SPIRE Science Verification Review

RAL

January 26, 27 2005

Instrument Throughput

Document Number: SPIRE-RAL-REP-002564

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17 Jan 2006

Contents

1. Introduction and scope

This report details the results on the measurement of the SPIRE photometer and spectrometer passband measurements and the overall instrument transmission. These results are based on the analysis of data from PFMI and PFMII test campaigns.

2. List of requirements that the test programme was designed to evaluate

Requirement Name	Description	Requirement
IRD-OPTP-R05	Throughput	The throughput of the photometer mirrors, filters, dichroics and baffles shall be greater than 0.27 over the instrument waveband. This includes losses due to manufacturing defects; surface finish and alignment tolerances.
IRD-OPTP-R07	Out of band radiation	The end to end filtering of the photometer shall control the out of band radiation to be no more than 10^{-3} for 40 cm-1 to 200 cm-1 10^{-6} for 200 cm-1 to 1000 cm-1 10^{-9} for 1000 cm-1 to 100000 cm-1 of the in-band telescope background radiation.
IRD-OPTS-R05	Theoretical throughput	The theoretical throughput of the spectrometer mirrors; filters; beam splitters and baffles shall be greater than 0.2 over the total instrument waveband including all losses due to manufacturing defects; surface finish and alignment tolerances.
IRD-DETP-R08	Spectral response	≥ 90% at the nominal edge frequencies of the appropriate passband
IRD-OPTS-R08	Out of band radiation	The end-to-end filtering of the spectrometer shall control the out of band radiation to be no more than 10^{-3} for 40 cm-1 to 200 cm-1 10^{-6} for 200 cm-1 to 1000 cm-1 10^{-9} for 1000 cm-1 to 100000 cm-1 of the in band telescope background radiation.

3. Test results and conclusions

3.1 List of tests carried out and tests still to be done

Two basic types of test were carried out separately on the photometer and spectrometer sides of the instruments these are described in outline here.

Spectral passband measurements:

These were taken using the internal cold black body for the spectrometer – see SPIRE-RAL-REP-002566 for a report on the spectrometer bandpasses

For the photometer the spectral passband was measured using the external FTS and the hot black body source. We report on these measurements here – details of the analysis are given in the appendices.

Transmission and throughput:

The total transmission of the instrument is measured using a cold black body (CBB) that fills the instrument field of view. This can be varied in temperature and has a surface made of a polymer/crystal matrix measured to be >0.98 absorbing. By taking V-I curves with the CBB set to a series of temperatures the absorbed power onto the bolometers can be measured and compared to the expected power using a set of model assumptions for the instrument. This is discussed in section 3.3

Tests that have not been fully carried out are those concerned with testing the out of band rejection of the instrument and therefore neither IRD-OPTP-R07 or IRD-OPTS-R08 on the out of band rejection are addressed in this note although there is good evidence from the individual component measurements that this should not be a significant problem.

For a complete list of the tests carried out and the operational parameters see the test team website at http://scott1.bnsc.rl.ac.uk:8080/hcss/test_area/index.htm

3.2 Subsystem requirements tested at instrument level and their verification status

IRD-DETP-R08 Detector Bandpass: The photometer requirements as listed in the Detector Subsystem Specification Document (RD1) are:

λ_b	**μm**	250	363	517
Design $\lambda_o/\Delta\lambda$		3.00	3.18	3.00
λ_L **(50% points)**	**μm**	208.3 +/- 2.1	306.0 +/- 3.1	430.8 +/- 4.3
λ_U	**μm**	291.7 +/- 8.5	420.0 +/- 12.3	603.2 +/- 17.6
$\lambda_o/\Delta\lambda$		3.00 +/- 0.39	3.18 +/- 0.45	3.00 +/- 0.39

The pixels measured and their measured effective band centre wavelengths and 50% band edges are given in appendices 7.1 and 7.2. Here we summarise the results

PLW:

Most pixel have a short wavelength cutoff slightly lower than the requirement however they all meet the bandpass, long wavelength cutoff, and resolving power requirements. An example of a typical PLW bandpass spectrum is shown in figure 3.2-1. Note in this figure and all subsequent the λ^2 dependence due to the instrument étendue has not been removed. The bandpass spectrum displayed is therefore not exactly that of the filters alone.

