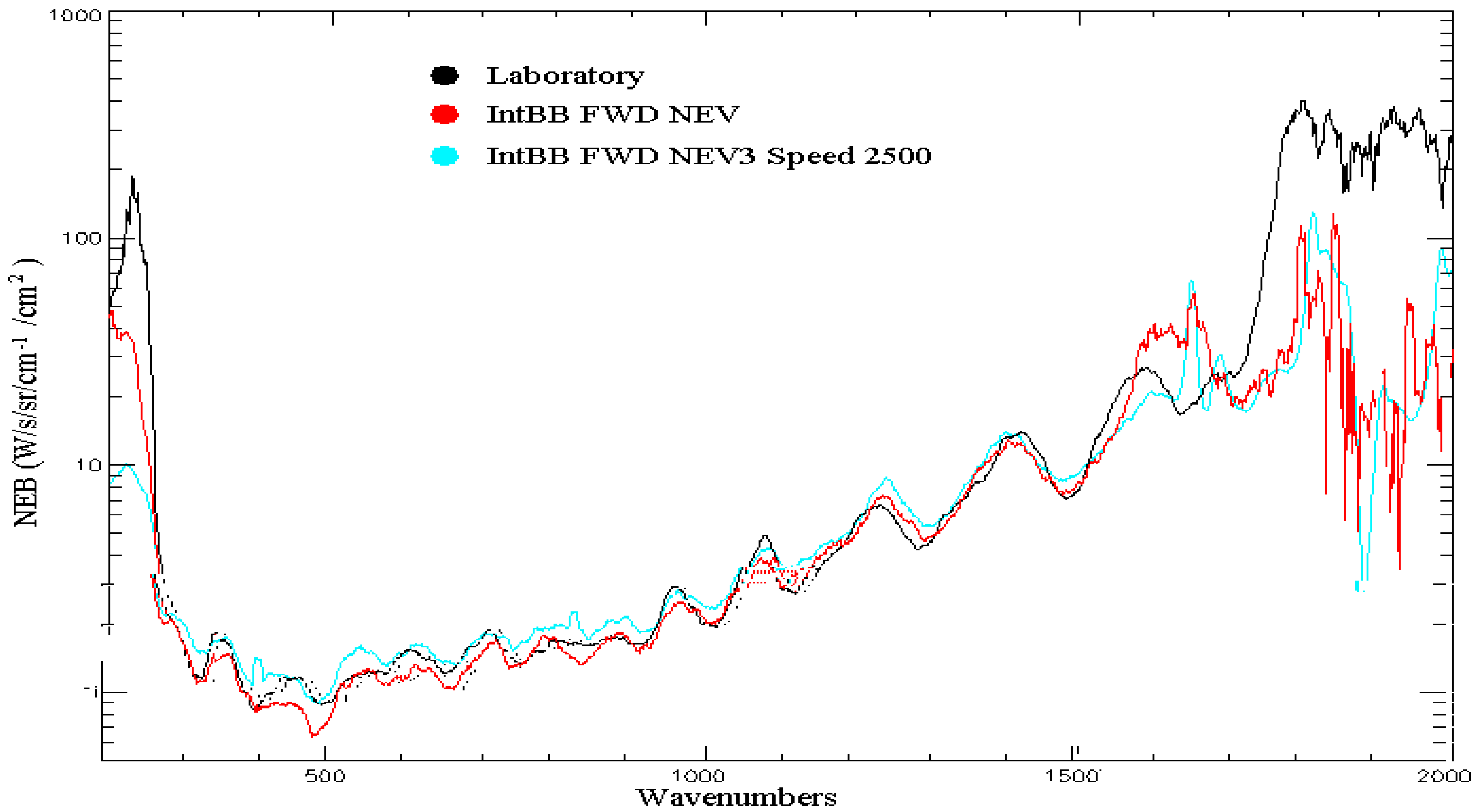


Figure 39 – Comparison between NEB as measured in the Lab, in space at speed 2000, and at speed 2500. The speed has almost no effect on the NEB.

5 SHORT WAVELENGTH CHANNEL CALIBRATION

5.1 THE EFFECT OF MECHANICAL DISTURBANCES.

The two PFS channels have a band pass filter which is related to the speed of the pendulum and the sampling frequency. The band pass frequency for the LW channel is 50 – 500Hz and for the SW channel is 500 to 2000 Hz. This is valid for the default speed of the pendulum. The frequencies of the mechanical disturbances described previously are all within the band pass of one of the 2 channels. It is clear that the effect will be seen in the spectrum .

Figure 40 shows average and standard deviation (sigma) of a set of measurements taken in the NEV1 test looking at Deep Space. Sigma has values around 0.03 and is identical to the values we found in the laboratory measurements. In the previous report, indeed we concluded that the noise is generated in the electronic chain, and therefore is not going to change with the temperature of the detector.

The noise shows 4 or 6 peaks go up to 0.1 (a factor 3 higher). These peaks are at 2120, 2560, 5800 and 6230 cm-1. In frequencies they are at : 530, 640, 1450 and 1557 Hz. Note that there are also small peaks in the centre between the tow sets of pairs (see figure 40). Essentially we see a frequency of 585 Hz modulated by a 110 Hz, and another frequency 1504 Hz modulated by 108 Hz. The last frequencies are actually aliasing from frequencies above 2000 Hz.

The first two peaks are direct frequencies disturbances : 590 Hz modulated by the 110 Hz. The second pair of disturbances is due to aliasing of higher frequencies : 2550 Hz would appear at 1450 and so on .

The same frequencies are seen when looking at Internal BB or at the calibration Lamp with the SW channel (see figure 41 and 42) .

It is important to note that the most instructive case is with the Internal Calibration Lamp, because this provides a good signal for the entire SW range. Both the Deep Space and the Internal BB show a sigma of 0.03 DU, but this is not the case of the Calibration Lamp, which shows a noise which is not constant on the wavenumber range, and has values between 0.03 and 0.11 DU. Note that the noise minimum is located around 4200 cm-1.

In conclusion : the mechanical vibrations disturb the SW channel more than the LWC, we have 3 + 3 noise peaks, and the noise increase at these peaks goes up by a factor 5. We can anticipate, however, that the strange behaviour of the Internal calibration Lamp is also due in part to the mechanical vibrations.

We should not forget that the Internal calibration Lamp, according to the Lab calibrations measurements, in space, at temperature of the SW detector of 200 – 210 K, should have been in full saturation. We see from figure 42 that it is not. In other words, the lamp intensity is apparently much lower than predicted and lamp related noise is much higher than the one related to other measurements. We shall see that also the lamp related noise is due to mechanical vibrations. In order to understand how this is possible, we shall first study spectral variations with the speed of the pendulum.

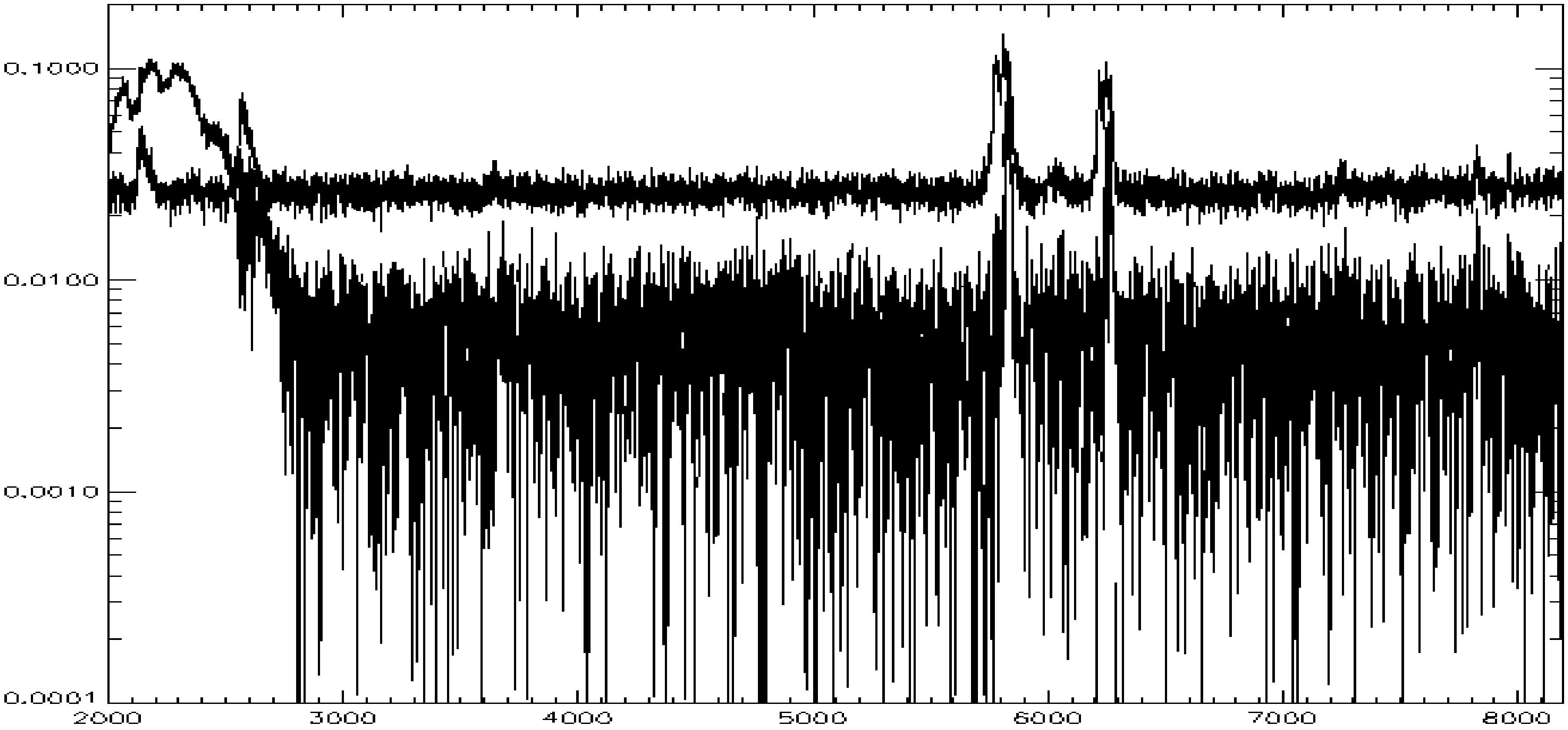


Figure 40 – Deep space observation. Average spectrum and sigma in the SW channel. Note the presence of 4 peaks at 2150, 2550, 5800 and 6250 cm-1 caused by possible mechanical disturbances. The observed spectrum is a measurement of the emission from the instrument and detector. Note the sigma at 0.03 as on ground and as predicted for all detector temperatures.

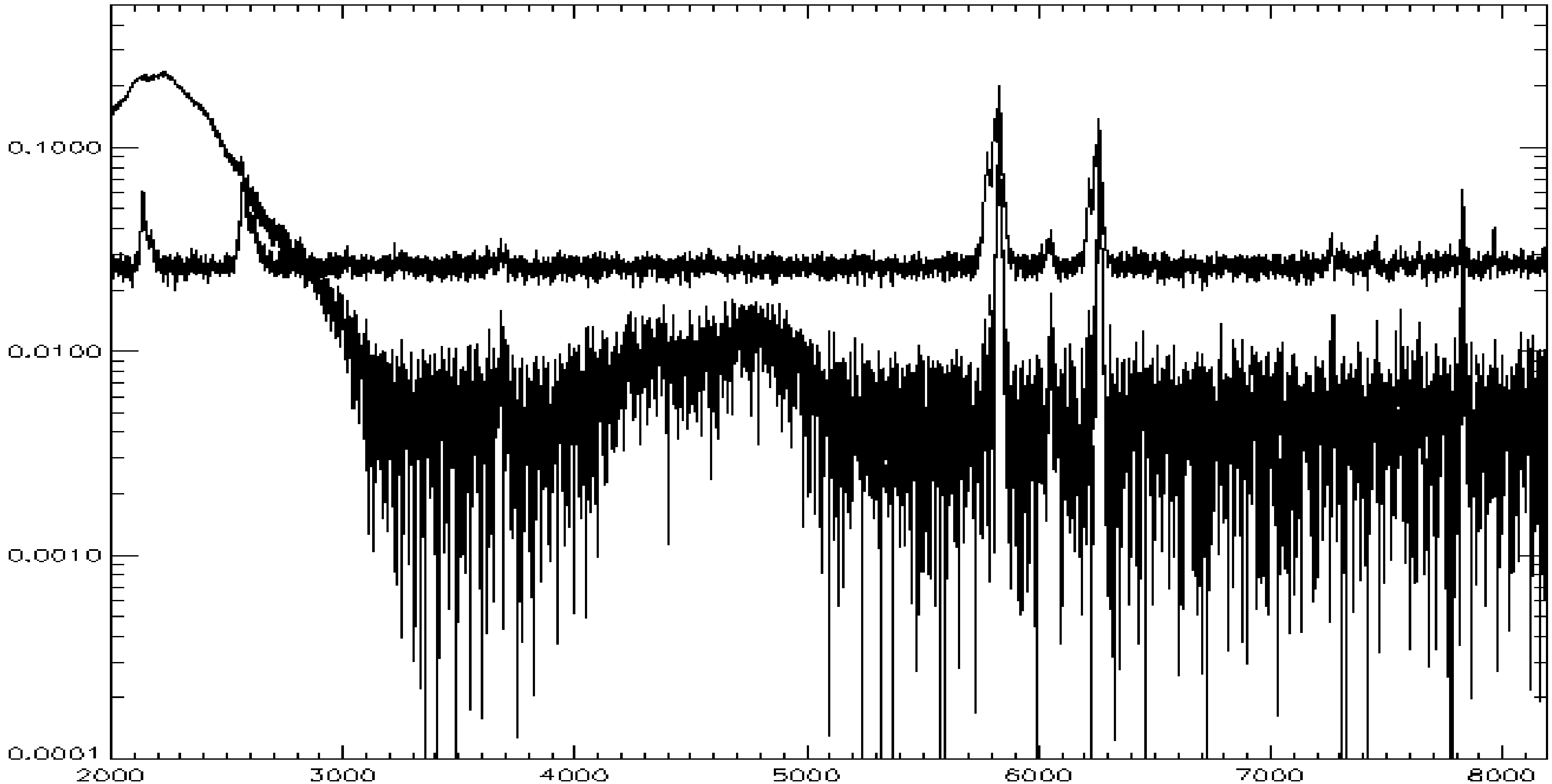


Figure 41 – Internal BB observation. Average spectrum and sigma in the SW channel.

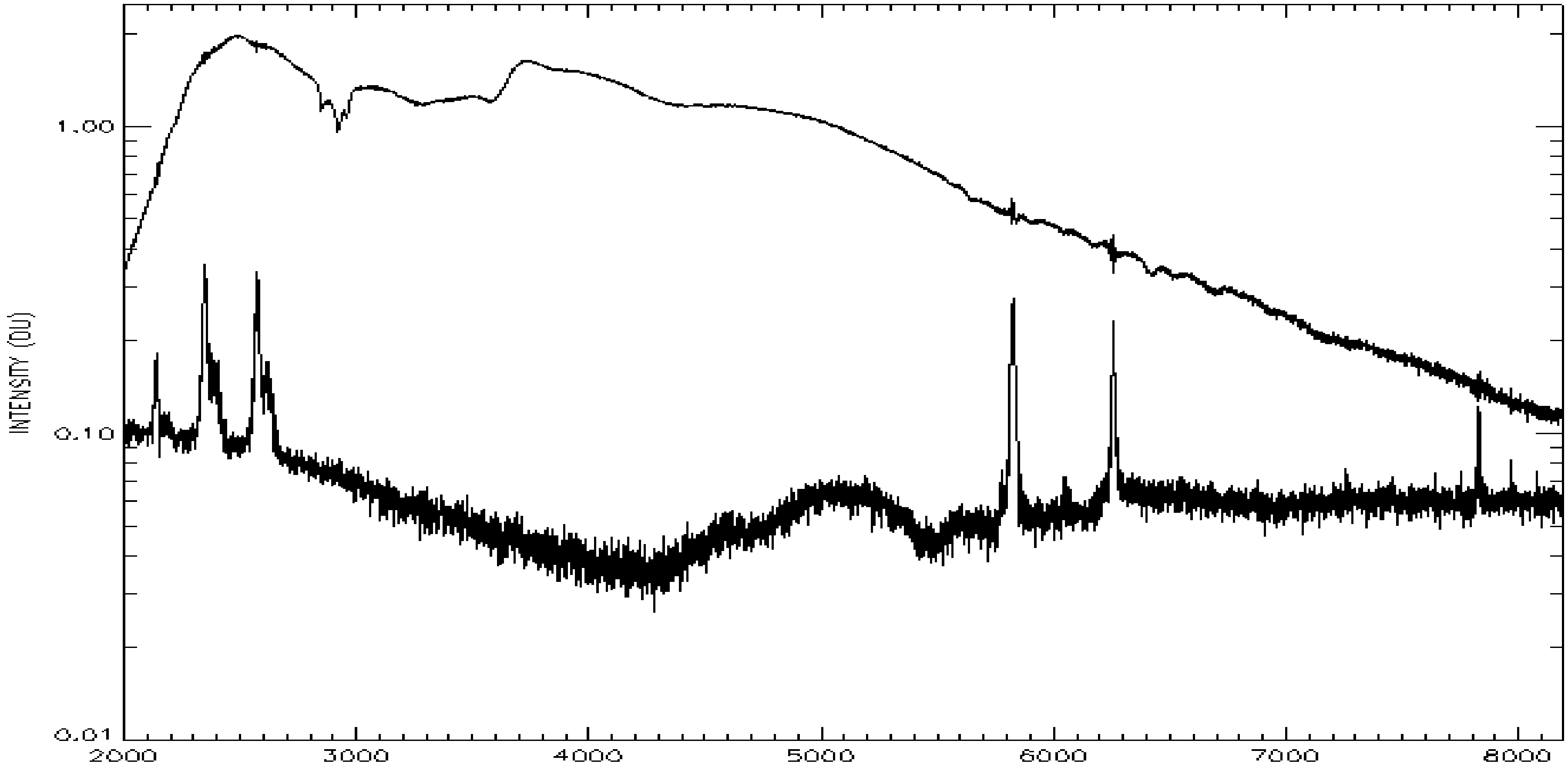


Figure 42 – Internal calibration lamp observation. Average spectrum and sigma in the SW channel

5.2 THE EFFECT OF CHANGING THE SPEED.

We could study the effects of speed variations on the spectra, as we have done for the LWC, using Deep space measurements. However, also as preparation to the next section, we prefer to study the effect on the spectra of the internal calibration lamp.
Figure 43 shows ICL average spectrum and standard variation when the speed was 1500 Hz .
Figure 44 shows ICL average spectrum and standard variation when the speed was 2000 Hz .
Figure 45 and 46 shows ICL average spectrum and standard variation when the speed was 2500 Hz. Figure 47 shows ICL average spectrum and standard variation when the speed was 3000 Hz .
At 1500 Hz speed, The SW spectrum of the ICL is above 0.3 DU everywhere, and is lower than 2 DU. The spectral shape is similar to the one measured in the Lab. The spectrum shows, as effect of mechanical disturbances, an increase of noise level, at 6 different wavenumber places : 2850, 3150, 3450, 4950, 5260, 5500. This 6 disturbances move 3 in one direction, and 3 in the opposite one, when the speed is increased to 2000 or above. Indeed we have

SPPED TABLE

1500 Hz	2850, 3150, 3450,	4950, 5260, 5500	4700-5000
2000 Hz	2150, 2350, 2570,	5800, 6050, 6250	4300
2500 Hz	-----, ------, 2020,	6150, 6320, 6500	3800
3000 Hz	----, ----, -----	6650, 6800, 6950	3700

The first 3 peaks disappear below 2000 cm-1, while the upper 3 peaks (the central one being very small), move toward higher wavenumbers.
From the analysis of the LWC we concluded that speed 3000 Hz should not be considered. From this study we conclude that the speed 2500 Hz is the best for the SWC, in the sense that the highest the speed the best is from the disturbances point of view, because the peaks- disturbances at higher speed move out of the SWC .
The last column in the table gives the wavenumber for which there is a minimum in the noise of the ICL standard deviation. This fact shall be discussed in the next section, here we simply add that for the Deep Space or for the internal BB the Std variation is constant over the entire wavenumber range, therefore we deduce that something is strange about the ICL.

