PFM1/PFM3 Transmission Analysis

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Introduction

The purpose of this document is to attempt to determine whether a profile of the relative transmission as a function of wavenumber can be determined for the two paths through the SPIRE spectrometer. In addition, an analysis will be carried out to determine if the transmission profiles changed significantly between the PFM1 and PFM3 test campaigns.

Background

The underlying hypothesis in the analysis presented here is that a spectrum recorded by the SPIRE detectors, $B(\sigma)_{Measured}$, can be described as a linear combination of the spectra from the signals at the two input ports (the Telescope port and the SCAL port) with each input signal modified by the *overall* transmission for each path through the spectrometer, $Tr(\sigma)_{Telescope}$ and $Tr(\sigma)_{SCAL}$. Note that for the purposes of this analysis, the transmission terms include all sources of signal modifiers from the beamsplitters to the filters to the responsivity of the detectors and that the transmission terms for each port are not assumed to be identical. Based on this model of the SPIRE spectrometer, the recorded spectrum can be written as:

$$B(\sigma)_{measured} = Telescope\ Input(\sigma)Tr(\sigma)_{CBB} + SCAL\ Input(\sigma)Tr(\sigma)_{SCAL} \quad (1)$$

One configuration employed in the PFM1 and PFM3 test campaigns, and the configuration that is the focus of this analysis, had the Cold Blackbody (CBB) as the source at SPIRE's Telescope input port, while the SCAL emitter was the source at the SCAL input port. In this configuration, the overall measured spectrum can be written as:

$$B(\sigma)_{measured} = P(T_{CBB}, \sigma)\epsilon(\sigma)_{CBB} Tr(\sigma)_{CBB} + P(T_{SCAL}, \sigma)\epsilon(\sigma)_{SCAL} Tr(\sigma)_{SCAL} \quad (2)$$

where $P(T, \sigma)$ is the Planck function representing the emission of blackbody, and $\varepsilon(\sigma)$ is the emissivity of a given input source. Note that the second term on the RHS of the above equation may be expanded such that it includes a term for each of the SCAL sources (the 2% emitter, the 4% emitter, and the remainder of SCAL, emitting at 94%). Also, for the purposes of this analysis, the emissivities of the CBB and of the SCAL components are assumed to be independent of wavenumber.

Based on the above model, the difference between two measured spectra, $B(\sigma)_2$ and $B(\sigma)_1$, can be written as:

$$\begin{aligned} B(\sigma)_2 - B(\sigma)_1 = {} & P(T_{CBB2}, \sigma)\epsilon_{CBB} Tr_{CBB} + P(T_{SCAL2}, \sigma)\epsilon_{SCAL} Tr_{SCAL} - \\ & P(T_{CBB1}, \sigma)\epsilon_{CBB} Tr_{CBB} + P(T_{SCAL1}, \sigma)\epsilon_{SCAL} Tr_{SCAL} \end{aligned} \quad (3)$$

or

$$B(\sigma)_2 - B(\sigma)_1 = (P(T_{CBB2},\sigma) - P(T_{CBB1},\sigma))\epsilon_{CBB} Tr_{CBB} + (P(T_{SCAL2},\sigma) - P(T_{SCAL1},\sigma))\epsilon_{SCAL} Tr_{SCAL} \quad (4)$$

If, for example, the temperature of the SCAL components is the same for both observations, then the above equation reduces to:

$$B(\sigma)_2 - B(\sigma)_1 = (P(T_{CBB2},\sigma) - P(T_{CBB1},\sigma))\epsilon_{CBB} Tr_{CBB} \cancel{+ (P(T_{SCAL2},\sigma) - P(T_{SCAL1},\sigma))\epsilon_{SCAL} Tr_{SCAL}} \quad (5)$$

In this case, the overall transmission for radiation that travels the path from the CBB (Telescope) input port to the detectors can be found as:

$$Tr(\sigma)_{CBB} = \frac{B(\sigma)_2 - B(\sigma)_1}{(P(T_{CBB2},\sigma) - P(T_{CBB1},\sigma))\epsilon_{CBB}} \quad (6)$$

Similarly, for two observations with differing SCAL input temperatures and the same CBB input temperatures, the overall transmission for the SCAL path is given as:

$$Tr(\sigma)_{SCAL} = \frac{B(\sigma)_2 - B(\sigma)_1}{(P(T_{SCAL2},\sigma) - P(T_{SCAL1},\sigma))\epsilon_{SCAL}} \quad (7)$$

Analysis

The observations that are the focus of this analysis are given in Tables 1 and 2 below.