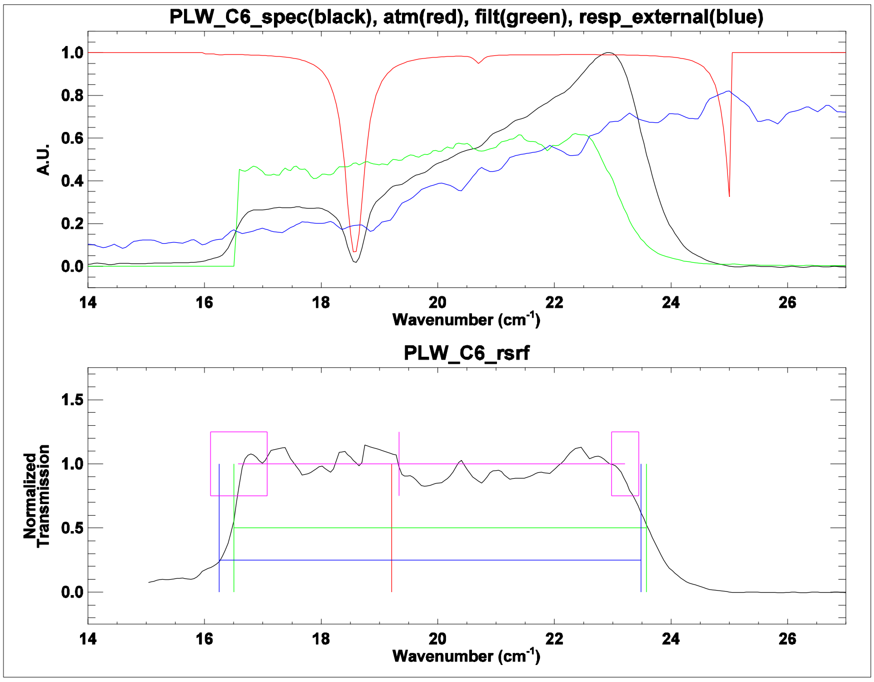


Figure 3.2-1: Spectral bandpass for PLW shown as product of the filters and the étendue. The upper plot shows the measured spectrum (black), the atmospheric transmission (red), external calibration curve (blue), and filter calibration data (green). The lower plot shows the rsrf (black), band centre (red), bandpass and band edges at the 50% points (green) The specification bandpass and band edges with quoted tolerances are shown in pink.

PMW

All of the measured PMW pixels have bandpasses and band edges within specification. A sample plot of the PMW bandpass spectrum is shown in figure 3.2-2.