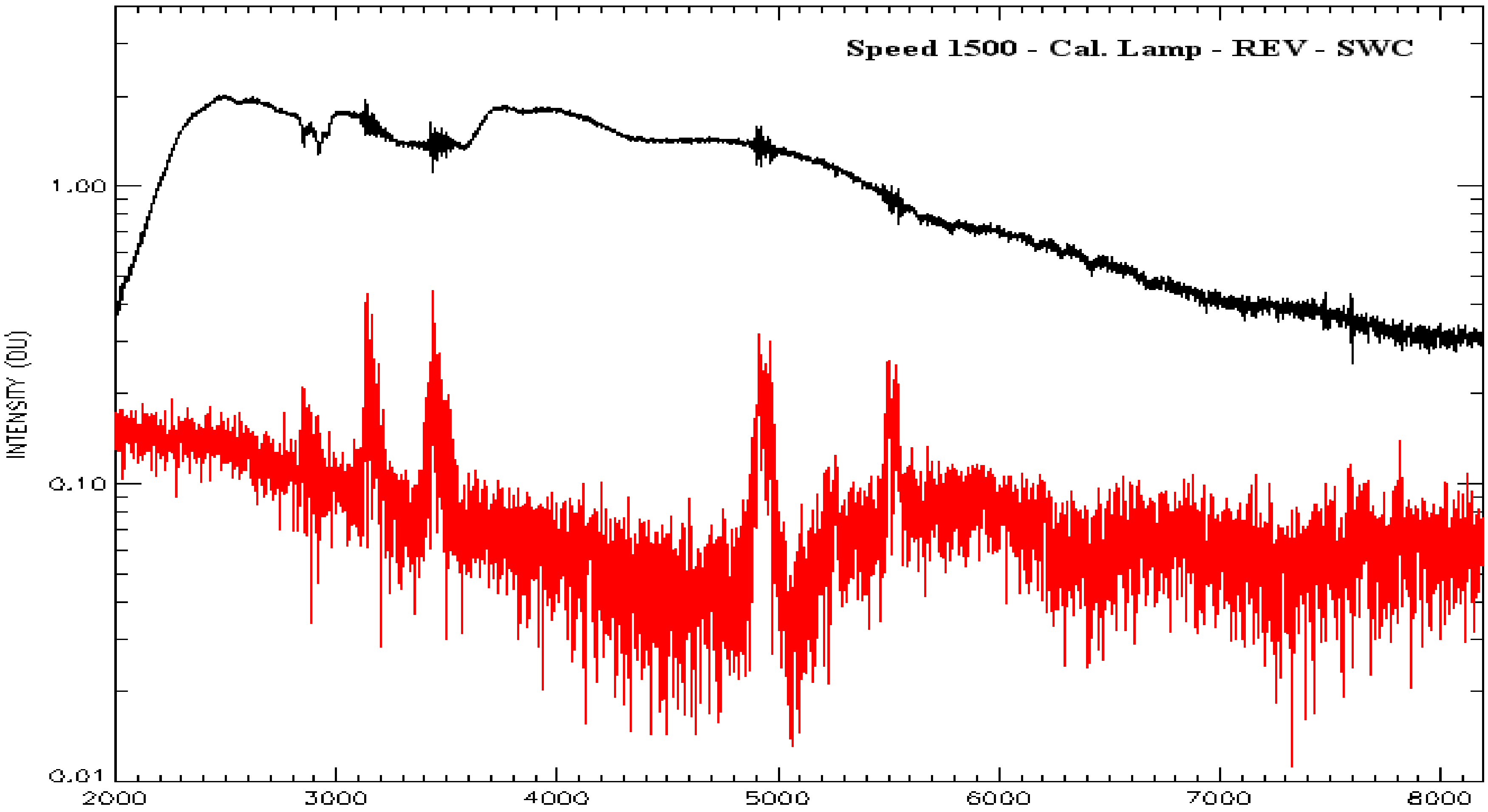


Figure 43 – Internal calibration Lamp average spectrum and std variation. Speed 1500 Hz.

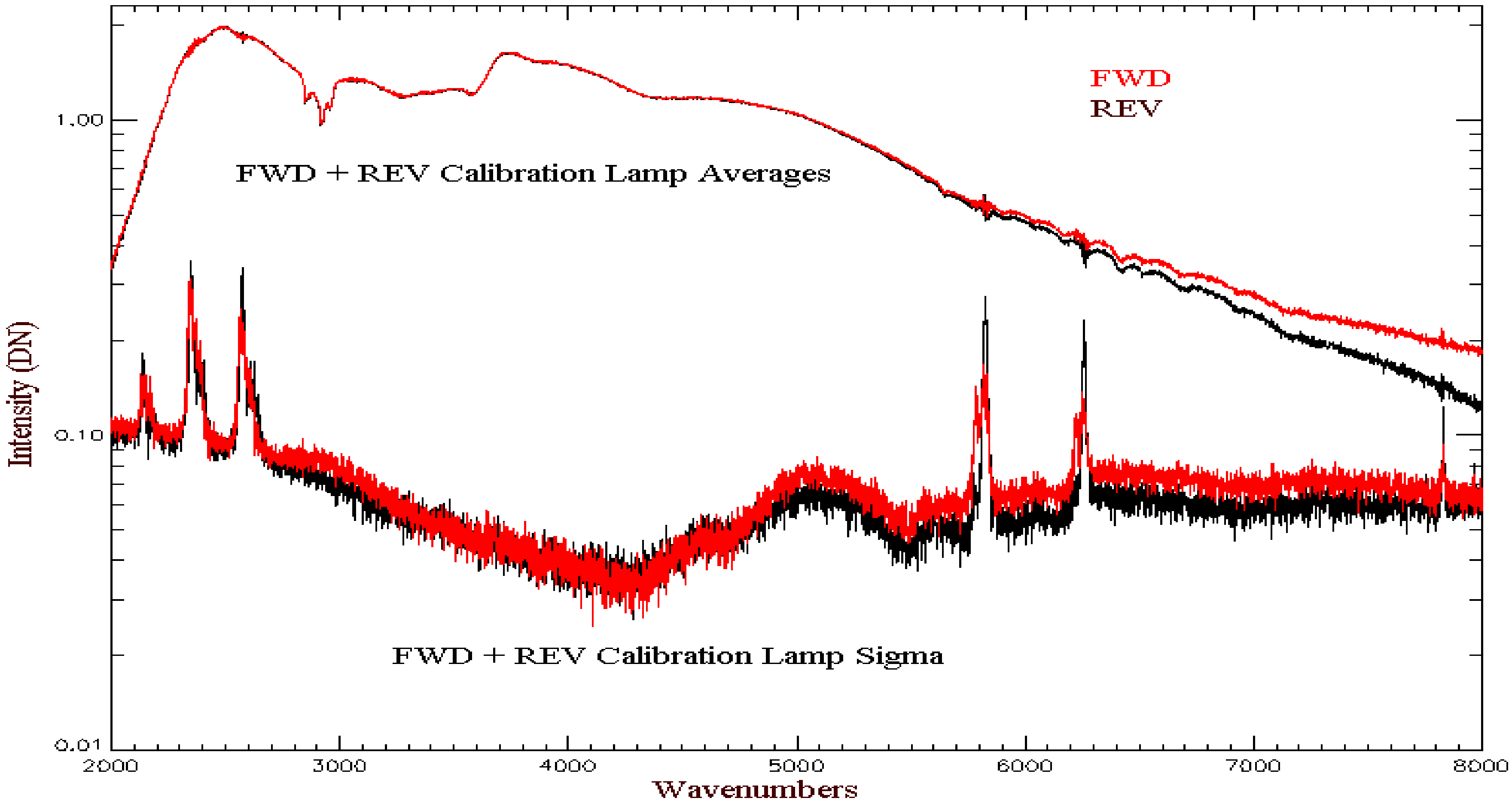


Figure 44 – Internal Calibration Lamp average spectrum and std variation. Speed 2000 Hz.

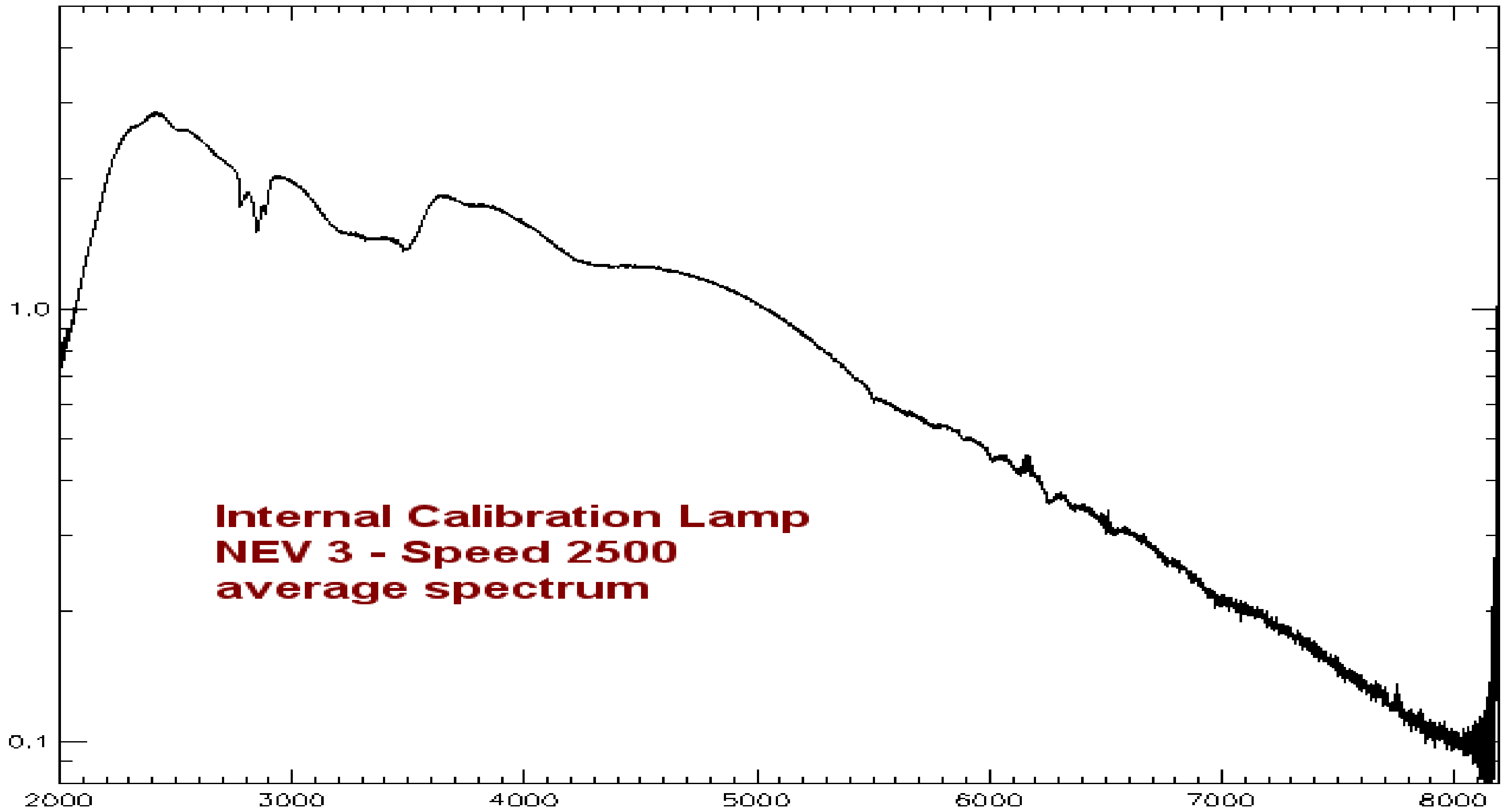


Figure 45 – Internal Calibration Lamp average spectrum. Speed 2500 Hz.

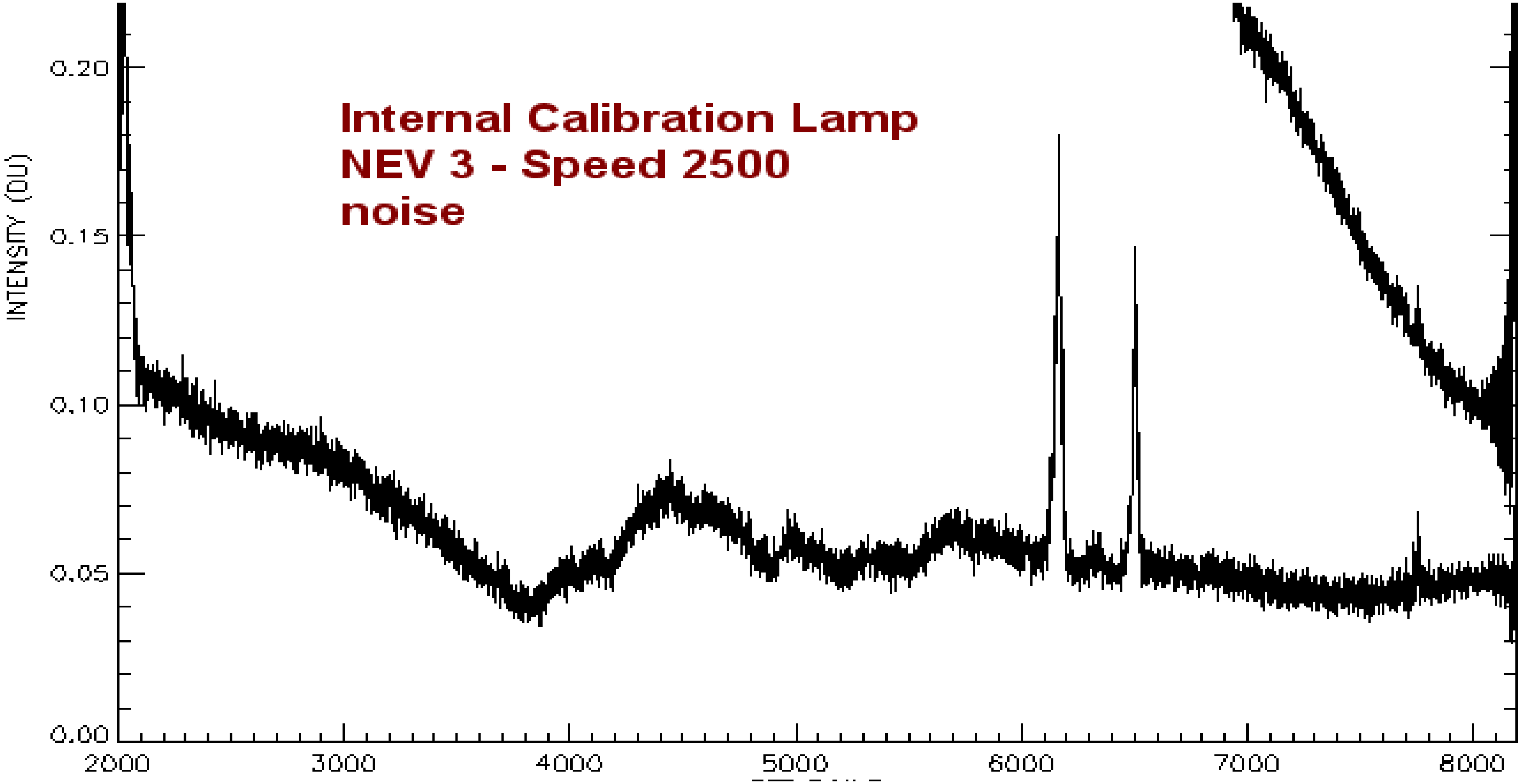


Figure 46– Internal Calibration Lamp standard variation. Speed 2500 Hz.