PFM1 Observations	***Temperatures (K)***			
	CBB	***SCAL***	***SCAL2***	***SCAL4***
pfm1_SMEC_HR_6K_Dark_0803_2036_2059	**6.5**	**4.98**	**4.77**	**4.77**
pfm1_SMEC_HR_7.5K_0803_2309_2329	7.5	5.00	4.85	4.79
pfm1_SMEC_HR_9K_0803_1733_1754	9.5	4.98	4.76	4.75
pfm1_SMEC_HR_11K_0803_1808_1829	11.5	4.98	4.76	4.75
pfm1_SMEC_HR_13K_0803_1946_1956	13.0	4.98	4.76	4.75
pfm1_SMEC_LR_SCAL2_0.22_0903_2012_2025	6.5	4.97	8.89	4.76
pfm1_SMEC_LR_SCAL2_0.45_0903_2135_2141	6.5	4.98	15.67	4.79
pfm1_SMEC_LR_SCAL2_0.70_0903_2231_2240	6.5	5.00	23.18	4.83

Table 1: PFM1 observations analyzed for this study.

NB: Entries in **red** denote values for which it was not possible to implicitly calculate the new converted temperature, but based on the similarity of the raw telemetry for these observations and others from 08 March 2005, the converted temperatures from the pfm1_SMEC_HR_13K_0803_1946_1956 observation were used for these observations. Also, The SCAL temperatures for the PFM1 observations are based on the new calibration curves. Unlike the temperatures derived from the original calibration curves, the three SCAL temperatures appear to be in good agreement when SCAL is off.

PFM3 Observations	*Temperatures (K)*			
	CBB	***SCAL***	***SCAL2***	***SCAL4***
3000E516_82030001	**6.33**	**4.66**	**4.64**	**4.65**
3000E512_82030001	8.07	4.66	4.63	4.64
3000E50F_82030001	8.87	4.66	4.63	4.64
3000E50A_82030001	10.92	4.66	4.63	4.64
3000E5C7_82030001	6.31	4.66	Variable	4.66

Table 3: PFM3 observations analyzed for this study.

NB: The 3000E5C7_82030001 observation consisted of 20 low-resolution scans. While the CBB, SCAL, and SCAL4 temperatures were held constant, the temperature of SCAL2 decreased gradually over the course of the observation. For this reason, each scan is treated as a separate observation, with the SCAL2 temperature for that observation given by its average for that scan.

These observations fall into four categories:

1. PFM1, CBB variable, SCAL2 constant:
   - pfm1_SMEC_HR_6K_Dark_0803_2036_2059 (**reference**)
   - pfm1_SMEC_HR_7.5K_0803_2309_2329
   - pfm1_SMEC_HR_9K_0803_1733_1754
   - pfm1_SMEC_HR_11K_0803_1808_1829
   - pfm1_SMEC_HR_13K_0803_1946_1956
2. PFM1, CBB constant, SCAL2 variable:
   - pfm1_SMEC_HR_6K_Dark_0803_2036_2059 (**reference**)
   - pfm1_SMEC_LR_SCAL2_0.22_0903_2012_2025
   - pfm1_SMEC_LR_SCAL2_0.45_0903_2135_2141
   - pfm1_SMEC_LR_SCAL2_0.70_0903_2231_2240
3. PFM3, CBB variable, SCAL2 constant:
   - 3000E516_82030001 (**reference**)
   - 3000E512_82030001
   - 3000E50F_82030001
   - 3000E50A_82030001
4. PFM3, CBB constant, SCAL2 variable:
   - 3000E5C7_82030001 (**reference**: SCAN 01 and SCAN 02)

The spectra from the observations highlighted in **bold** were used as the reference observations. The remaining observations in a given set were the “hot” observations. In each case, only the low- or medium resolution ($\Delta\sigma$~$0.4cm^{-1}$ and $\Delta\sigma$~$0.2cm^{-1}$, respectively) portion of the measured interferogram was considered.

Measured Spectra

The first set of plots (Figures 1-4) show the measured spectra for each observation. Note that while the spectra for only one pixel per array are shown here, this analysis was carried out for every active pixel for each test campaign. The spectra for the remaining pixels are shown in the attached files (pfm1_CBB_spectra.pdf, pfm1_SCAL_spectra.pdf, pfm3_CBB_spectra.pdf, and pfm3_SCAL_spectra.pdf).