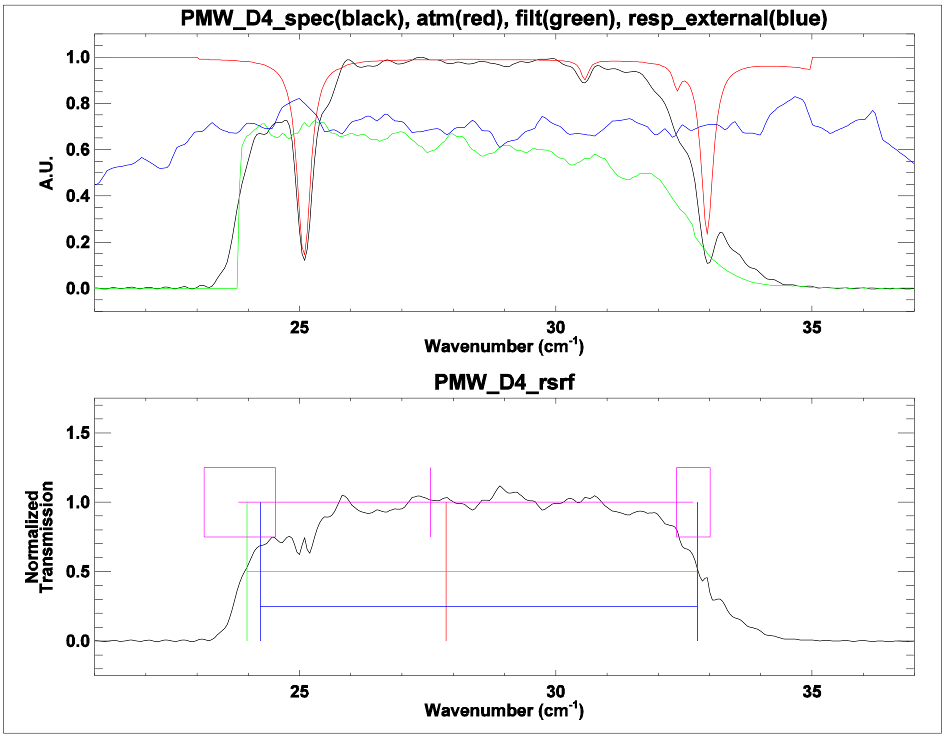


Figure 3.2-2: Spectral bandpass for PMW – see caption on figure 3.2-1 for explanation

PSW

A typical PSW bandpass spectrum is shown below. It is important to note that there is significant atmospheric absorption saturation within this band and artefacts are expected in the atmospheric removal due to division by zero and imperfect fit. The data processing attempts to minimize these errors however does not completely eliminate them.

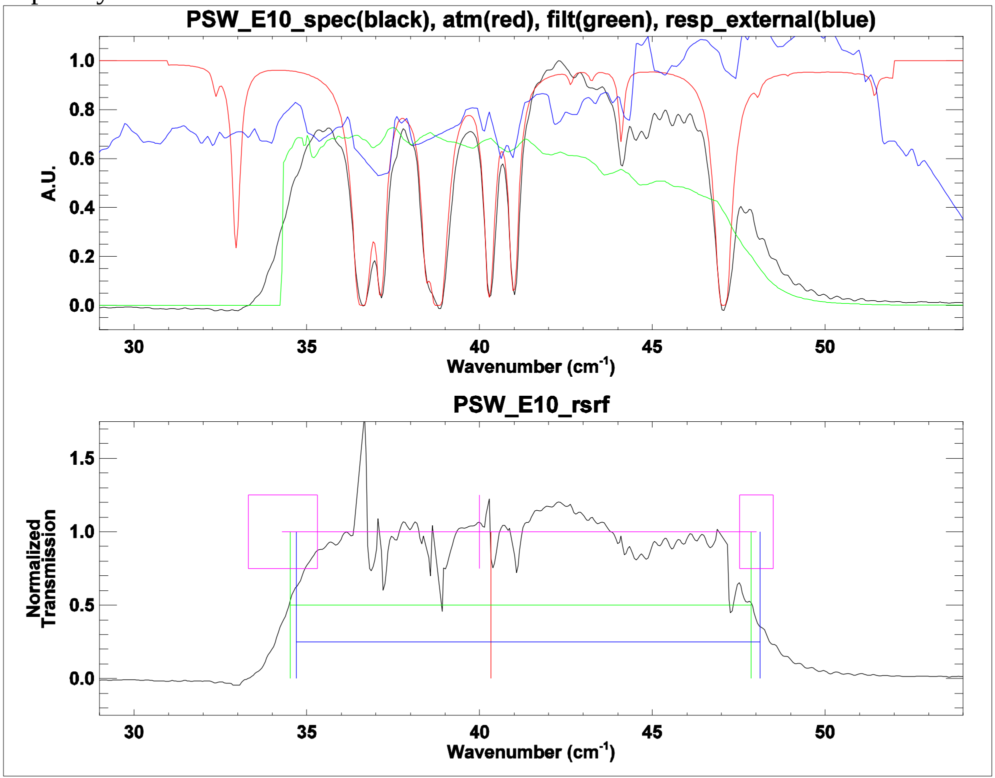


Figure 3.2-2: Spectral bandpass for PSW – see caption on figure 3.2-1 for explanation

3.3 Instrument-level requirements and their verification status.

IRD-OPTP-R05: Throughput

The throughput of the photometer mirrors, filters, dichroics and baffles shall be greater than 0.27 over the instrument waveband. This includes losses due to manufacturing defects; surface finish and alignment tolerances.