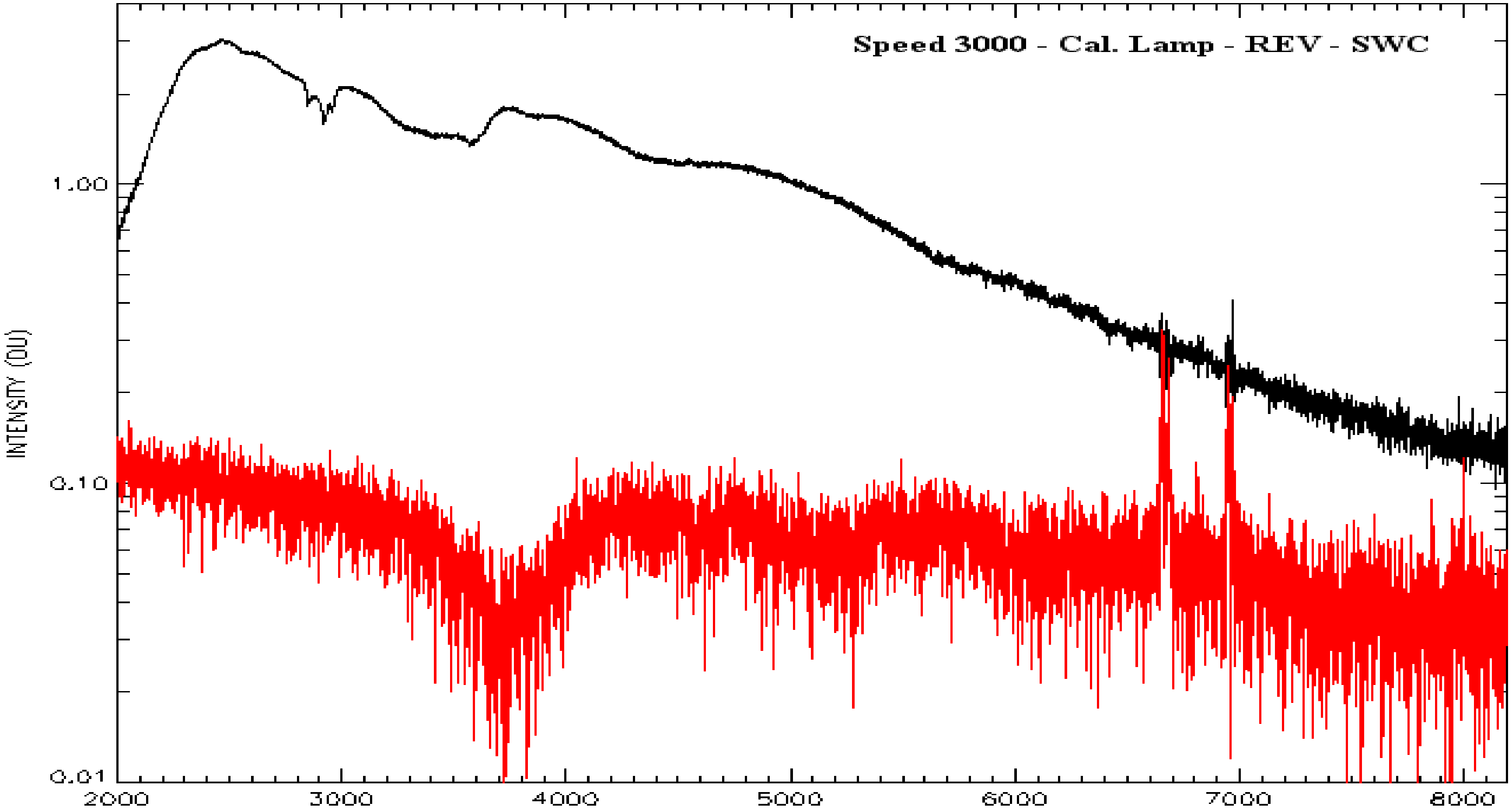


Figure 47 – Internal Calibration Lamp average spectrum and std variation. Speed 3000 Hz.

5.3 A STUDY OF THE INTERNAL CALIBRATION LAMP.

The Internal Calibration Lamp was included in the PFS experiment in order to be able to calibrate the SWC in space, on the basis of the calibrations done in the Lab. From this work, the conclusions of the work presented in the second volume were that the responsivity of the detector was increasing with decreasing temperature, and we could, indeed, predict an increase of a factor 7 going from room temperature to 200 K. The ICL, that was already in the regime of strong non linearity of the PbSe detector at room temperature, would then, at 200 K generate a saturated interferogram. Figure 48, which shows the spectrum of the ICL, demonstrates that in space the ICL was not generating a saturated interferogram, but rather a spectrum with an intensity lower than in the laboratory at 250 K. The spectral shape of the lamp is generally the same as in the Lab, however there are two important differences :

- first the peak of the spectrum is shifted toward the 2000 cm-1 edge, indeed it is located at 2450 cm-1 in the NEV case. This is understood by the fact that by cooling the detector we have already seen the predominant increase of the responsivity of the detector in the 2000 –3000 cm-1 range.
- The second important difference is the presence of a triple band between 2800 and 3000 cm-1 wavenumber, which is typical of organic material, and which was absent in the laboratory measurements.

There are several points to be addressed here concerning the ICL :

- Why the lamp has lower intensity than on ground?
- Why the standard deviation of the ICL spectrum is higher than 0.03 DU?
- Is the lamp stable in the new conditions?
- What has caused the 3 bands observed in the spectrum?
- Why the standard deviation of the ICL spectrum shows a spectral dependent behaviour?
- Can we use the ICL to calibrate the SWC, and how?

5.3.1 WHY THE LAMP HAS LOWER INTENSITY THAN ON GROUND?

The simplest answer is that the optical axis of the calibration lamp has been tilted somewhat during the launching of the spacecraft.

We remind that the ICL was arranged as a lamp in the focus of a parabolic mirror (inside the Scanner module), which was in this way sending all the energy as parallel beam concentrated by the PFS SWC parabolic mirror on the PbSe detector(inside the Module O). Helmut Hirsh has shown, see figure 49, that it is enough to tilt the lamp by 1.1 degree to have a decrease by a factor 10 in the lamp intensity.

We conclude therefore that the lamp optical axis has been tilted with respect to the PFS optical axis, with a consequent reduction of the lamp intensity by a factor of 2.5-3 with respect to the observed intensity at 250 K, certainly higher reduction with respect to the predicted intensity of the spectrum at 210 K. In practice the tilt of the ICL can be of the order of 0.6 deg.

5.3.2 WHY THE STANDARD DEVIATION OF THE ICL SPECTRUM IS HIGHER THAN 0.03 DU? WHY THE STANDARD DEVIATION OF THE ICL SPECTRUM SHOWS A SPECTRAL DEPENDENT BEHAVIOUR?

The standard deviation of the ICL spectra should be 0.03 Digital Units, as it is for spectra of Deep Space and for Internal Black Body and as it was predicted on the basis of lab studies. On the contrary the observed std is 3 to 5 times higher, as it can be seen from figures 43-47. Our conclusion is that the same cause that has generated the tilt (a loose screw, for example), can also cause the higher apparent noise, by means of mechanical vibrations effects. Indeed mechanical vibrations plus a tilted and loose source, can generate fluctuating signals. In other words the source being measured is in this sense not stable (after the tilt we have it on a sharp decreasing shoulder) and the mechanical vibrations can increase or decrease the source intensity.
An important point to be noted is that the apparent noise of the SWC on the ICL, is not constant with wavenumbers. A minimum of "noise" is observed at different frequencies when the pendulum speed is changed. The wavenumbers at which the minimum is observed is listed in the last column of the speed table. Our interpretation of these minima is as follows : the spectrum wavenumbers correspond with a fixed relation to a frequency values, which we scan as we scan the wavenumbers. The "noise" minima correspond to mechanical fluctuations in which the source intensity changes in phase with our interferogram sampling, therefore source variations are not seen, and the noise comes closer to the real electronic noise value. Note also that the mechanical- source variations do not appear as big and evident in the average spectrum, as they are mostly averaged out, but they appear in the single spectrum, therefore they appear as noise increase.

5.3.3 WHAT HAS CAUSED THE 3 BANDS OBSERVED IN THE SPECTRUM?

The calibration lamp set (lamp plus parabolic mirror) is located in the scanner, sideways with respect to the rotating mirror. The rotating mirror uses lubricated ball bearings. We suspect that the oil from this lubrication has sublimated in space contaminating the parabolic mirror of the lamp. The 3 bands observed at 2775, 2845 and 2880 cm-1 (3. 6036, 3.5149, 3.4722 microns) are typical of the CH stretching of organic materials. Figure 50 shows a blow up of the NEV5 ICL spectrum, in order to identify these bands. The same bands were observed in NEV1 (see figure 52) with the same intensity. In the figures shown above we have noticed also small amplitude oscillations (present both nights Nev1 and Nev5 but only in the first part of the spectrum. Figure 51, showing another blow up, of another section of the Nev 5 spectrum, demonstrates that these small amplitude oscillations disappear at smaller wavelengths. The origin of these small amplitude oscillations, or their cause, is not understood and very unclear.

5.3.4 IS THE LAMP STABLE IN THE NEW CONDITIONS?

Unfortunately the answer cannot be positive. Figure 53 and figure 54 show a collection of ICL spectra : in the figure 53 at speed 2000 Hz, and in figure 54 at speed 2500 Hz. Some measurements in NEV 1, NEV3-1, NEV3-2 and NEV5-1 are very close and could indicate a stable lamp situation (colors red, cyan, yellow, light bleu in figure 53). There are other cases at speed 2000, in which there are important differences appearing in the interval of 2600 – 3600 cm-1.

In this sense the worst case has been NEV2, when the observed ICL spectrum appears substantially reduced- distorted. We have no explanation for these changes as later they disappear with no reason. In the NEV2 case the entire spectrum has a lower intensity, and the contamination band appears to be much deeper. If we neglect the NEV2 case (it is a unic case), the spectrum above 4000 cm-1 is stable enough, and this may be important for further thinking on how to use the ICL. In the case of speed 2500, however, out of 3 averages, only one is at the upper level, and 2 are at reduced intensity. In conclusion it seems rather impossible to use the ICL as planned to calibrate the SW channel.

5.3.5 CAN WE USE THE ICL TO CALIBRATE THE SWC, AND HOW?

The real question is : HOW TO CALIBRATE THE SW CHANNEL ?

In the ideal case the calibrations performed in the Lab (responsivity and NER) can be assumed valid for the space measurements. This is true under the two assumptions : calibrations have been performed under space equivalent conditions (vacuum and temperature), and second : no deformation (loss of optical alignement) has occurred during launch.
In the case of PFS the Lab calibrations have been performed mostly in air at room temperature, we do have calibrations in vacuum with cooled detector, but the temperature we reached was only 250 K, while in space we have 210 K. We know that responsivity still increases going from 250 to 210 K. Furthermore we have the unknown : Has the optical alignement been kept as on ground? The answer to this question is possibly positive because the LW channel has indeed been kept exactly as on ground, but we know that the SW channel is more sensitive to optical disalignements.
Finally there is another aspect (minor) : in the Lab all the measurements have been performed at double pendulum speed 2000 Hz, while in space we shall use mostly speed 2500 Hz .The solution to this aspect is rather simple : in space we take measurements of the same source (possibly very stable) with the two speeds, and from the ratio we can get the transfer function from one speed to another.
If we call S the measured spectrum, I the radiance of the source, L the deformation for optical alignement, K the gain in responsivity obtained by decreasing the detector temperature, V the spectral modification due to speed change (all functions of the wavenumber v),
We have :

$$I_{290}(v) = S(v) / Res_{290}(v)$$

$$I_{210}(v) = S(v) / (Res_{290}(v) * K_{290}^{210}(v) * L(v) * V_{2000}^{2500}(v))$$

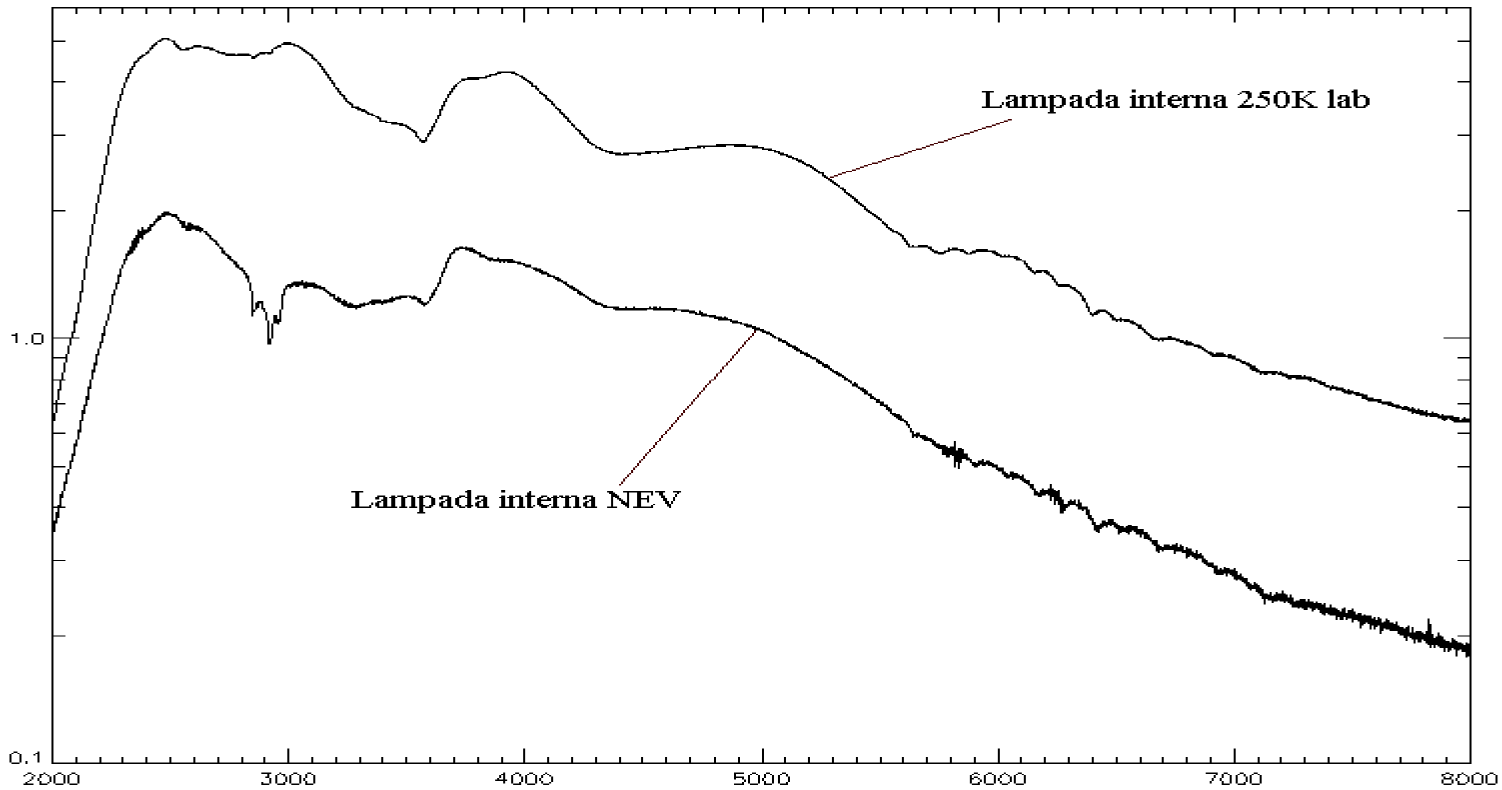


Figure 48 – ICL spectrum with the detector cooled at 210 K (NEV in space), and at 250 K in the termovacuum measurements.

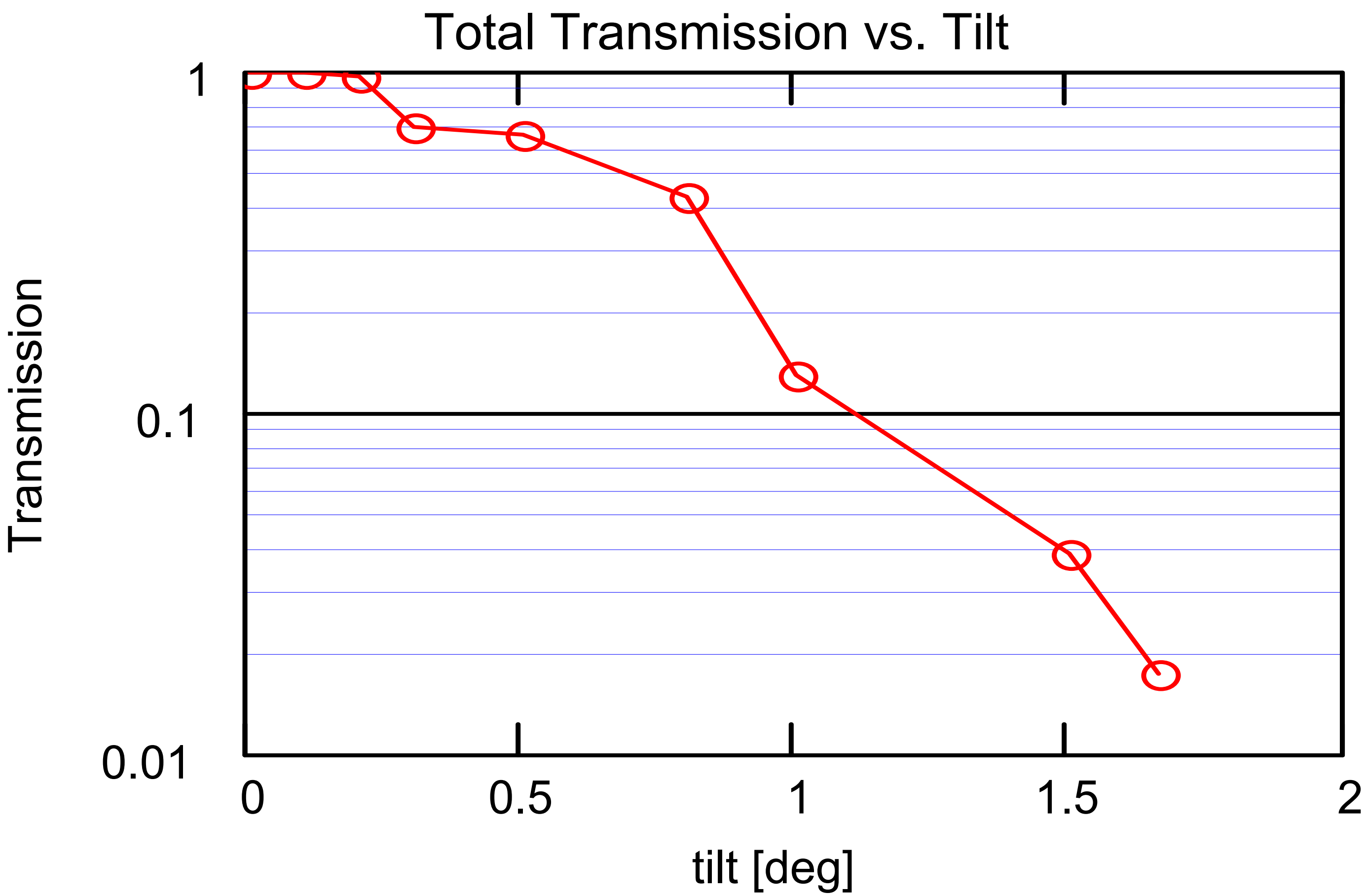


Figure 49 – Signal transmitted after a tilt of the lamp by the amount shown in the ascissae.