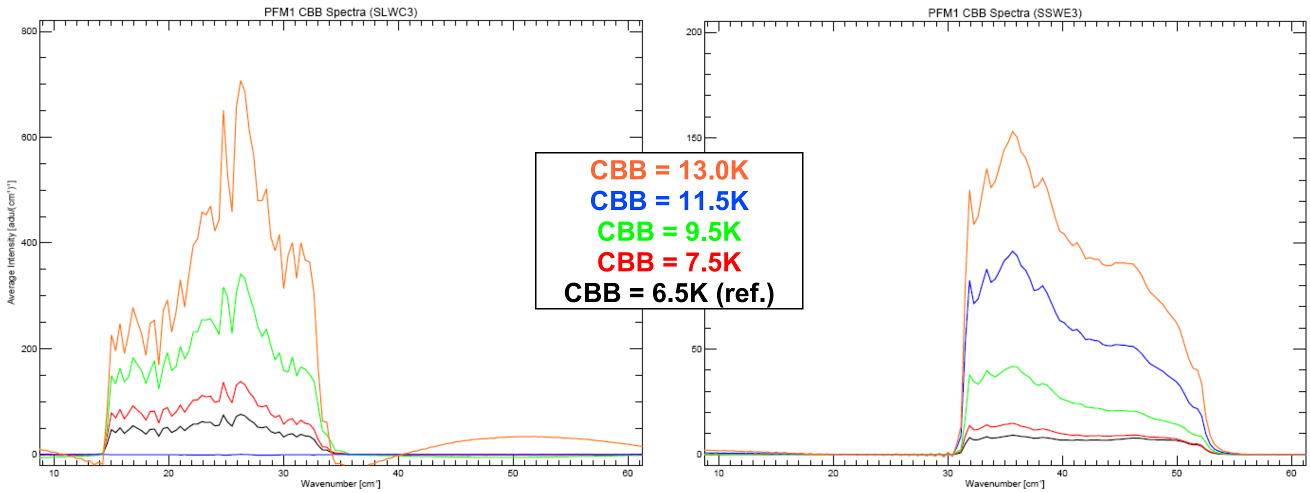

Figure 1: PFM1 Measured Spectra; CBB variable, SCAL2 constant. The left panel features pixel SLWC3, while the right panel shows pixel SSWE3. The CBB temperatures are listed in the legend.

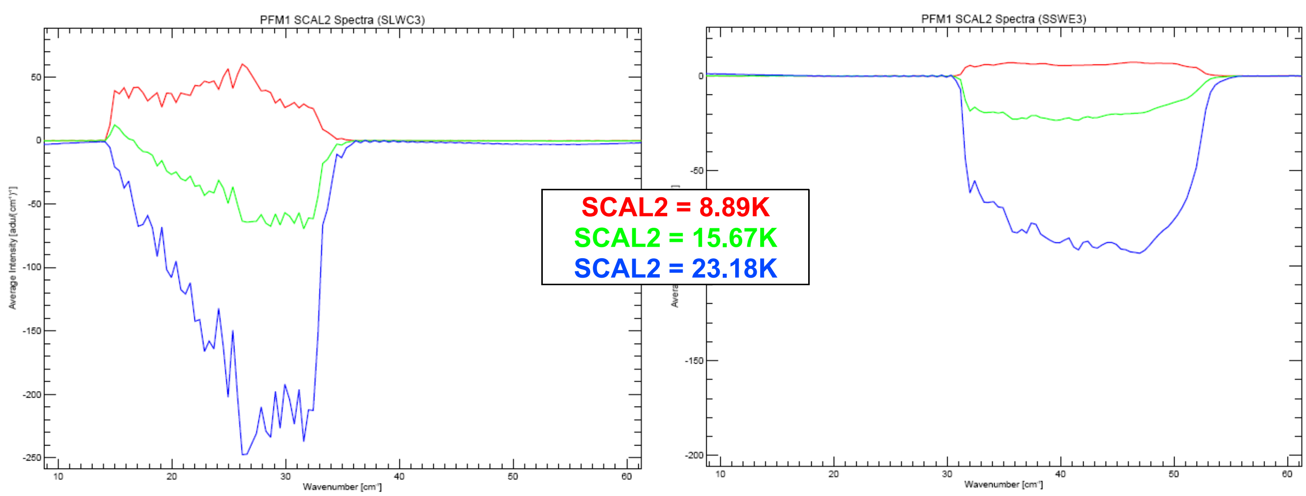

Figure 2: PFM1 Measured Spectra; CBB constant, SCAL2 variable. The left panel features pixel SLWC3, while the right panel shows pixel SSWE3. The SCAL2 temperatures are listed in the legend.