We can test the total throughput of the system by comparing the power absorbed by the detectors to that expected taking into account our knowledge of the instrument performance as measured or estimated from measurements of the individual components and theoretical expectations – *viz.:*

Parameter	Where derived from	Value
Instrument spectral bandpass	Measurements of individual filters and feedhorn specification	See figure 3.3-1 below
Detector optical efficiency	Taken from the BDA EIDP	Varies
Etendue (AΩ)	Theoretical expected for single mode	λ^2
Expected cold stop efficiency	Optical model	0.84
Loss due the hole in the BSM for PCAL	Metrology	0.95
Loss due to absorption and scattering from the mirrors	Estimate	0.99
Cold black body Emissivity	Estimate	1.0

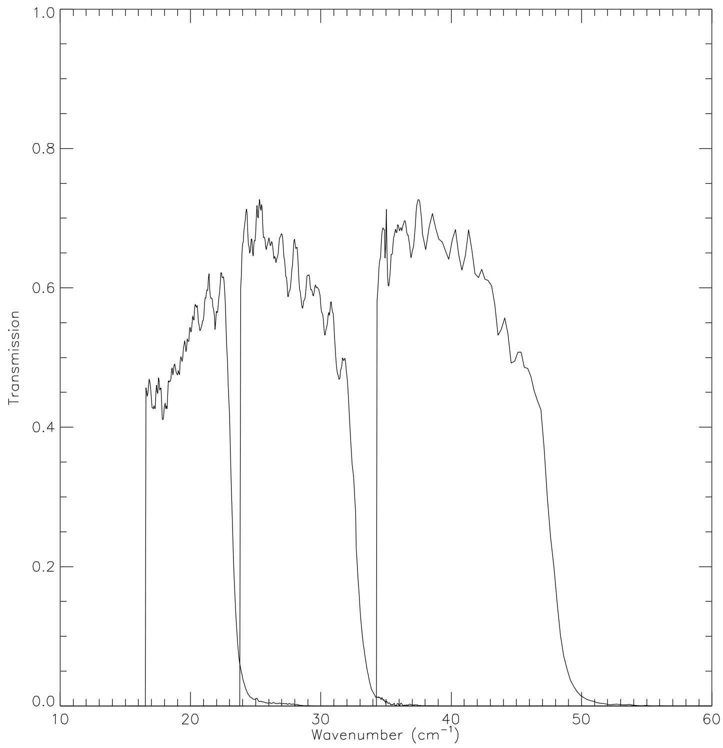


Figure 3.3-1: Expected instrument bandpass from the three photometer bands taken from filter profiles supplied with their EIDPs.

Using load curves taken with the CBB at 6.4 K and at 13 K we can measure the temperature rise and absorbed power in the detectors using the detector characteristics supplied in the EIDPs. Using the parameters in table 1 we integrate over the black body function to derive the expected absorbed power. The ratio of the measured and expected should be 1 if there are no unaccounted losses in the instrument.

As a guide the expected transmission taking an average filter transmission value and not including the feedhorn efficiency, is

0.37 – PLW
0.44 - PMW
0.48 - PSW

The estimated overall efficiency for the three arrays are presented in a graphical form in figures 3-2-2 for the case of where we compared the load with the CBB set at 6.4 K (minimum temperature we can reach) and 13.168 K. To estimate the true transmission efficiency we can multiply the expected transmission given above by the figures for the deficits shown by the dotted lines in the figures - these are ~0.9, 0.77, 0.85 respectively for PLW, PMW and PSW, giving ~0.33, 0.34 and 0.41. These are the maximum figures and as we see from the plots there are some gradients across the arrays.

The requirement of 0.27 is met except in the case of PMW which has more severe problems as discussed below.