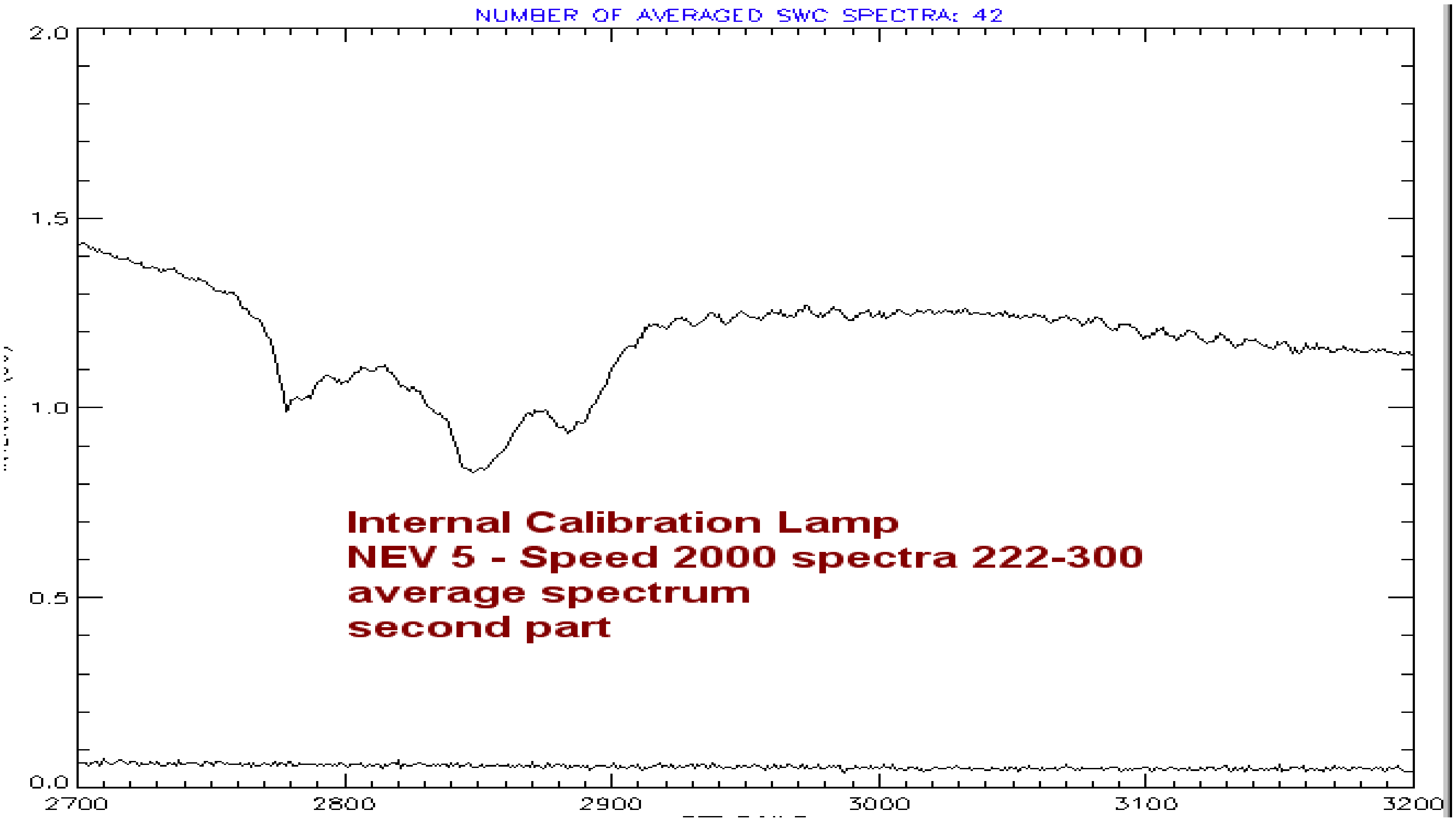


Figure 50 – Blow up of the internal calibration lamp spectrum around the 3 bands at 2775, 2845, 2880 cm-1 .These bands are probably due to contamination. Note the presence of small amplitude oscillations present only in the first Part of the spectrum.

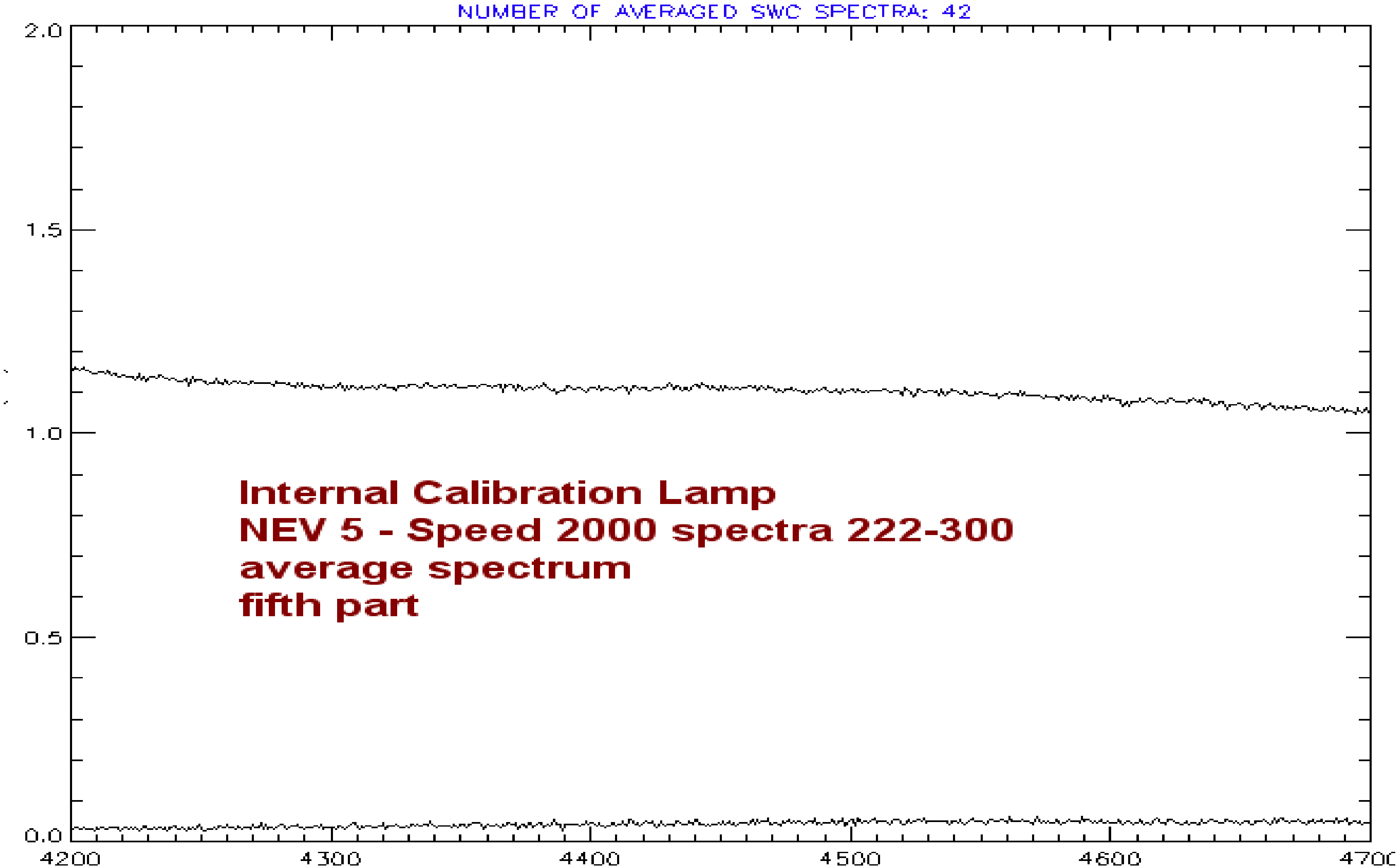


Figure 51 – Part of the same spectrum of previous figure to show the absence of the small amplitude oscillations.

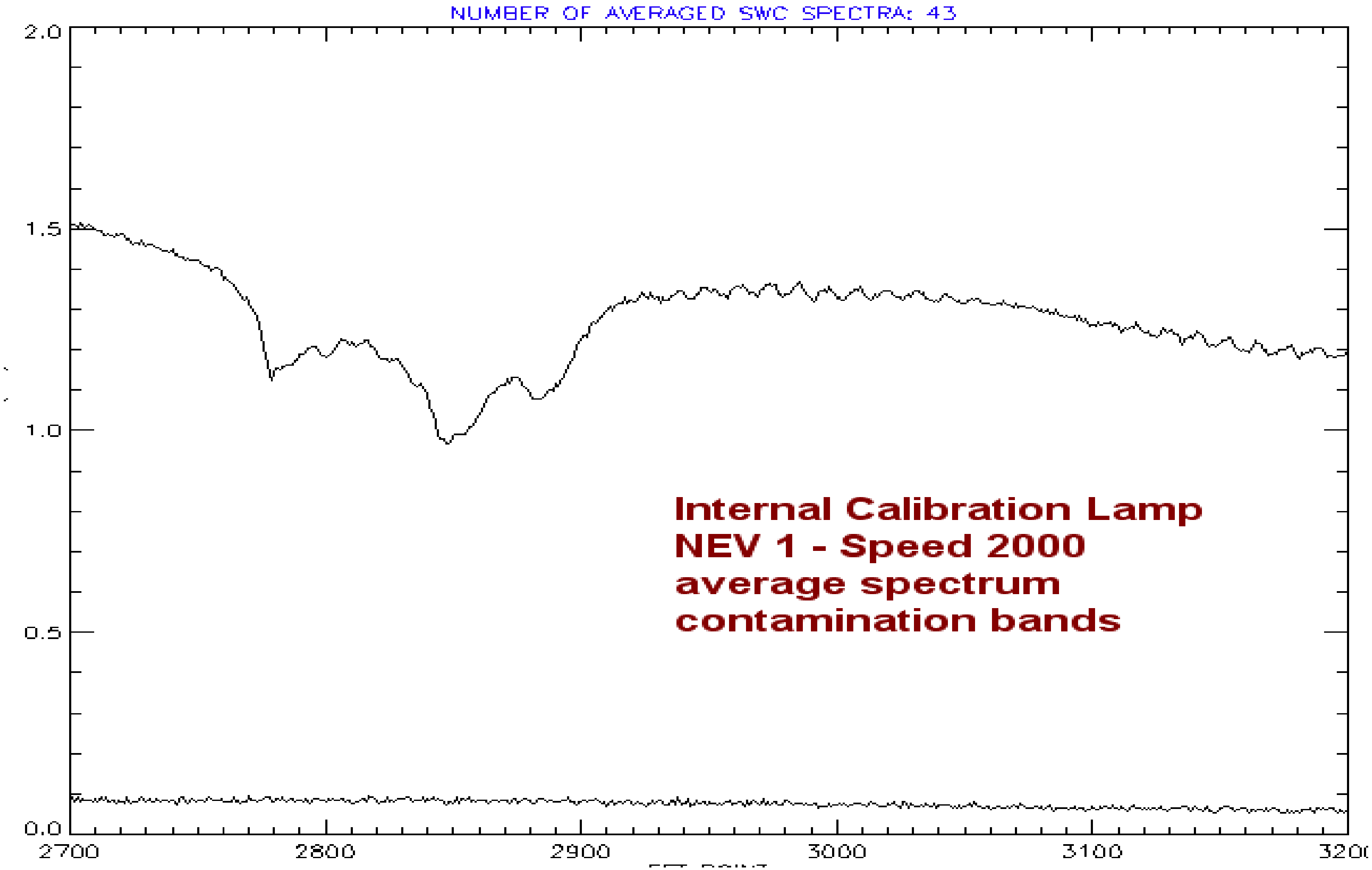


Figure 52 – Blow up of the internal calibration lamp spectrum around the 3 bands at 2775, 2845, 2880 cm-1 .These bands are due to contamination. Note the presence of small amplitude oscillations present only in the first Part of the spectrum.

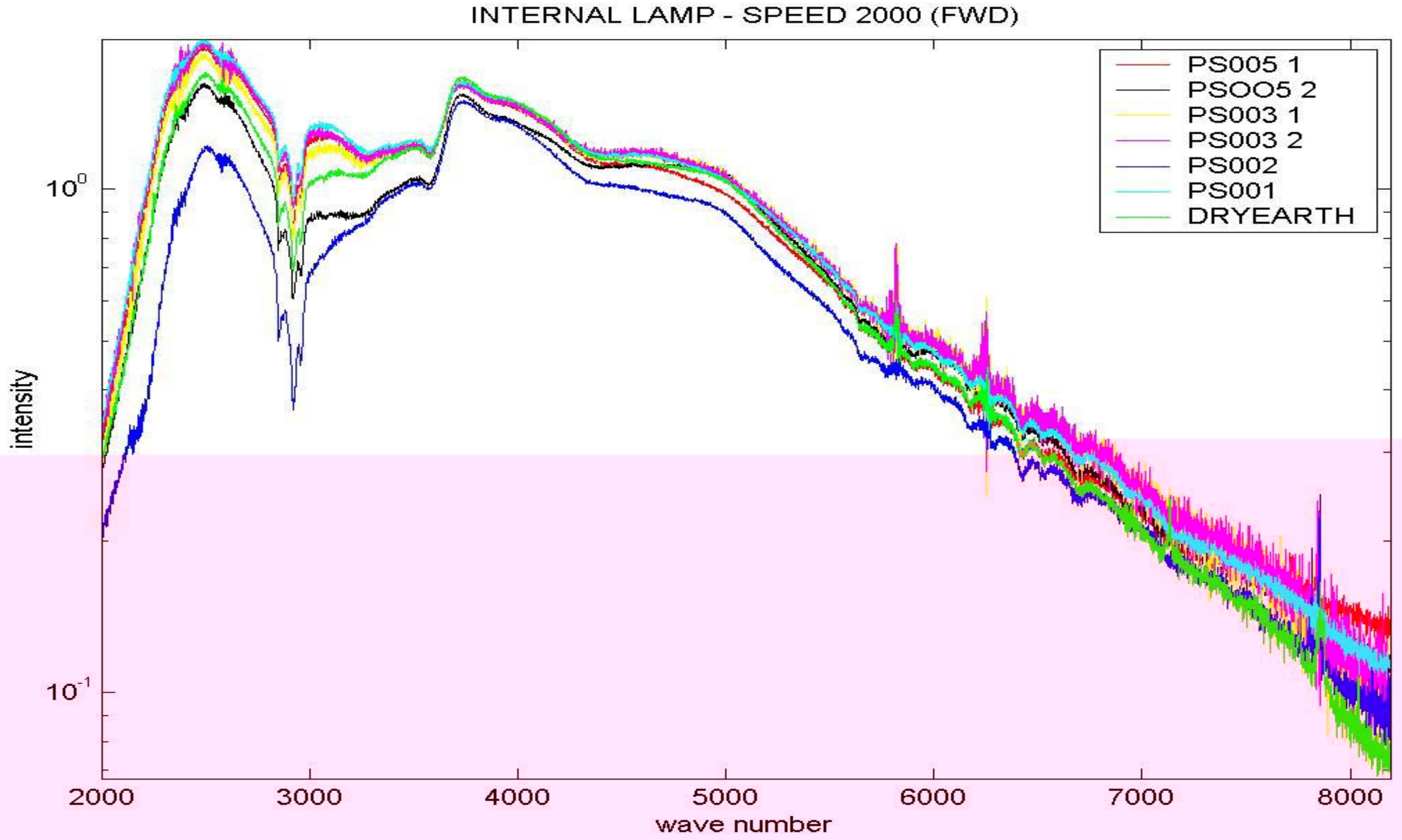


Figure 53 – Several averages of ICL spectra. Large variations are seen between 2600 and 3600 cm-1. Speed was 2000 Hz.

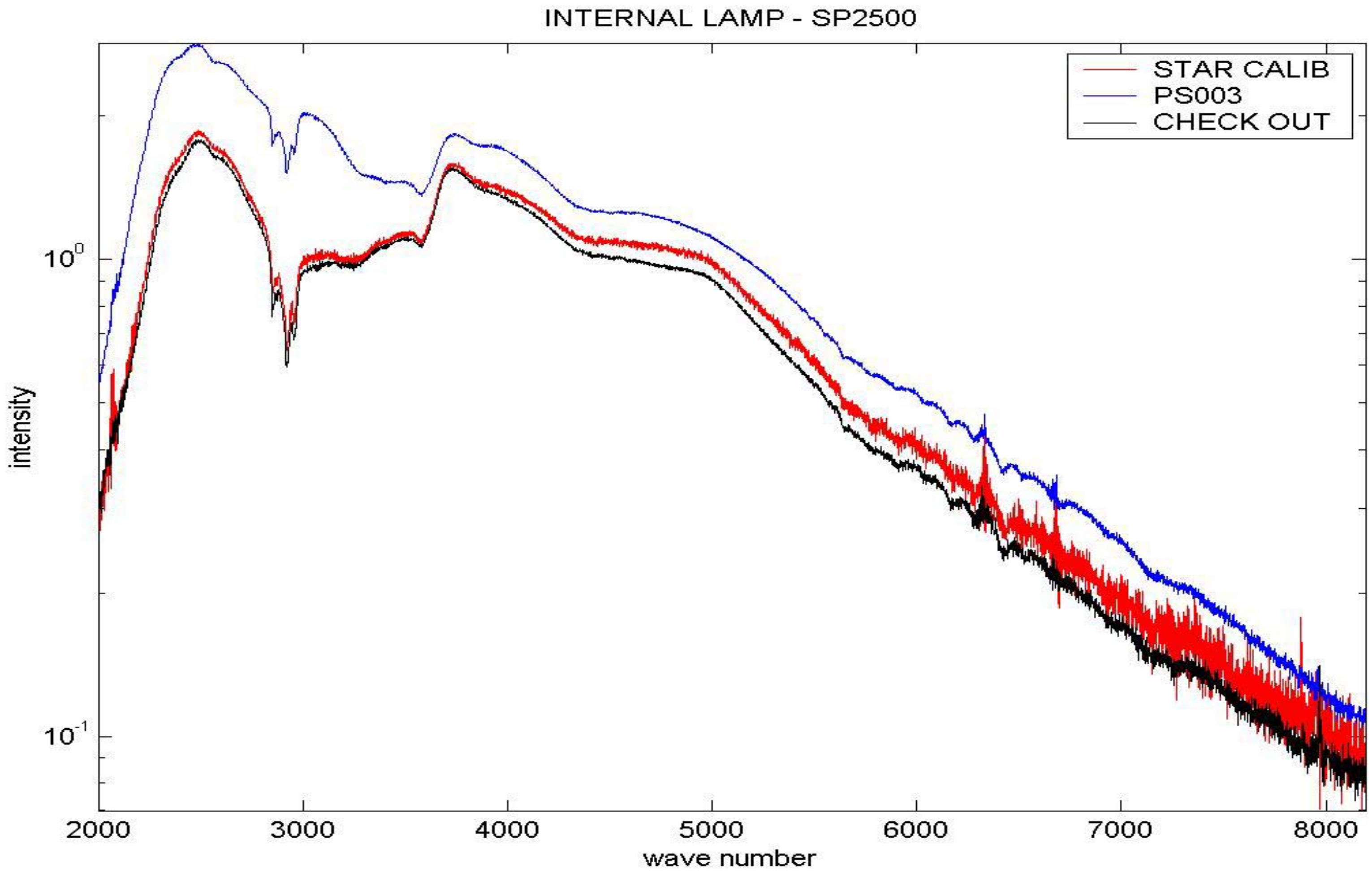


Figure 54 -Several averages of ICL spectra. Large variations are seen between 2600 and 3600 cm-1. Speed was 2500 Hz.