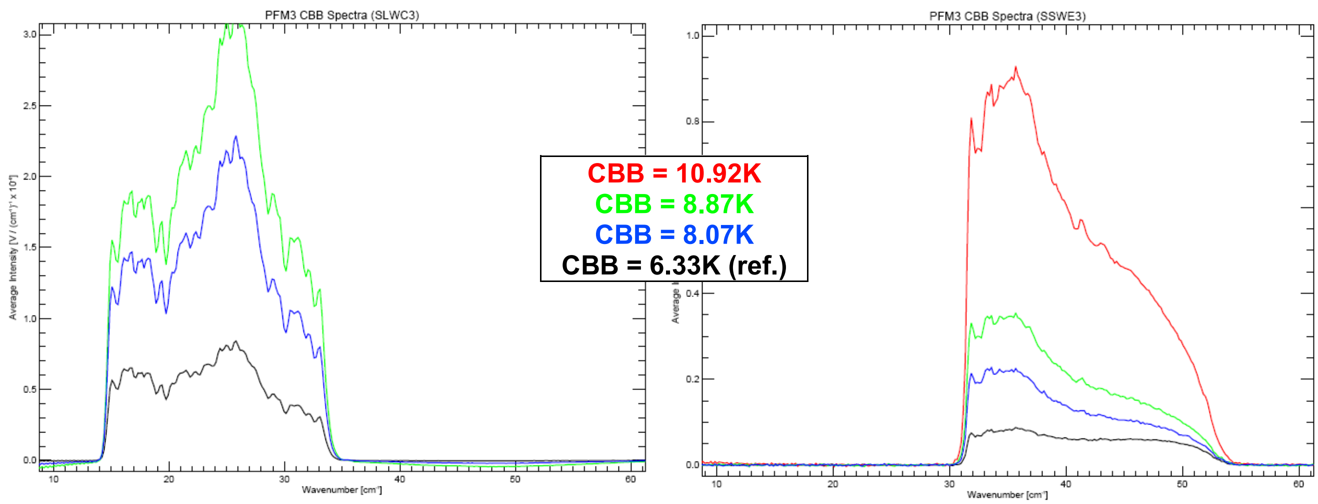

Figure 3: PFM3 Measured Spectra; CBB variable, SCAL2 constant. The left panel features pixel SLWC3, while the right panel shows pixel SSWE3. The CBB temperatures are listed in the legend. The measured spectrum for CBB=10.92K was omitted from the SLWC3 plot because this observation was saturated.

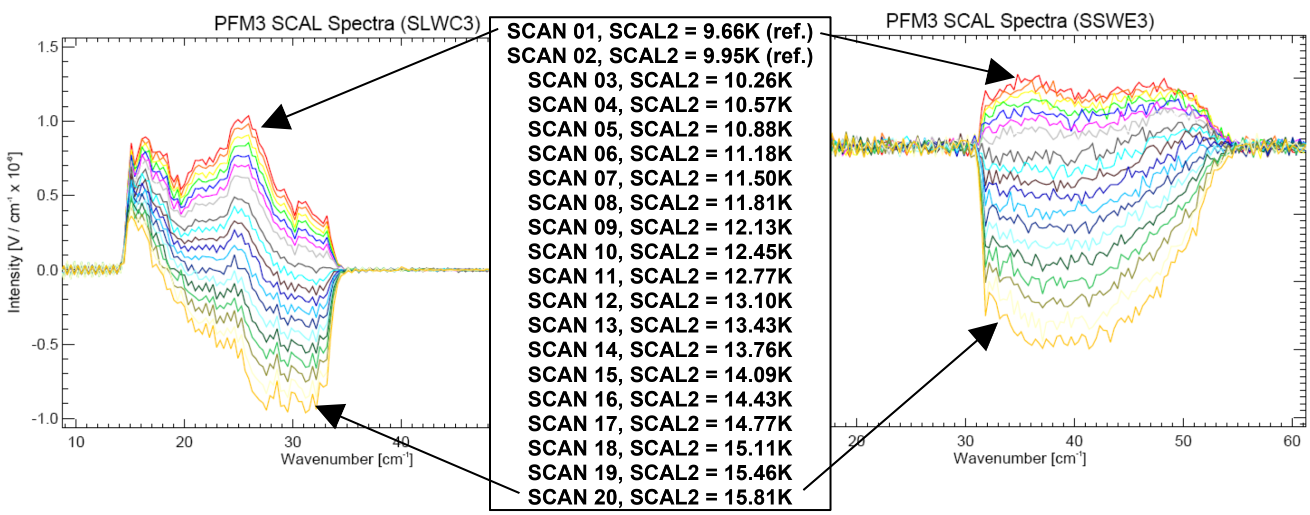

Figure 4: PFM3 Measured Spectra; CBB constant, SCAL2 variable. The left panel features pixel SLWC3, while the right panel shows pixel SSWE3. The SCAL2 temperatures are listed in the legend.

As can be seen from the curves in Figures 1-4, the measured spectra qualitatively follow the expected pattern with increasing CBB temperatures resulting in spectra that are more positive, while increasing SCAL2 temperatures result in spectra that are more negative.

Derived Transmission

Next, a reference spectrum was chosen for each group of observations. The difference between the spectra of the other observations in a group ("hot" observations) and this reference spectrum were then computed. As per equations 6 and 7, a simple model of the input source was then divided out of the difference spectrum in order to determine the overall transmission of a given path through the SPIRE spectrometer[1].