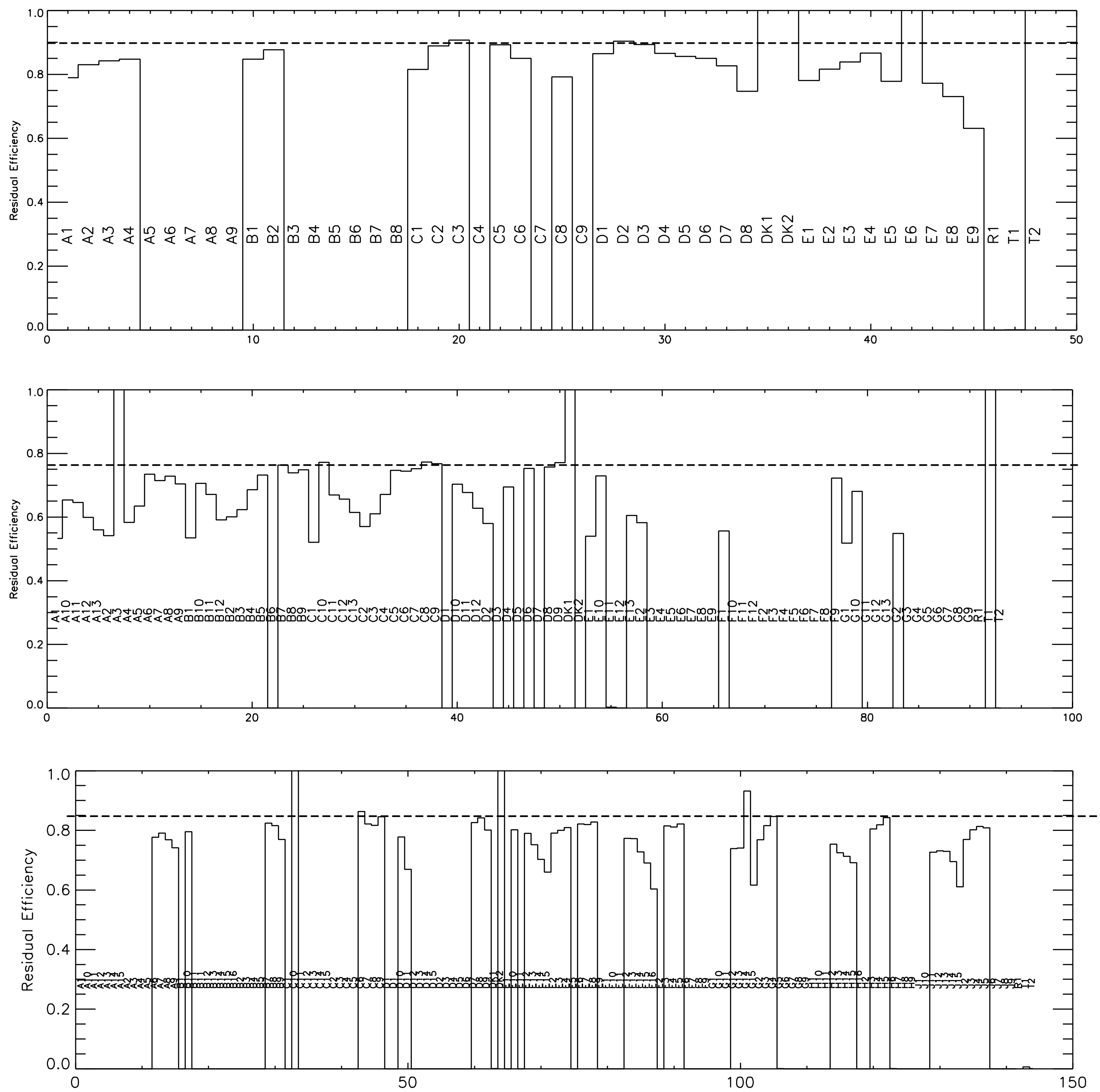


Figure 3.3-2: Ratio between measured and expected absorbed power onto the bolometers for PLW, PMW and PSW – top, middle and bottom respectively – taken from a comparison between the absorbed power with the CBB at 6.4 and 13.168 K.

IRD-OPTS-R05: Throughput

The theoretical throughput of the spectrometer mirrors; filters; beam splitters and baffles shall be greater than 0.2 over the total instrument waveband including all losses due to manufacturing defects; surface finish and alignment tolerances.