In the equation

$I_{210}^{2500}(v) = S(v) / (Res_{290}(v) * K_{290}^{210}(v) * L(v) * V_{2000}^{2500}(v))$

The terms K, L, and V are unknown. We have to find a way to compute or measure these 3 quantities.
We have two possibilities:

- first is : assume that either a Martian spectrum somewhere is well known, and we intercalibrate there, or we intercalibrate with Omega (it is rather difficult on the basis of the different spectral resolution) on some Martian spot. Intercalibration means we know I and S and we compute K*L*V. We whish for the moment to neglect this possibility, hoping to be able to obtain a consistent reasonable value of the terms K, L, V separately .
- second possibility : we can get the 3 terms separately in the following way (starting from the easy part):
-

$Res_{290}(v)$: is available, see figure 55.
$V_{2000}^{2500}(v)$: as stated previously we can get this function of v as ratio between measurements (averages) of the ICL spectrum PS003 / PS001. The result is shown in figure 56.

$K_{290}^{210}(v)$: This can be obtained from laboratory measurements. In the vacuum chamber, indeed, we had a sequence of measurements while the detector was being cooled (see figure 57). The source was the ICL. When we cool the detector we have an increase of responsivity, but this increase is not simply a constant, but is also function of v : indeed the maximum responsivity moves toward longer wavelengths by cooling the detector .From the sequences of measurements at different temperatures (from 290 to 250 K, but we were unable to reach 210 K, see figure 58) we can linearly extrapolate to 210 K, at each wavenumber, the measured spectra .The linear behaviour at several different wavenumbers is demonstrated in figure 59. In this way we get the ICL spectrum for a detector at 210 K. We shall have

$K_{290}^{210}(v) = S_{ICL}^{210}(v) / S_{ICL}^{290}(v)$

The two spectra, measured at 290 K and extrapolated from measurements up to 210 K, are shown in figure 60, together with some other measurements. Note the difference in the position of the peak of the spectrum : at 3000 cm-1 at room temperature, and at 2400 both in the 210 extrapolated spectrum, and in the space measurements NEV1. Finally in figure 61 is given the function $K_{290}^{210}(v)$ as obtained from the above process.

Finally we need to find L(v). If we compare the spectrum of the ICL as measured in space with the extrapolation to 210 K from the vacuum chamber measurements, the ratio will give us the resulting of two effects : the decrease in intensity of the ICL and the spectral attenuation due to some possible loss of the optical alignement. If we assume that tilting of the ICL lamp will not change the spectral shape, but it is only a constant, then the ratio

$$L(v) = S_{ICL}^{210}(v) / PS001(v)$$

Can give us the loss of the optical alignement, or better the effect of the reduced optical alignement. Figure 62 gives the above ratio with a factor (4.3) taken away. It is not clear to us if the function obtained is indeed what we need. Certainly the function is dominated by the contamination of the ICL with organic material. From our point of view, interested in obtaining a function describing the loss due to optical alignement modification, we see that up to 5000 cm-1 the function is around a constant value (4.3, taken away, or 1 in the figure), while between 5000 and 8000 cm-1 we have a slope going from 1 to 0.5. The function L(v) is indicated as red line in figure 62, and is what we should use to take into account the fact that a small optical misalignement is indeed occurred.

We can eventually test the results by using the measurements in space of the internal BB.

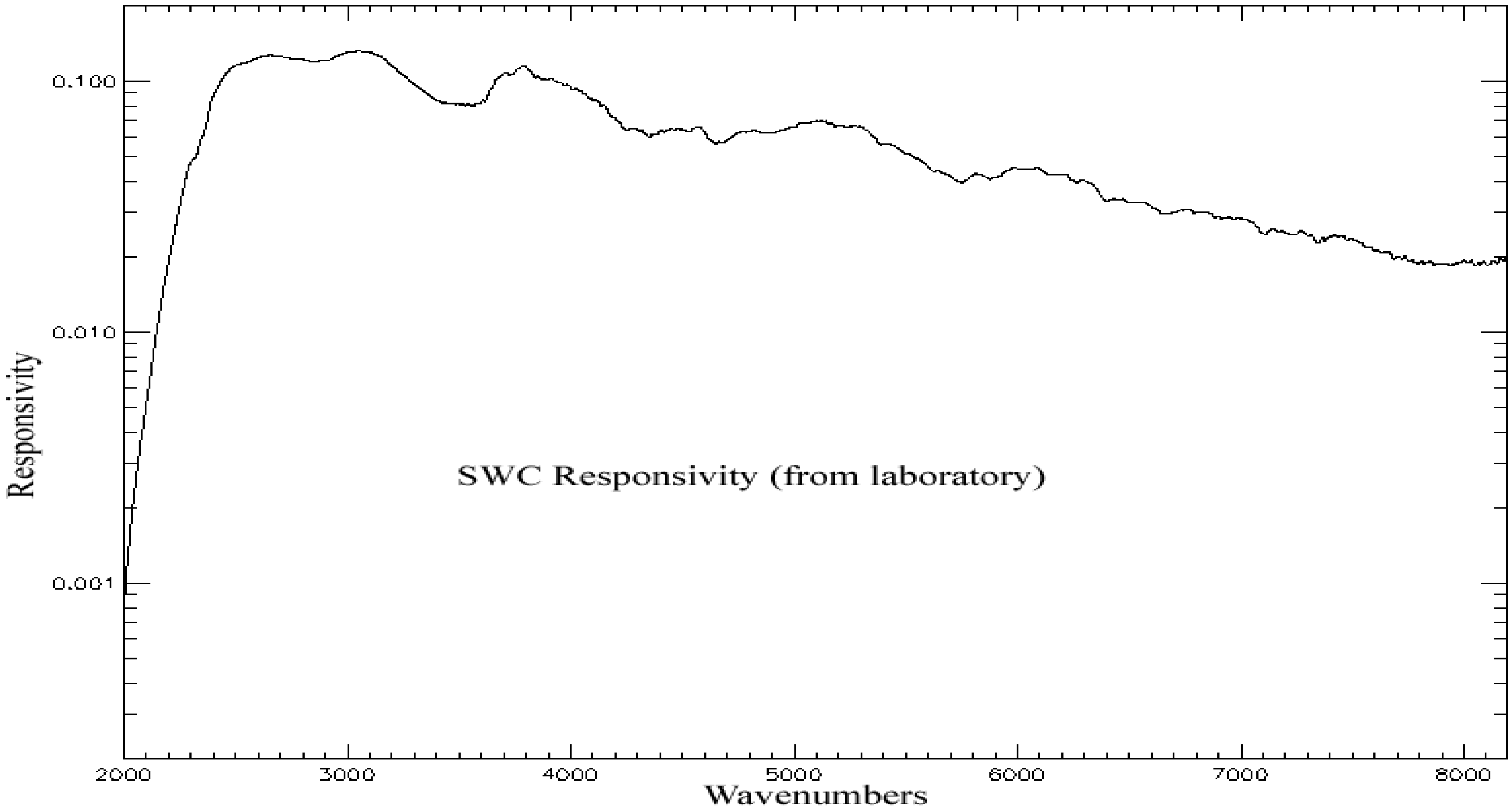


Figure 55 – Responsivity of the SW channel from laboratory measurements at room temperature.

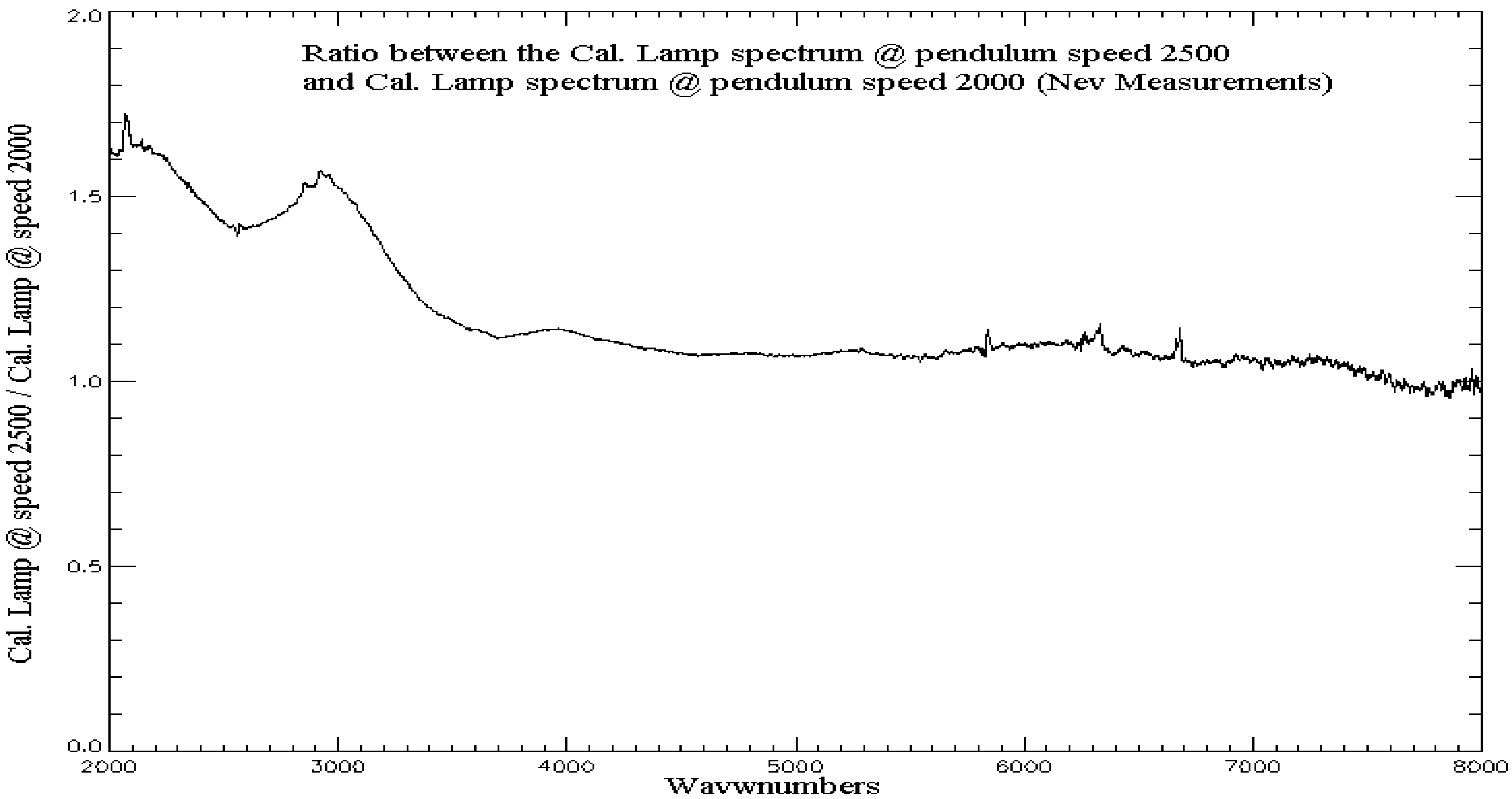


Figure 56 – The speed ratio between 2500 and 2000 Hz. This is the function $V_{2000}^{2500}(\nu)$

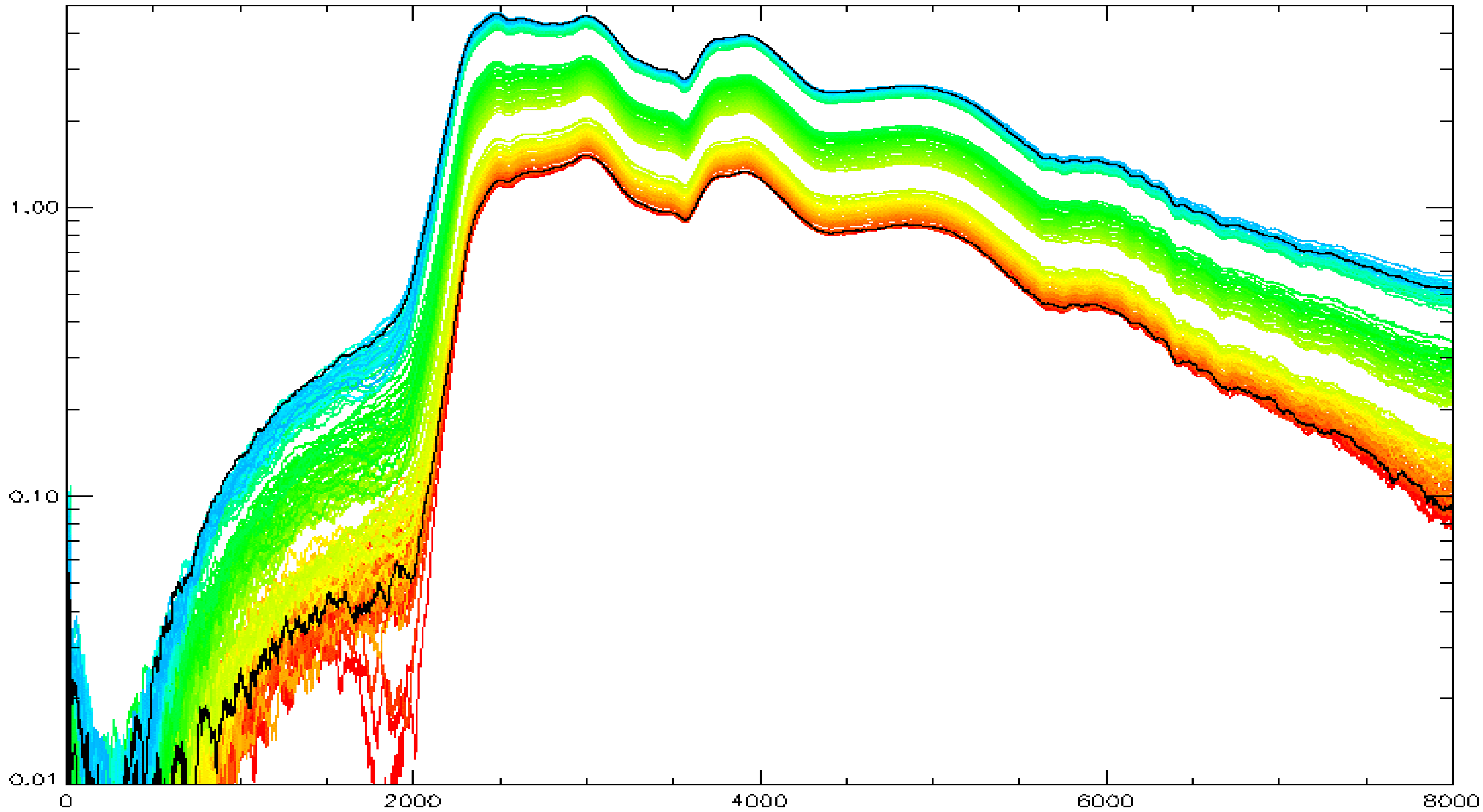


Figure 57 – Sequence of Lab measurements in the thermovac while cooling the detector of the SW channel.