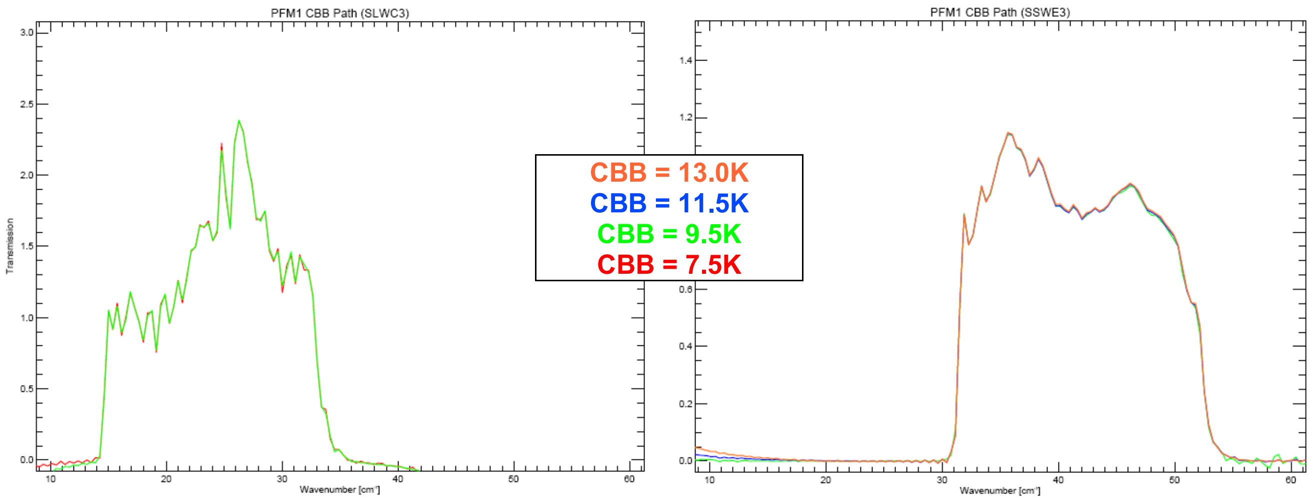

Figure 5: Derived transmission for the CBB path, PFM1 test campaign. The left panel features pixel SLWC3, while the right panel shows pixel SSWE3. The reference spectrum in each case was the observation where CBB temperature was 6.5K. The legend lists the “hot” CBB temperatures for each difference spectrum. The derived CBB path transmissions for “hot” observations with CBB=11.5K and CBB=13.0K are not show for the SLW pixel because these hot observations were saturated.

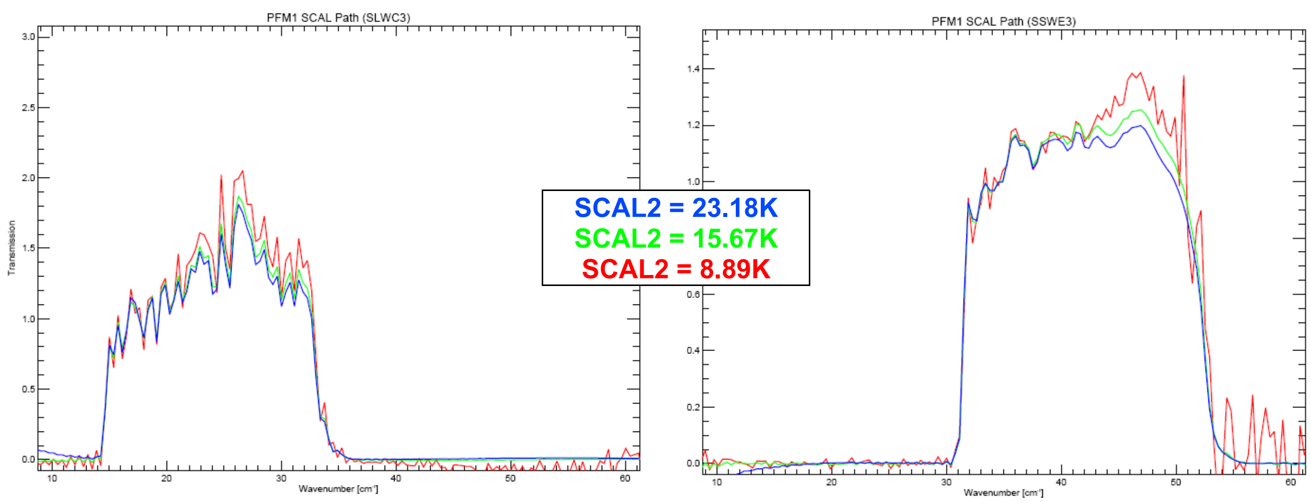

Figure 6: Derived transmission for the SCAL path, PFM1 test campaign. The left panel features pixel SLWC3, while the right panel shows pixel SSWE3. The reference spectrum in each case was the observation where SCAL2 temperature was 4.77K. The legend lists the “hot” SCAL2 temperatures for each difference spectrum.

[1] The transmission curves shown in Figures 5-8, were each multiplied by a scaling factor to make the transmission at 18cm^{-1} for SLW and 35cm^{-1} for SSW equal to one. This was done in order to allow for a direct comparison between the transmission curves from PFM1 and PFM3. The curves were normalized by first finding the average “transmission” over the wavenumber range of 16-19cm^{-1} for SLW and 32.5 to 35.5cm^{-1} for SSW. These average values were the scaling factors by which the actual transmission was divided.