The same procedure as used for the photometer was carried out on the spectrometer during PFM1 testing. The bandpass and throughput assumptions are given here:

Parameter	Where derived from	Value
Instrument spectral bandpass	Measurements of individual filters and feedhorn specification	See figure 3.3-3 below
Detector optical efficiency	Taken from the BDA EIDP	Varies
Etendue (AΩ)	Theoretical expected for single mode	λ^2
Expected cold stop efficiency	Optical model	0.84
Loss due the hole in the BSM for PCAL	Metrology	0.95
Loss due to absorption and scattering from the mirrors	Estimate	0.99
Reflectivity of the alochromed roof top mirror (2 surfaces)	Measured warm – this is a lower limit	0.81
Cold black body Emissivity	Estimate	1.0

Additionally we assume that only 50% of the power is seen as the SMEC was always set away from ZPD. In a similar manner to the photometer we can estimate the total transmission of the spectrometer assuming 11 mirrors and taking the beam splitters in both reflection and transmission (i.e. 2RT or R^2+T^2) but not including the 50% for not being a ZPD, to be about 0.17. It is not clear whether the requirement includes the double pass through the beam splitters. If so then it is not met even before the instrument test results are considered.

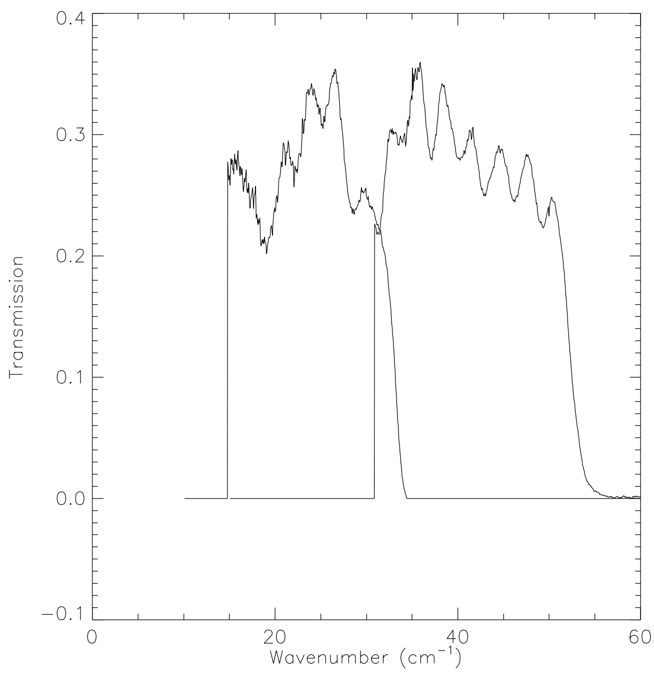
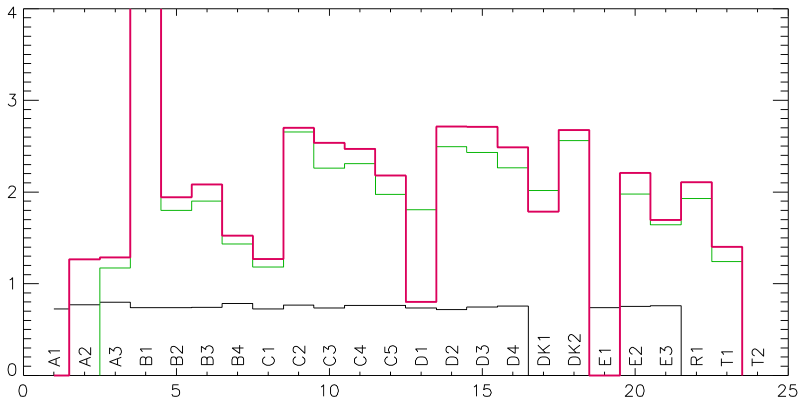


Figure3.3-3: Spectral bandpass for the spectrometer channels based on individually measured filter and beam splitter measurements and specified detector waveguide cut offs.

To evaluate the transmission efficiency the CBB was set to 6.4 K and 15.5 K and the increase absorbed power calculated from a comparison of load curves. Figure 3.3-4 presented to derived transmission efficiencies for the two spectrometer arrays. We can see the efficiency is greater than 1 for almost all detectors!