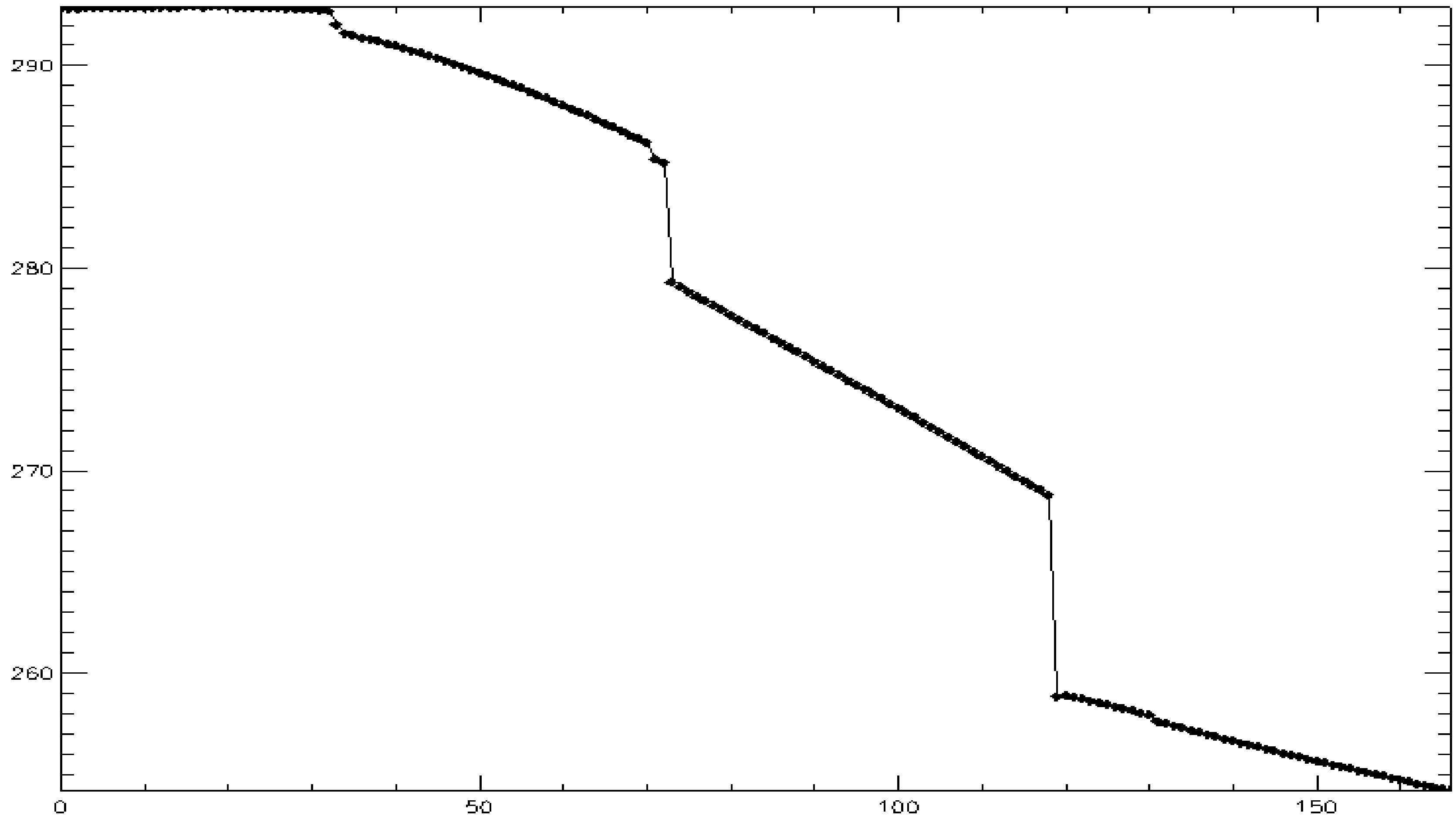


Figure 58 – Temperatures of the SW detector while observing the ICL in the termovac.

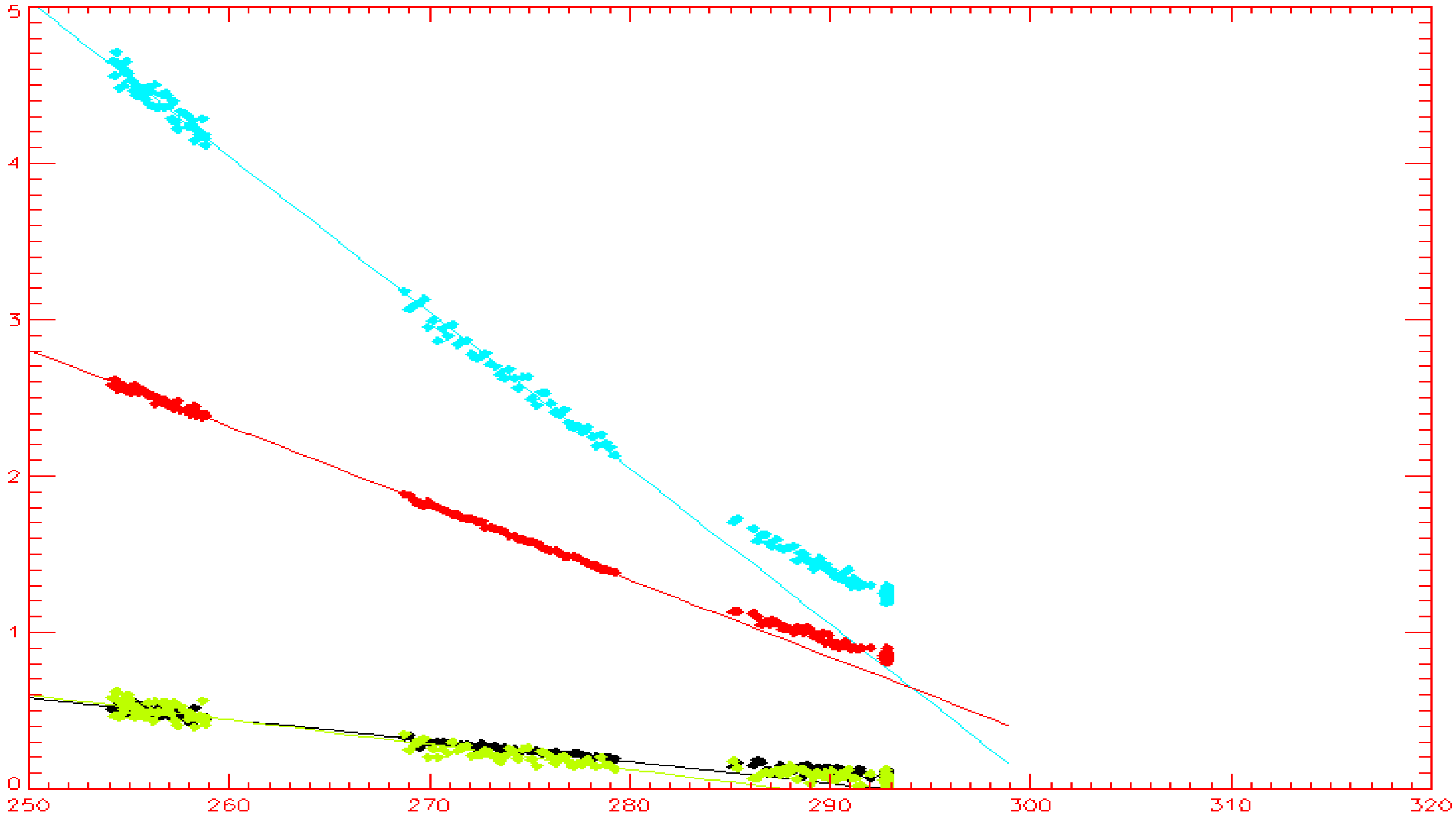


Figure 59 – Linear behaviour in the temperature interval explored.

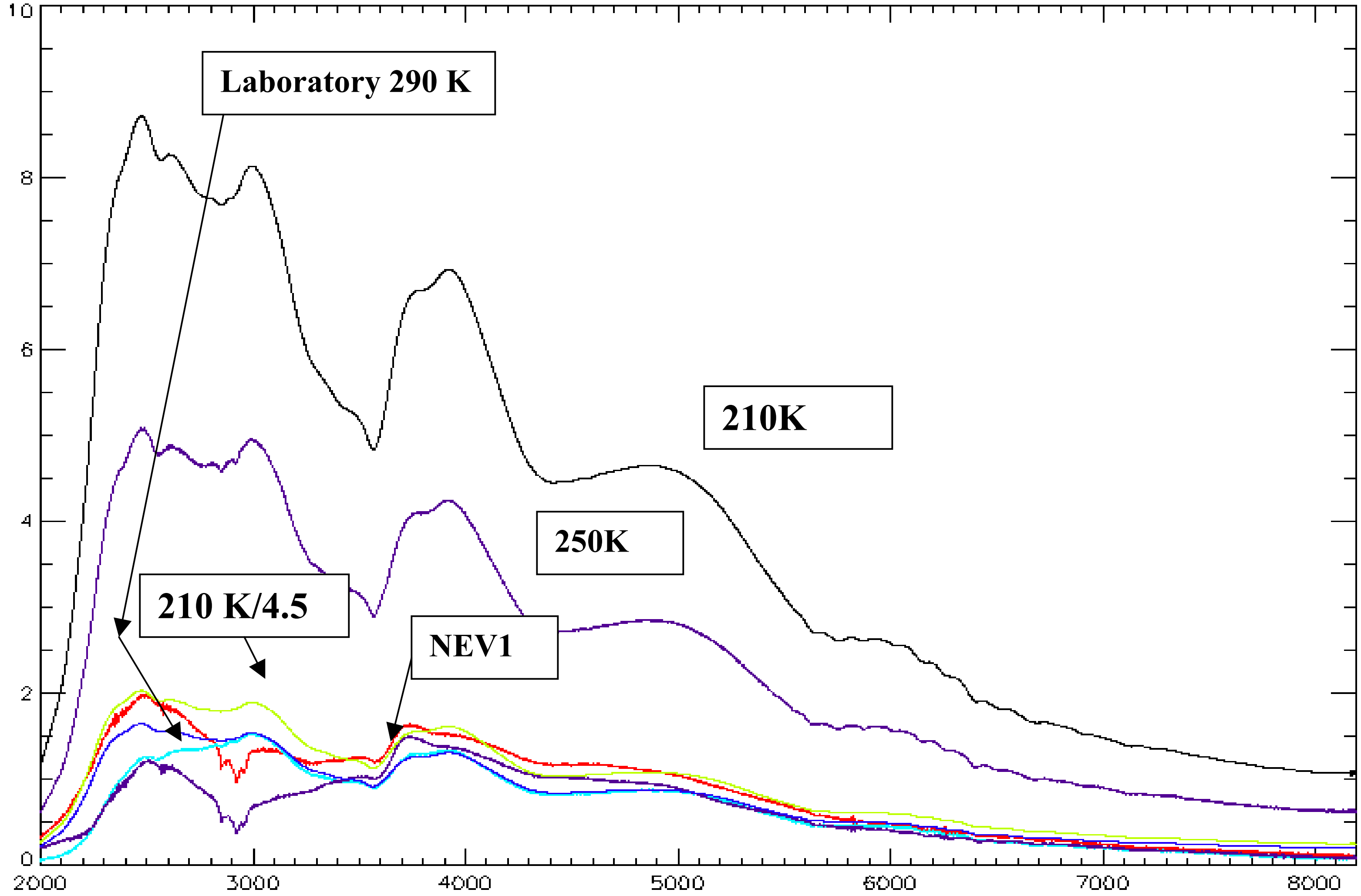


Figure 60 – A number of spectra of the ICL: the extrapolated at 210 K (black), the measured at 250 K (violet), the measured at 290 K (light bleu), and in space at NEV 1(red curve).

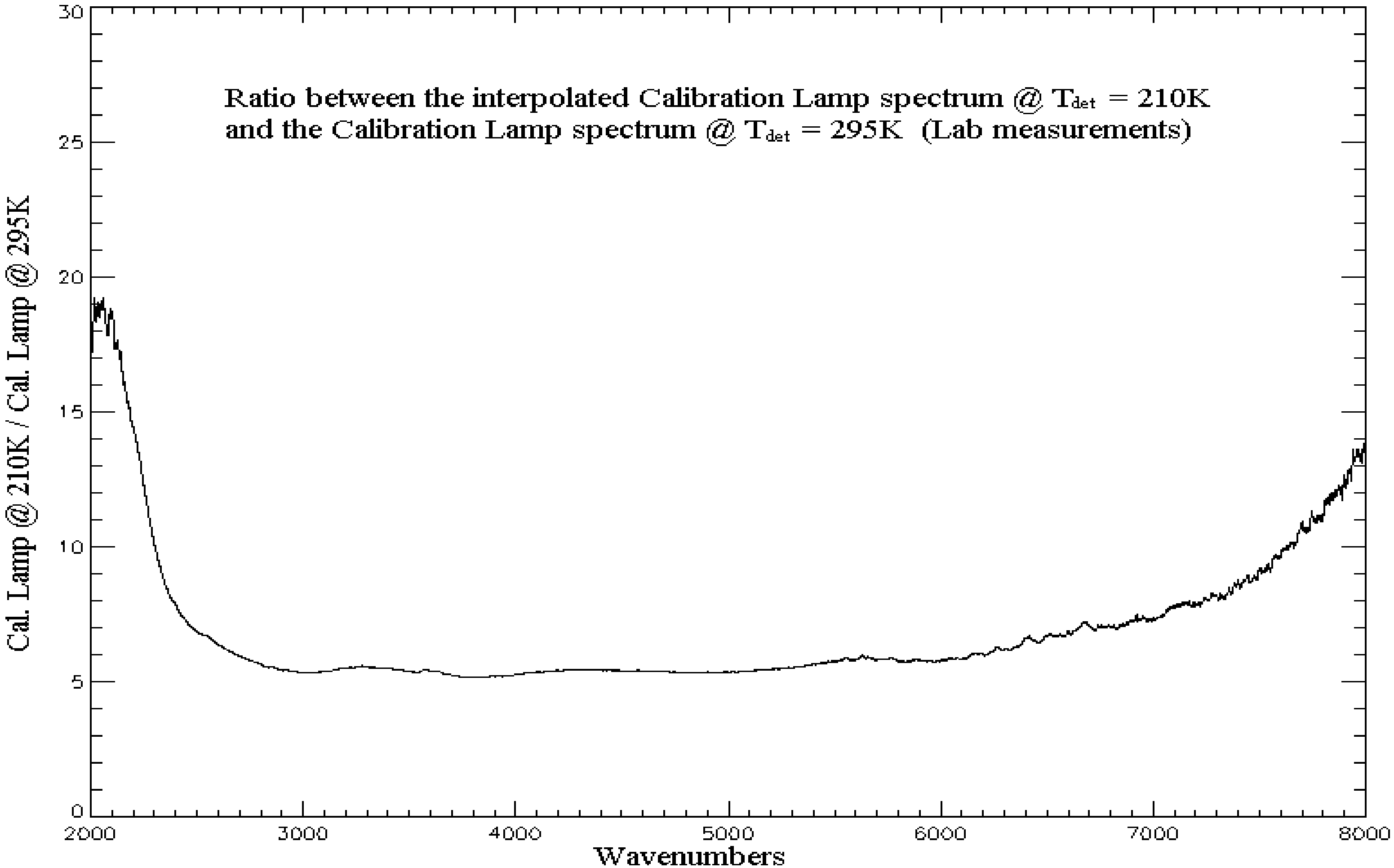


Figure 61 – Ratio between ICL spectrum at 210 K and at 290 K. This is the function $K_{290}^{210}(\nu)$.

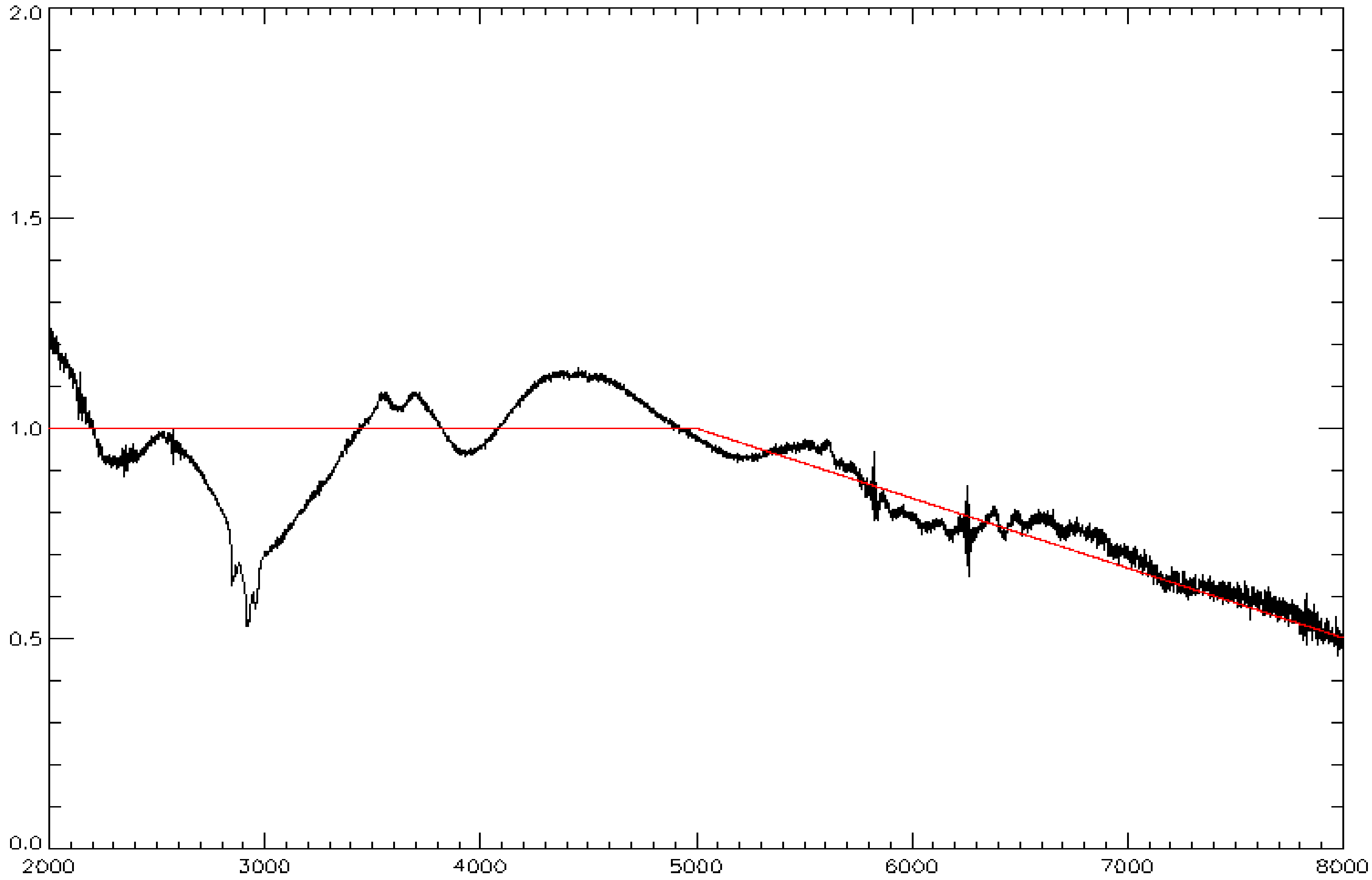


Figure 62 – The function L(v) = S_{ICL}^{210} (v) / PS001(v), and its linear approximation.

5.3.6 CALIBRATION AT SPEED 2000 HZ AND 2500 HZ.

We shall proceed now to obtain the actual responsivity and NER for the SW channel in the two cases of different double pendulum speed : 2000 Hz and 2500 Hz, using the appropriate version of the equation given previously :

$$I_{210}{}^{2500}(v) = S(v) / (Res_{290}\ (v)\ {}^*K_{290}{}^{210}(v)\ {}^*L(v)\ {}^*V_{2000}{}^{2500}(v))$$

In order to test the final results, we need observations of an external source of known intensity. For the moment the only data we have to test the results, are the measurements over the internal BB, as seen by the SW channel.