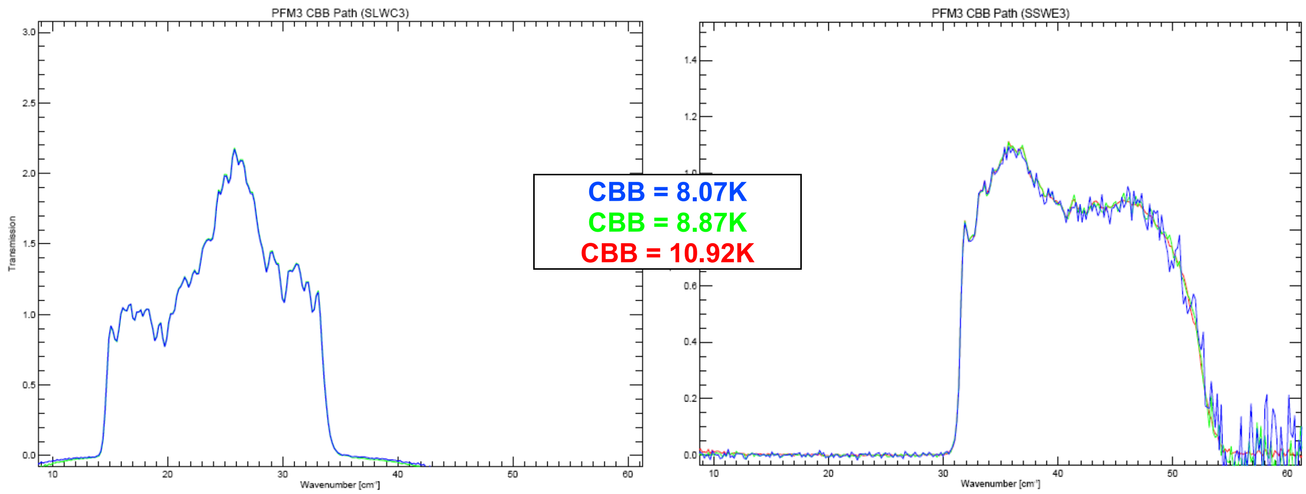

Figure 7: Derived transmission for the CBB path, PFM3 test campaign. The left panel features pixel SLWC3, while the right panel shows pixel SSWE3. The reference spectrum in each case was the observation where CBB temperature was 6.33K. The legend lists the "hot" CBB temperatures for each difference spectrum. The derived CBB path transmissions for "hot" observations with CBB=10.92K is not show for the SLW pixel because this hot observations was saturated.

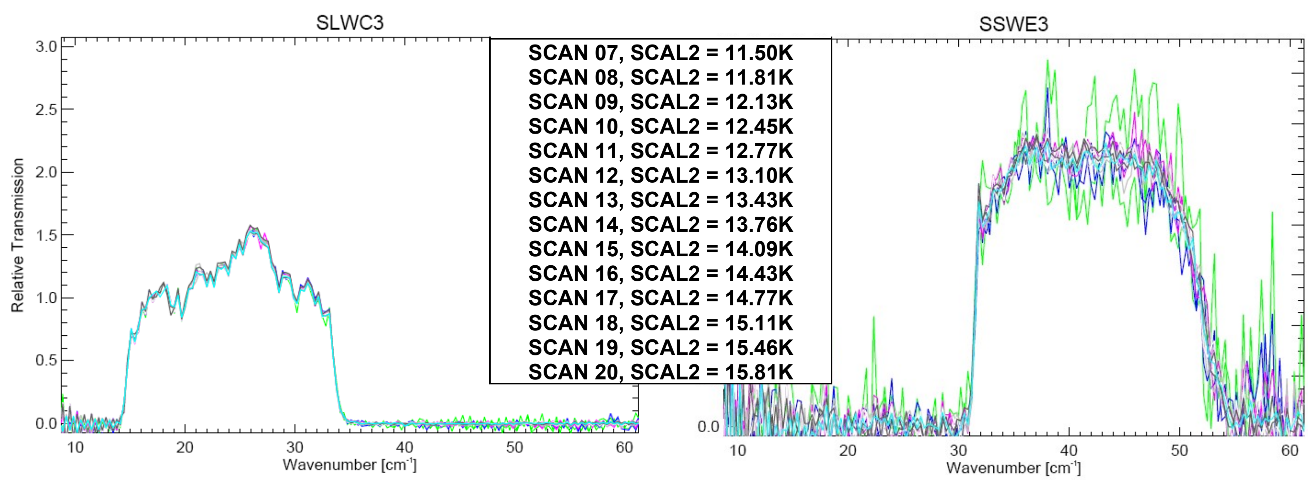

Figure 8: Derived transmission for the SCAL path, PFM3 test campaign. The left panel features pixel SLWC3, while the right panel shows pixel SSWE3. The reference spectrum for odd-numbered hot scans was SCAN 01, while the reference for even-numbered hot scans was SCAN02. The legend lists the "hot" SCAL2 temperatures for each difference spectrum. The SCAL transmission as derived by hot scans whose temperature was close to the reference temperature (SCANs 03, 04, 05, and 06) were omitted for clarity as the small difference between these "hot" and reference temperatures resulted in particularly noisy transmission curves.