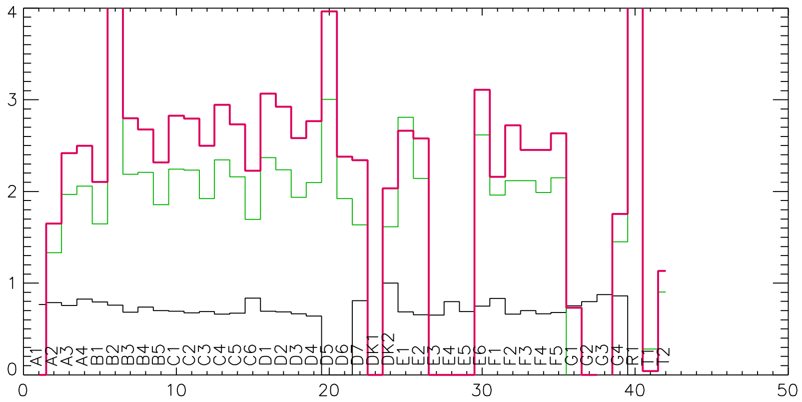


Figure 3.3-4: Ratio between measured and expected absorbed power onto the bolometers for SLW and SSW – top and bottom respectively – taken from a comparison between the absorbed power with the CBB at 6.4 and 15.5 K. As there is an obvious discrepancy here the absorbed power was derived both from a comparison of the load curves (green) and by using the increase in temperature and the derived thermal conductance (red). The reasonable agreement between the two methods gives us confidence that there is no serious error in the calculation. For information the JPL derived pixel optical efficiency is shown in black.

Two possibilities present themselves for this apparently non-physical result:

1. The model transmission has taken into account too many factors of 50% - this explains some of the problem but not all
2. The feedhorns are not single moded for a substantial fraction of the pass band. That this is certainly true is apparent when look at the measured band pass spectrum expressed as the ratio of the power observed to that expected from a single moded instrument, That is some measure of the degree of "over moding" at a particular wavelength. This is shown for the case of the CBB at 13 K in figure 3.3-5

The second explanation seems plausible for SLW but doesn't seem to be entirely correct for SSW where the degree of over-moding is less and confined to the smaller wavelength range.

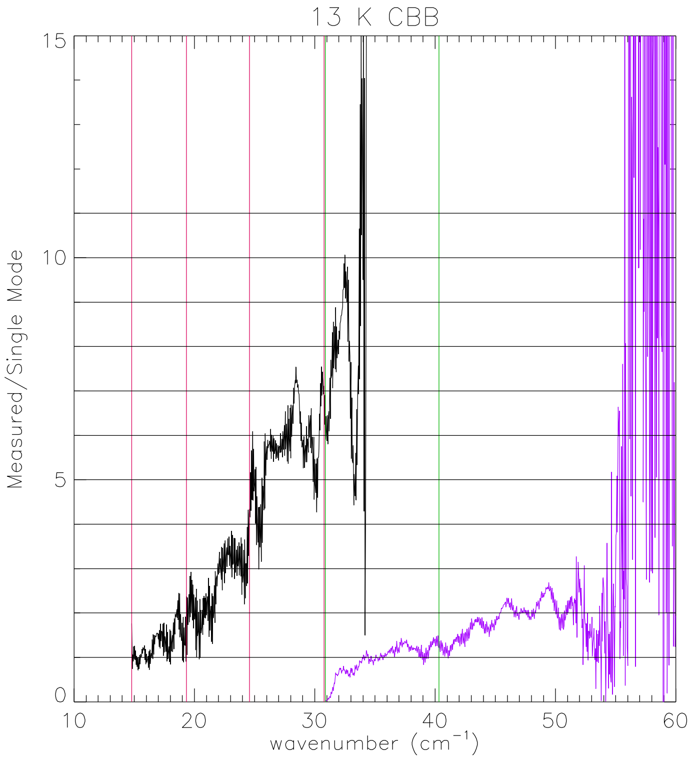


Figure 3.3-5: Plot of the measured spectrum divided by the expected spectrum generated from the transmission profiles of the filters, a black body emission spectrum at 13 K and a throughput assumption of λ^2. The vertical lines are the edges of the modes from RD1 and the horizontal lines are integer tick marks to guide the eye. The spectra were approximately normalised at the low frequency end of each detector range. The pixels used were SLW C3 and SSW D4 – the central pixel in each case.