The responsivity of the SW channel with speed 2000 Hz, GAIN 0, at 210 K (therefore valid for most measurements made in space in the NEV activity) is given in figure 63. Note that the peak moves from 3000 cm-1 at room temperature, to 2500 cm-1 in space. In the region 2500 – 3500 cm-1 we gain a factor 7 in responsivity, while in the region 7500 – 8000 cm-1 the gain is only a factor 5, due to the loss of signal at launch.

Between 2000 and 2500 cm-1 the SW channel observes mostly thermal radiation, therefore to the previous formula for the calibration of the SW channel, we have to add an approachsimilar to the one used for the LW channel. In this sense it is very important to understand that the relative thermal conditions for the SW channel are very different from the LW channel. In the SW channel the detector is at 210 K, therefore is colder than the source (we use the internal BB as source at 260 K) and it is colder than the instrument which is at 290 K. It is therefore the emission from the instrument to the detector that becomes important, and the approach correct is to ignore the emission from the detector. We use, therefore formula 3 from the LW channel, as we did in the laboratory calibrations. We have found that the best description of the interaction is

$S(v) = Res\ (I(v) – 0.10 * B(Ti))$

With this correction for the thermal part (2000-2500 cm-1) the responsivity at speed 2000 and 2500 become the ones given in figure 63 and 64. Note the large increase of responsivity at 2000 cm-1, resulting from cooling the detector.

The NER is given in figure 65 and it is the ratio of the noise sigma (0.03 DN) and the responsivity .
The responsivity of the SW channel with speed 2500 Hz, GAIN 0, at 210 K (therefore valid in space in the NEV activity) is given in figure 64. Note that the peak moves from 3000 cm-1 at room temperature, to 2500 cm-1 in space. In the region 2500 – 3500 cm-1 we gain a factor 10 in responsivity compared to room temperature (speed 2000 Hz), while in the region 7500 – 8000 cm-1 the gain is only a factor 5, due to the loss of signal at launch.
The NER is given in figure 65 and it is the ratio of the noise sigma (0.03 DN) and the responsivity .
Note that in the NER we have evidence of two things : first the responsivity with speed at 2500 being higher than the one with speed 2000, the NER is consequently lower. Furthermore we have the effect of the mechanical disturbances which with speed move away from the central part of the spectrum.

It is finally important to add that, as noted in the calibration report of PFS, Vol.II, increasing the gain factor from 0 to 3, increases the SNR by a factor 3-5.
In order to evaluate the obtained responsivity and NER, we can use the measurements done in NEV 4, when we took 200 spectra of internal calibration BB (known temperature) at gain 3 with speed 2000.

In figure 66 the radiance (average and smoothed) of the internal BB calibrated spectrum is compared with a computed Planckian at the BB temperature. The fit is very satisfactory.

We have used the obtained responsivity with the measured spectrum of the ICL at speed 2000 and speed 2500. The speed do not change the radiance emitted by the lamp, therefore the fact that the 2 curves in figure 67 are coincident is a demonstration of the fact that the responsivity we have and the procedure used are correct.

Finally we show in figure 68 2 synthetic Martian spectra to which the noise has been added for a speed 2000 Hz. This may be considered a pessimistic attitude, and shows that we may have SNR between 15 and 40 on the single measurement.

Figure 69 shows the testing of the gain factors done looking at deep space.

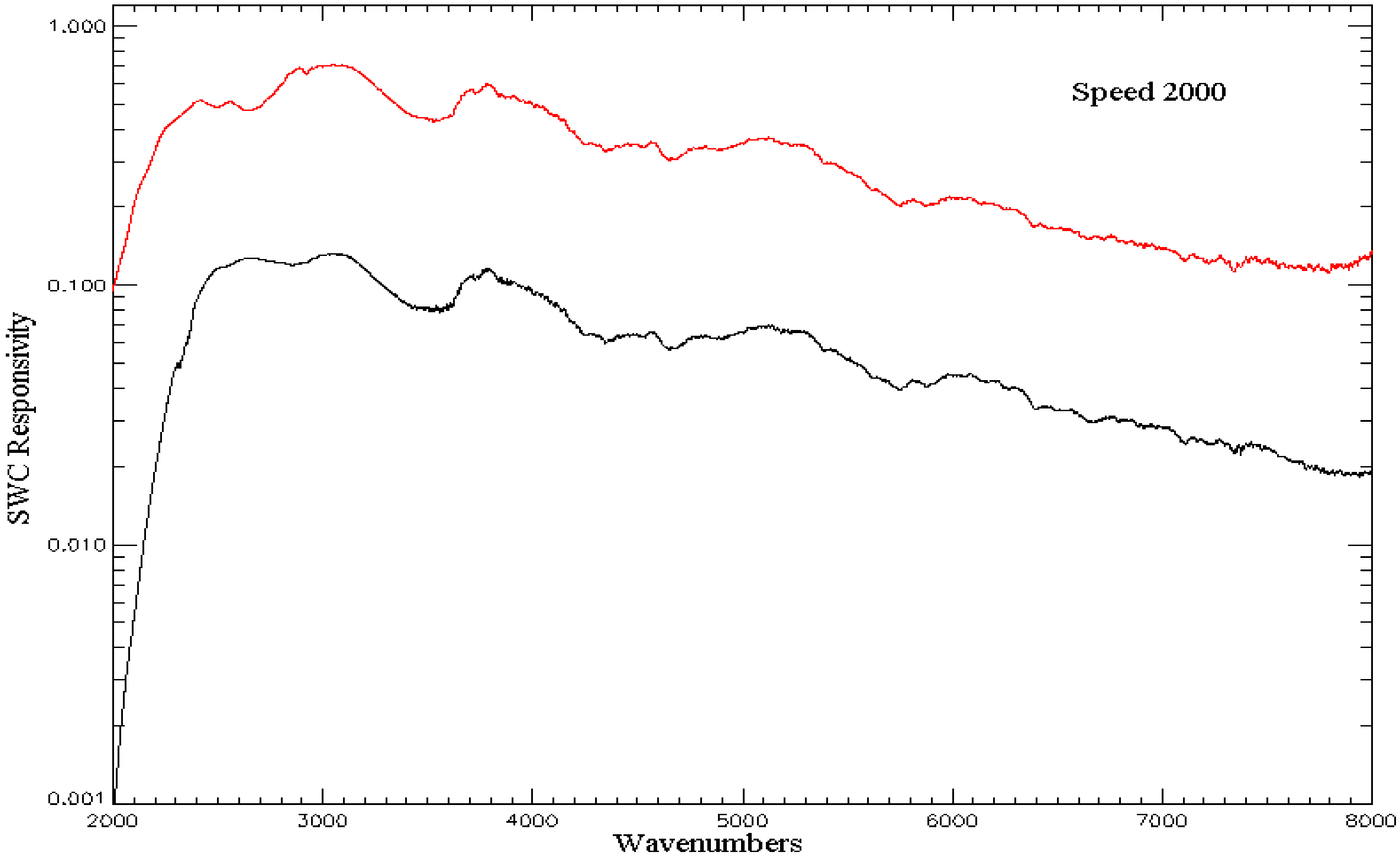


Figure 63 – Responsivity of the SW channel as obtained in the Lab at room temperature (black curve), and as in space at 210 K (yellow curve). Gain 0, speed 2000 Hz in both cases.

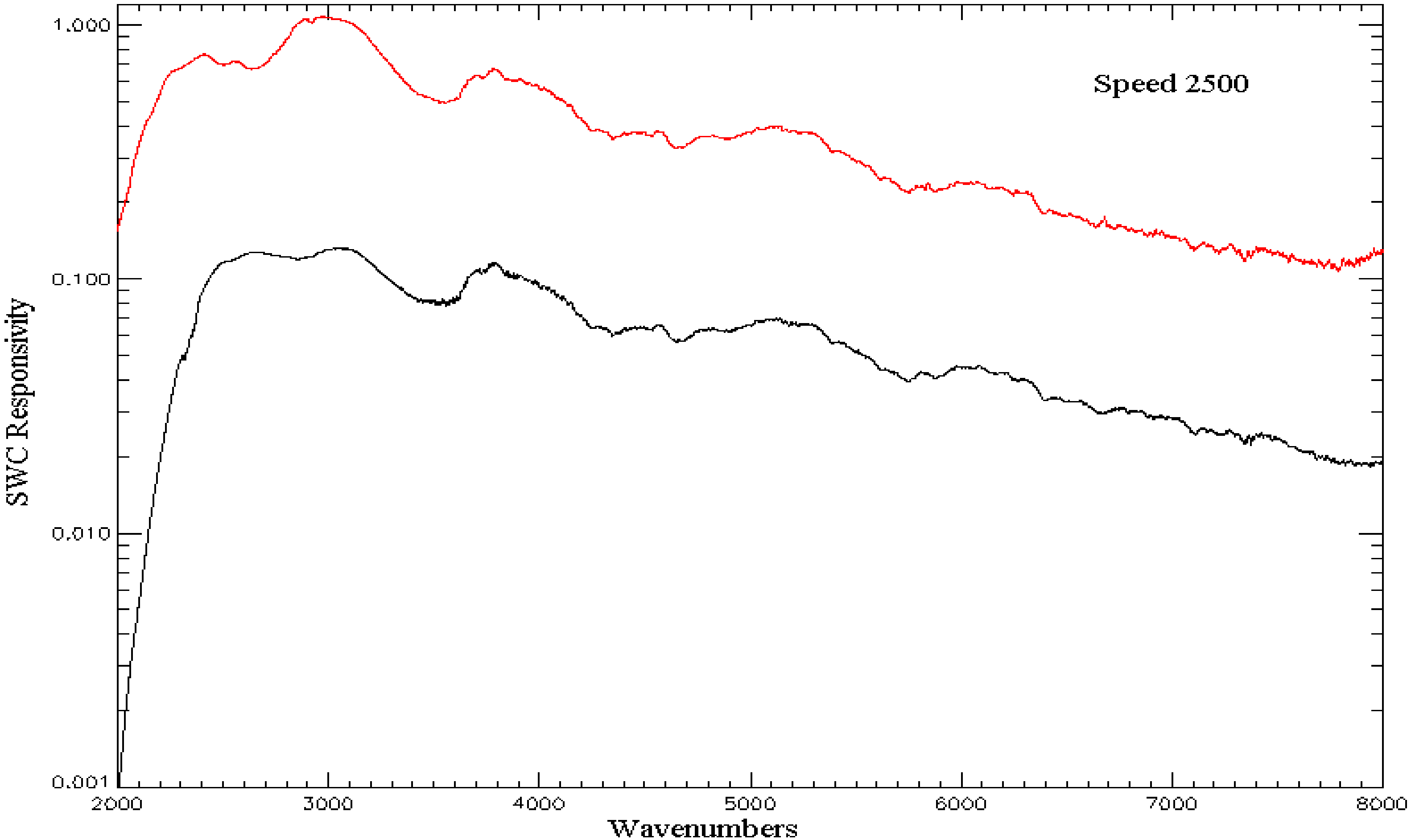


Figure 64 – Responsivity of the SW channel as obtained in the Lab at room temperature (black curve), and as in space at 210 K (violet curve). Gain 0, speed 2000 Hz in the lab and 2500 in space.

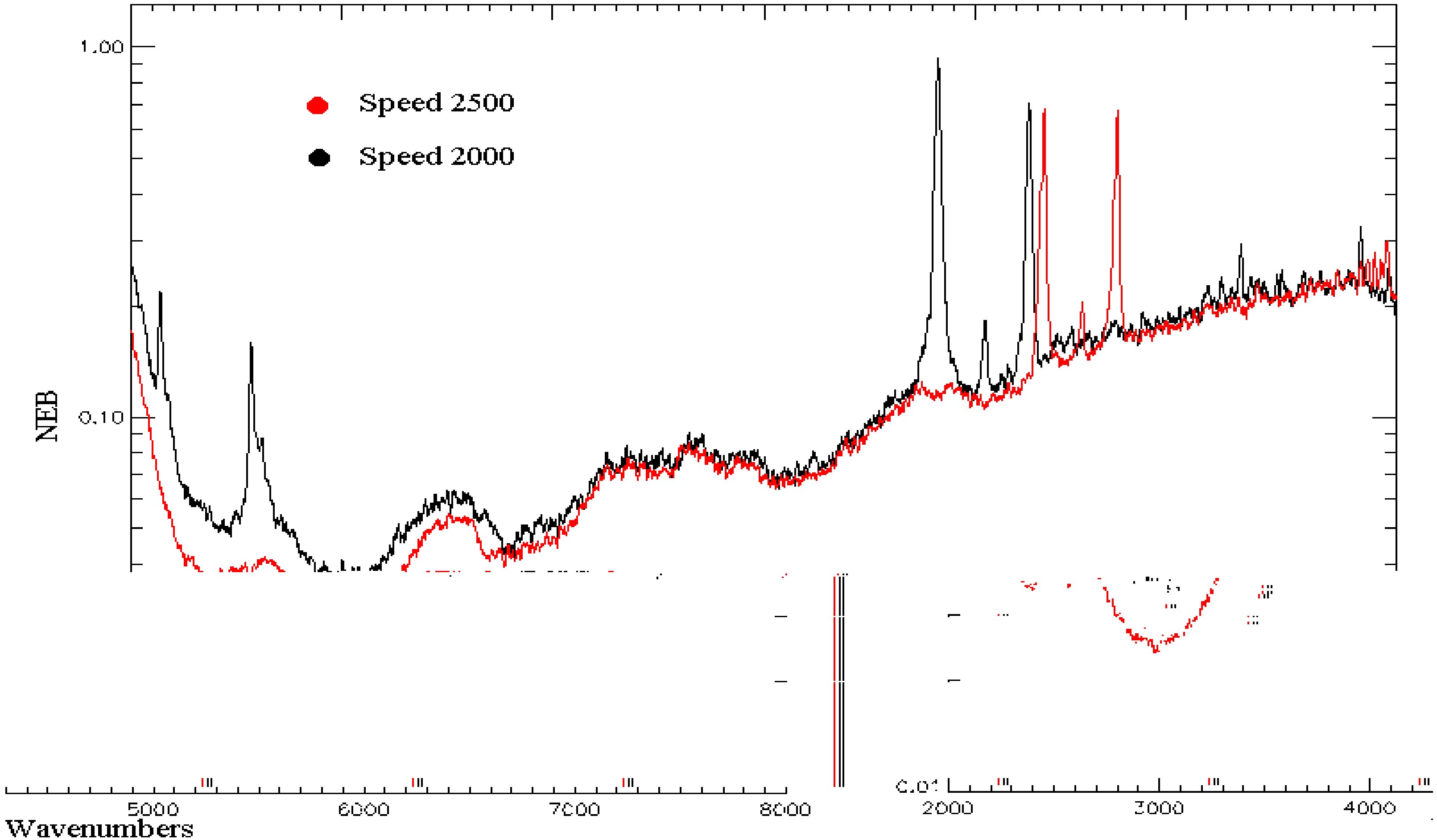


Figure 65 – NER for the SW channel for the speed 2000 Hz (red curve) and 2500 Hz (black curve). Units are CGS. The large peaks are caused by the mechanical vibrations.

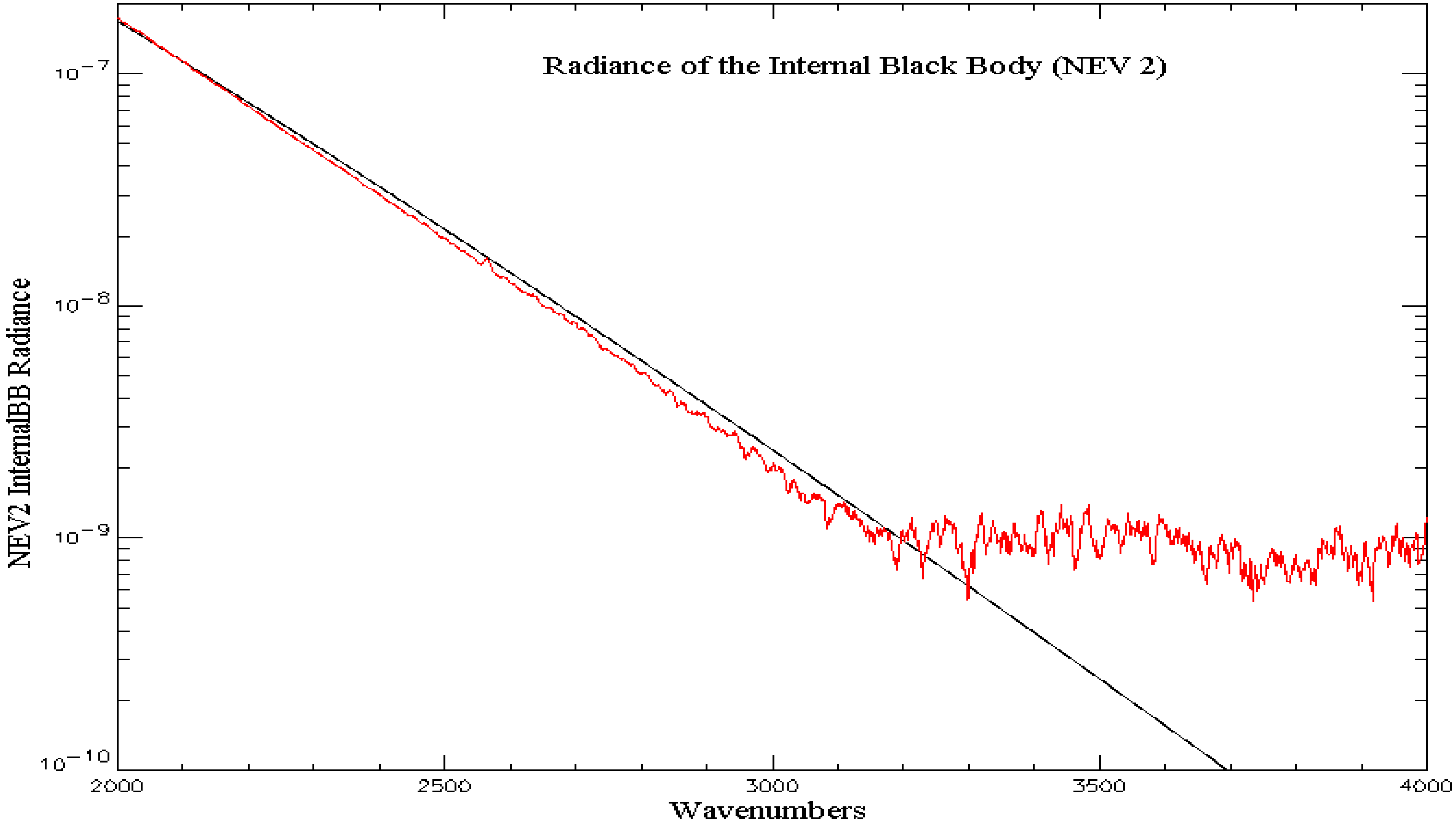


Fig 66 – Radiance of the Internal BB, calibrated with the previous responsivity, compared with the computed Planckian. Units are CGS.