As for the first set of plots, this analysis was carried out not just for the pixels shown but for all active pixels. The plots of the "transmission" for all pixels for each category can be found in the files pfm1_CBB_transmission_scaled.pdf, pfm1_SCAL_transmission_scaled2.pdf, pfm3_CBB_transmission_scaled.pdf, and pfm3_SCAL_transmission_scaled2.pdf).

With the exception of the SCAL path from PFM1, the curves of the derived transmission show a large degree of self-consistency. It is possible that the inconsistency of the SCAL curves for PFM1 is due to an incorrect calibration of the SCAL thermometers even though these curves are based on the latest calibration curves. This is one aspect that requires further investigation.

PFM1/PFM3 Comparison

Finally, the transmission curves as derived from the PFM1 and PFM3 test data were compared. For clarity and owing to the consistency between the curves shown in Figures 5, 7, and 8, the curves for the CBB Path from PFM1 and for both paths for PFM3 were averaged together. Figures 9 and 10 show a comparison between these average transmission curves. The comparisons of the transmission for all of the pixels can be found in: pfm1_pfm3_CBB_transmission_scaled.pdf and pfm1_pfm3_SCAL_transmission_scaled.pdf).

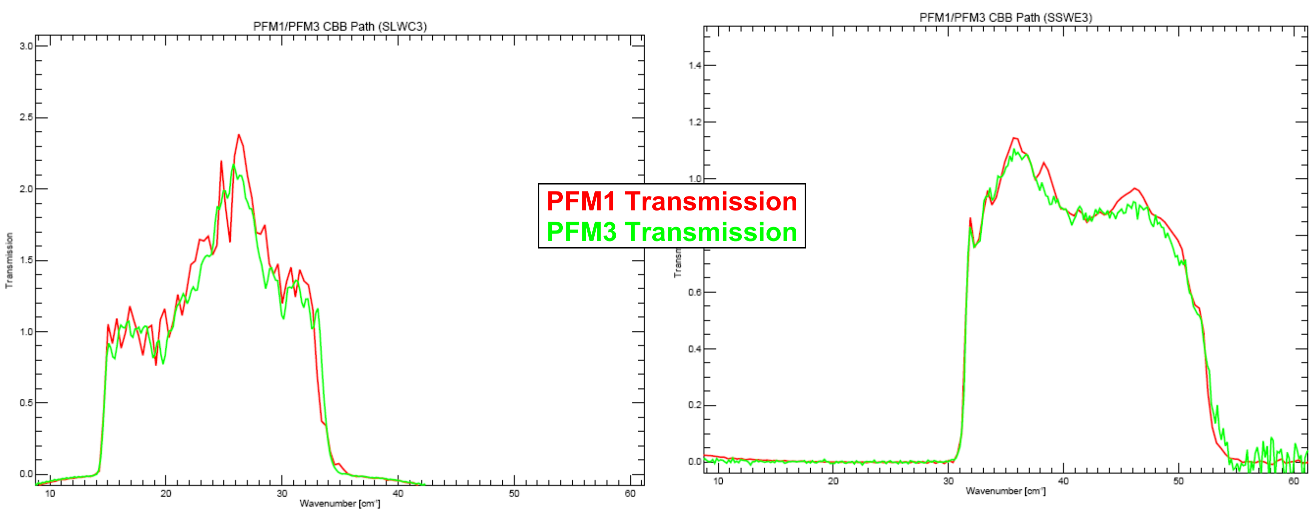

Figure 9: Comparison of the transmission for the CBB path as derived from the PFM1 and PFM3 data. In each case the non-saturated transmission curves for each test campaign were averaged together.

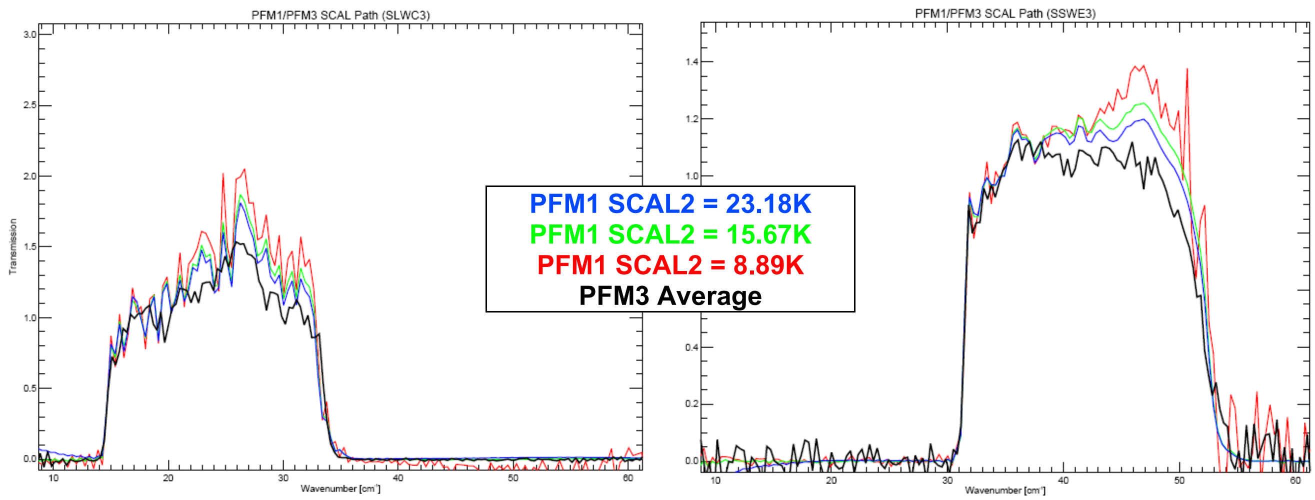

Figure 10: Comparison of the transmission for the CBB path as derived from the PFM1 and PFM3 data. In each case the non-saturated transmission curves for each test campaign were averaged together.

Discussion

1. Based on the plots shown here (Figure 9), the average transmission curves for the CBB Path as calculated from the PFM1 and PFM3 data appear to good agreement. Upon inspection of the other SLW and SSW pixels, slight differences in the calculated CBB path transmissions can be seen, in particular for the SLW pixels. One possible explanation for for this is that the spectral resolutions for each set are not equal. The spectral resolution for the PFM1 data is ~0.4cm^{-1}, while that for PFM3 is is ~0.2cm^{-1}.
2. The PFM1 transmission curves for the SCAL port still do not agree with one another even with the updated temperature calibrations. As mentioned above, this requires further attention. One possibility is that the calibration curves are only well defined for certain temperature regimes. If this is the case, this would have had a greater effect on the PFM1 data since the hot and references observations would have spanned different regimes, whereas for the PFM3 data, the hot and reference spectra were all confined to one regime.
3. Upon inspection of the spectra from the SCAL variable observation from PFM3 (ID = 3000E5C7_82030001), it is clear that for a for a given set of CBB and SCAL temperatures, the amount of spectral nulling is dependent on the location of the (see pfm3_SCAL_spectra.pdf). In particular, refer to the plots in Figure 11, which show the spectra for pixels SLWA2 and SLWE2 (i.e. opposite ends of SLW). Note that for a given CBB and SCAL2 temperature combination, (i.e. the top-most red curves or the bottom-most yellow curves), the distribution of the spectral energy between is noticeably different for the two pixels. In all cases, pixel SLWA2 appears to “see” more energy from SCAL than does pixel SLWE2. This is indicated by the fact that, in general, the spectra for SLWA2 are more negative that those for SLWE2. One possible cause of this difference is a misalignment or mis-positioning of SCAL, which may lead to some pixels “seeing” more of the SCAL2 (and likely SCAL4) emitter than other pixels.

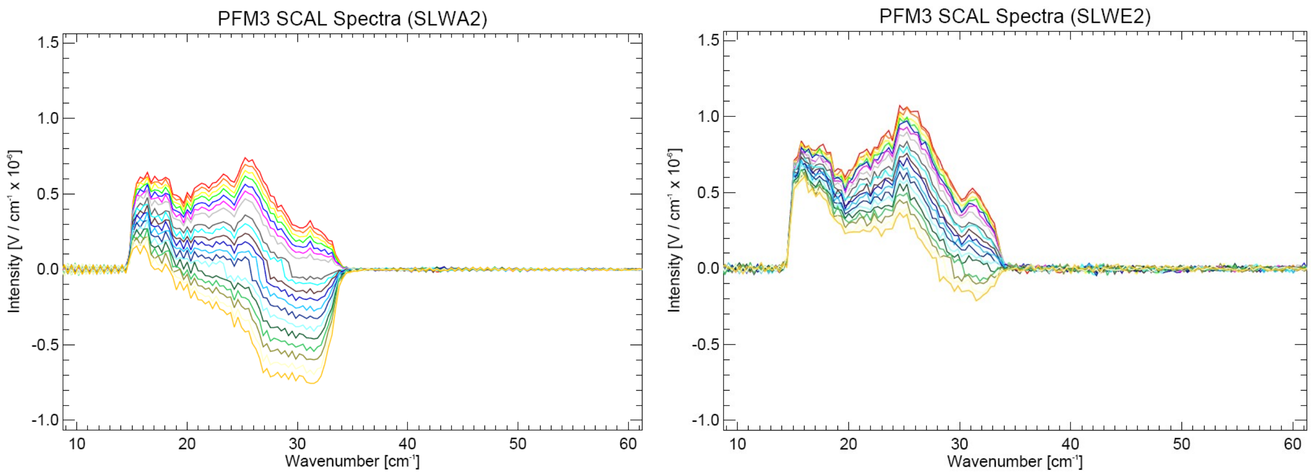

Figure 4: PFM3 Measured Spectra; CBB constant, SCAL2 variable. The left panel features pixel SLWA2, while the right panel shows pixel SLWE2.