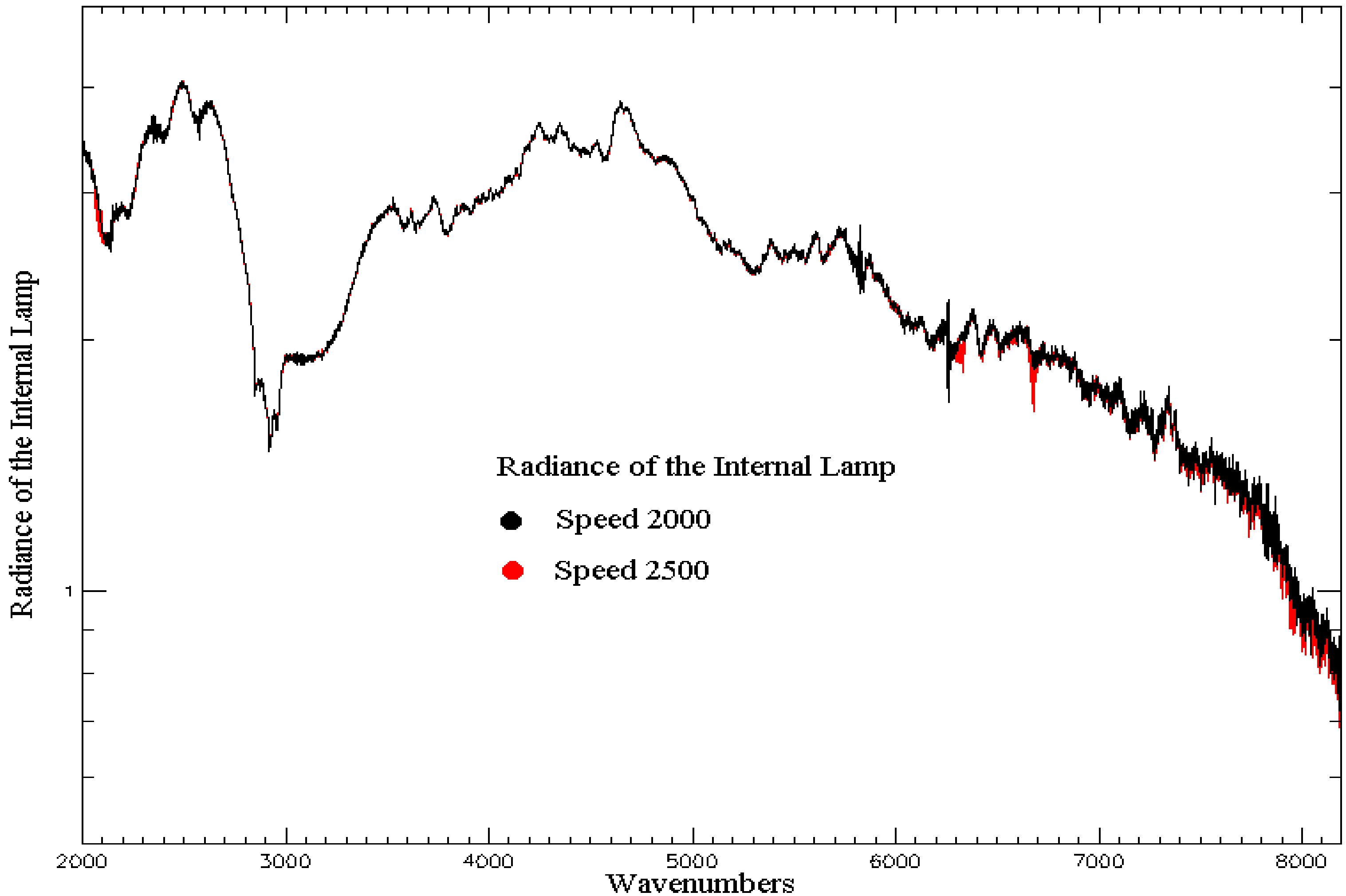


Figure 67 – Radiance of the ICL as measured at speed 2000 and speed 2500. Units are CGS.

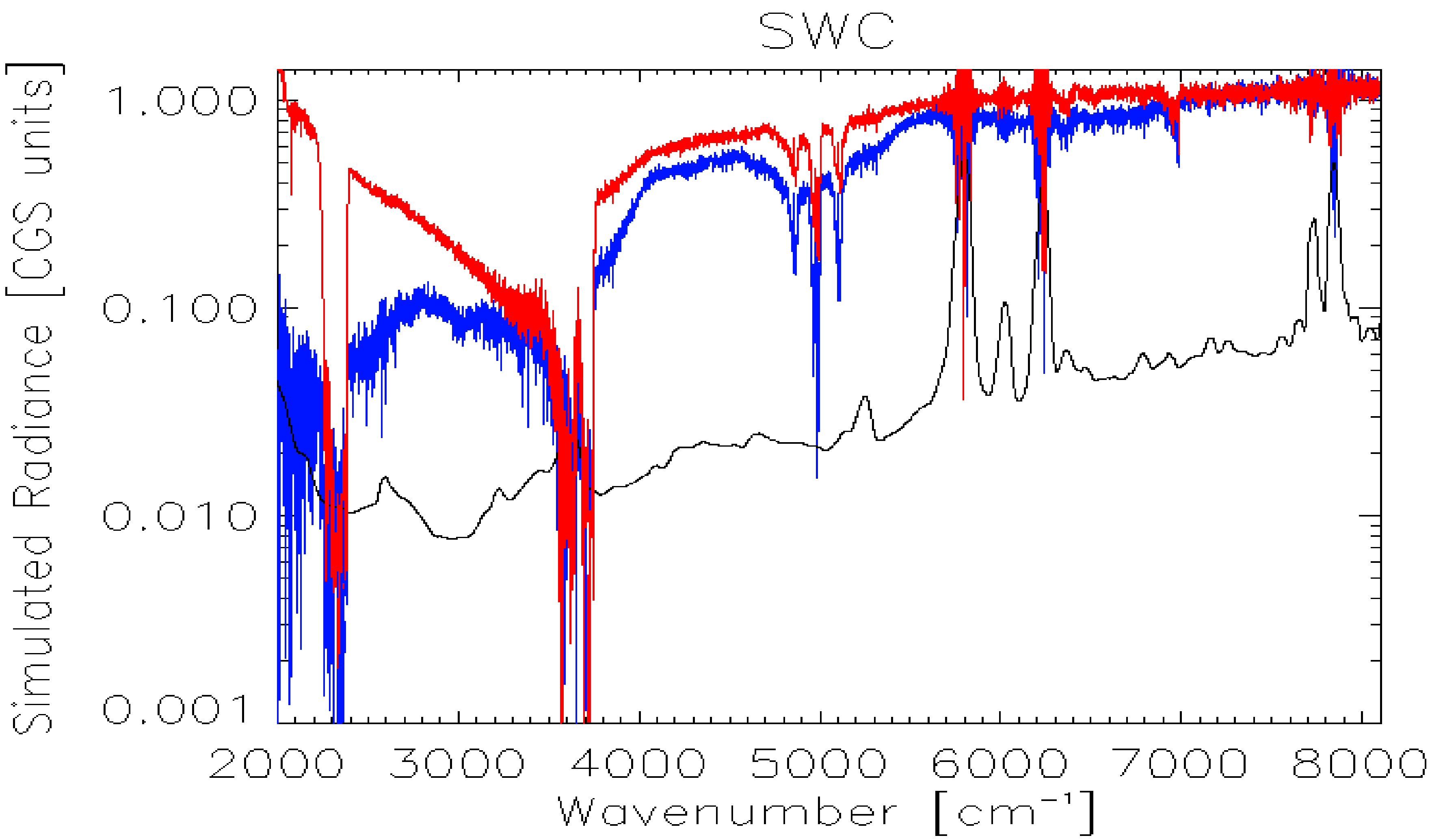


Figure 68 – Synthetic martian spectra with real noise and NER. Speed 2000. SNR varies between 15 and 40.

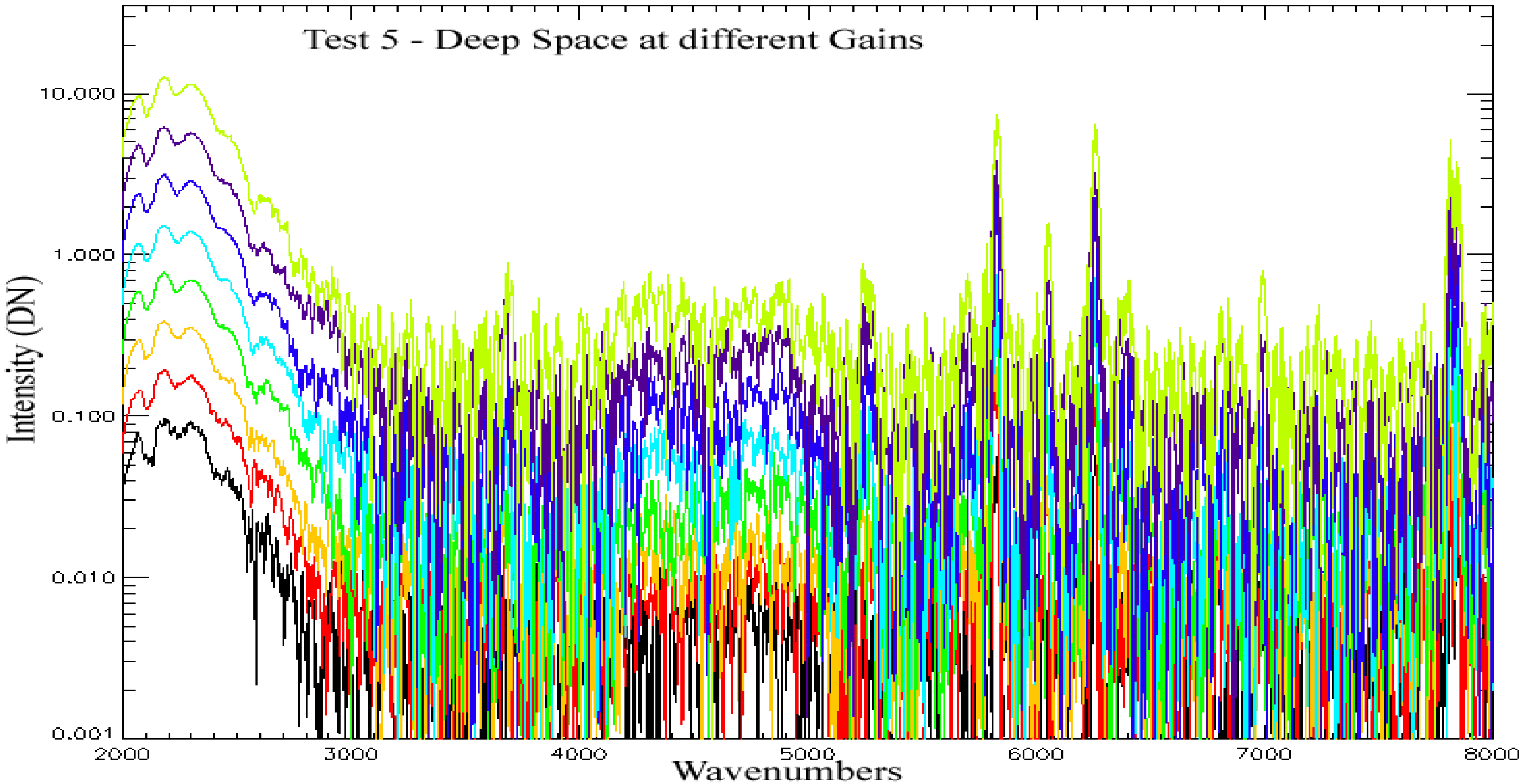


Figure 69 – Deep space spectra in a Test 5 : gain factors change between 1 and 128

APPENDIX : LIST OF THE TESTS PERFORMED.

List of the nights when tests were done :
June 23 night : 4 hours
June 25 night : 4 hours
June 26 night : 1 hour
June 27 night : 2 hours
June 30 night : 4 hours all experiments together.
July 1 night : 6 hours
July 2 night : 6 hours
July 3 night: 2 + 2 hours = Earth observations + interference test
July 11 night : 6 hours.
July 13 night : 3 hours
July 23 night : 2 hours

JUNE 23 NIGHT : 4 HOURS

Pfs switch on
Housekeeping data enable every 4seconds
150 minutes of housekeeping data with module O and S on.
Toward the end there was a problem : telemetry interrupted and lost .
PFS switch off and on again .
Synthetic interferogram 10 measurements
Autotest 1 measurements 34
Calibration measurements
100 measurements Black Body
100 measurements Deep Space
100 measurements Internal Lamp
All measurements gain 0,0 – DTM17
PFS switch off
File name NEV_PS001_FULL_2003_06_24.ifg

JUNE 25 NIGHT : 4 HOURS

Pfs switch on
Housekeeping data enable every 20 seconds
Autotest 1 measurements 34
Calibration measurements
100 measurements Black Body
100 measurements Deep Space
100 measurements Internal Lamp
All measurements gain 0,0 – DTM17
Autotest 1 measurements 38
Test 5 Calibration Lamp 5x16 measurements
Autotest 1 measurements 33
Test 6 Calibration Lamp 10x210 measurements
Autotest 1 measurements 37

Test 5 Deep Space 5x16 measurements
Nadir Scanner 10 measurements
Test 1F 10 measurements
Test 5 Black Body 5x16 measurements
PFS switch off
File name NEV_PS002_2003_06_from_25d-23h-00m_to_26d-02h-30m.ifg

JUNE 26 NIGHT : 1 HOUR

Pfs switch on
Housekeeping data enable every 20 seconds
Secondary motor
Internal BB 10 measurements
Autotest 1 measurements 34
Primary motor speed 2500
Internal BB 10 measurements
Autotest 1 measurements 34
Secondary motor speed 2500
Internal BB 10 measurements
Autotest 1 measurements 34
PFS switch off
File name NEV_EXTRA1_2003_06_from_26d-17h-55m_to_26d-18h-55m.ifg

JUNE 27 NIGHT : 2 HOURS

Pfs switch on
Housekeeping data enable every 20 seconds
Primary motor speed 3000
Internal Calibration Lamp 10 measurements
Autotest 1 measurements 34
Primary motor speed 1500
Internal Calibration Lamp 10 measurements
Autotest 1 measurements 34
Primary motor speed 2000 control to LW laser
Internal Calibration Lamp 10 measurements
Autotest 1 measurements 34
Scanner to BB
Test 6 Black Body 21x10 measurements
PFS switch off
File name NEV_EXTRA2_SPEED-TEST_2003_06_from_27d-19h-00m_to_27d-20h-40m.ifg

JUNE 30 NIGHT : 4 HOURS ALL EXPERIMENTS TOGETHER.

Interference test all experiments (no Radar)
Pfs switch on
Housekeeping data enable every 20 seconds
Calibration measurements
    100 measurements Black Body

100 measurements Deep Space
100 measurements Internal Lamp
All measurements gain 0,0 – DTM17
In the measurement 280 we see a spike due to the cooler of Omega being switched off .
No other interference is seen.
Go to sleep. It has been sleeping for 24 hours. And it wake up well.
File name NEV_DRYEARTH_2003_06_from_30d-19h-00m_to_30d-20h-30mTEMP.ifg

JULY 1 NIGHT : 6 HOURS

PFS wake up
Autotest 1 measurements 34
DTM test N=10

2	10
4	10
5	10
6	10
7	10
8	10
18	10
27	10
28	10
9	10
10	10
15	10
16	10

All the DTM with FFT have not worked : the data are in DTM 28 .
Go to sleep. – start pericentre pass simulation .
Autotest 1 measurements 34
Calibration measurements
10 measurements Black Body
10 measurements Deep Space
10 measurements Internal Lamp
All measurements gain 0,0 – DTM17
500 measurements – taken on BB
Calibration measurements
10 measurements Black Body
10 measurements Deep Space
10 measurements Internal Lamp
All measurements gain 0,0 – DTM17
Autotest 1 measurements 34
Go to sleep
Wake up
Calibration measurements
200 measurements Black Body
200 measurements Deep Space
200 measurements Internal Lamp
All measurements gain 0,0 – DTM17 speed 2500
Go to sleep

JULY 11 NIGHT : 6 HOURS

Activity performed :
Switch on, unblock, initialisation.
Temperature SW detector set to 220 K. (never reached ?).
1-Autotest 34
Calbrations dtm 17, N=100, speed 2000
302-Autotest 34
Calibrations dtm 17, n=100, speed 3000
Temperature SW detector set to 250 K (never reached).
Scanner deep space
603-Autotest
Test 5 dtm 17, n=10
Calibration lamp
764-autotest
Test 5 dtm 17, n=10
Scanner bb
925-autotest
Test 5 dtm 17, n=10
Speed 2000
1086-Autotest
Calibrations dtm 17, n=100, speed 2000
Speed 3000
1387-Autotest
Calibrations dtm 17, n=100, speed 3000
Block pendulum
Off
File name NEV_PS005_2003_07_from_11d-17h-30m_to_11d-23h-00m.ifg

JULY 13 NIGHT 3 HOURS

It is star calibration, but something went wrong and the spacecraftwent into safe mode.
The data were recovered 2 days later.
File name : NEV_StarCalibrationmerd.ifg

JULY 22 PAYLOAD CHECKOUT

It was a check on the status of PFS after the MEX safe mode, and closing for ibernation.
File name : NEV_Check-Out_2003_07_from_22d-16h-00m_to_22d-18h-00m.ifg