4. Open Issues and Anomalies

Measurements of the instrument level out of band rejection must be systematically carried out during PFM3 using the laser to check for spectral leaks.

The short wavelength PLW band edges measured do not appear to lie within the specified boundary. Many fall very close the required boundary, but not within the specified tolerance of it.

It is important to note that the external calibration curve for the TFTS and Telescope simulator was only measured using one blackbody temperature (1200C) and it is unknown whether this curve will remain accurate for other temperatures. This may effect the quality of the spectral bandpass measurements and it is recommended that the measurements are repeated at other HBB temperatures.

It is not possible at this time to understand the transmission of the spectrometer or whether the detailed shape of the spectral bandpass is as expected. This is a major anomaly and both testing and further data analysis is required to urgently address this problem. Analysis of the coupling of the detectors to SCAL carried out in a similar manner to reported here has so far proved inconclusive and further investigations are required.

5. Recommendations for further data analysis and test

Spectrometer transmission efficiency and passband

Priority must be given to understanding the spectrometer spectral performance and coupling efficiency to the background and, in particular SCAL. Data exist for the initial investigation but higher temperatures of SCAL must be used during PFM3 in order to fully evaluate the spectrometer performance. This was not possible during PFM2 due to limitations in the electronics.

Photometer passband

The reason for the small non-compliance in the PLW passband needs to be understood. This may be resolved once the étendue correction has been made. More pixels need to be spectrally characterised in the photometer to ensure compliance over the whole array.

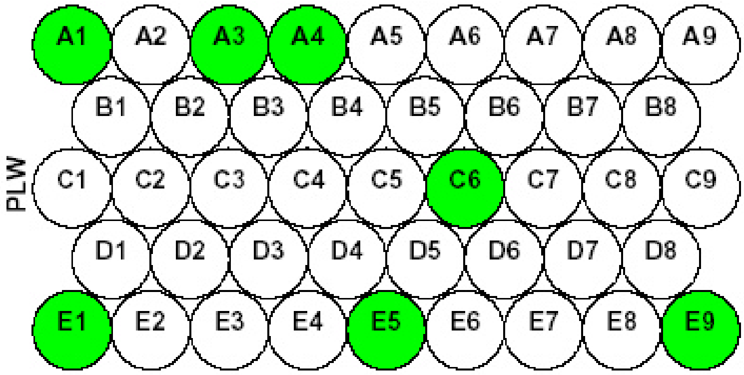
6. References

RD1 - BDA Subsystem Specification - SPIRE-JPL-PRJ-000456
RD2 – SMEC and Spectrometer Performance - SPIRE-RAL-REP-002566

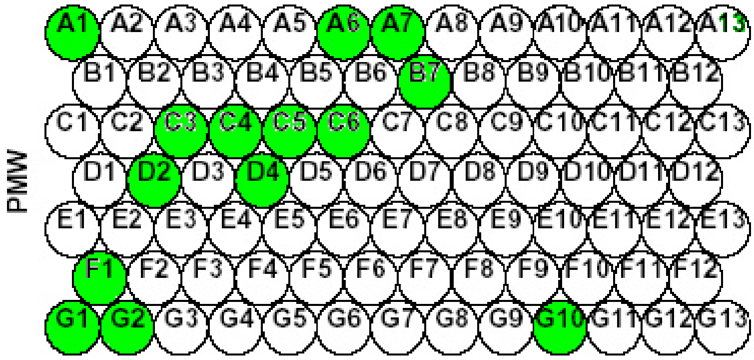
7. Appendices

7.1 Pixels where spectra were taken during PFM2

PLW Pixels evaluated



PMW Pixels evaluated



PSW Pixels evaluated

7.2 Measured Band Edges

The tables in this appendix give the measured band centres and 50% band edge points for the three photometer arrays.

specification	517	172.4 +/- 18.1	430.8 +/- 4.3	603.2 +/- 17.6	3.00 +/- 0.39
		154.3 - 190.5	426.5 - 435.1	585.6 - 620.8	2.61 - 3.39
Pixel	λ_c (um)	$\Delta\lambda'$ (um)	λ_1' (um)	λ_2' (um)	R'
PLW_A1	516.6	177.5	425.6	607.5	2.9
PLW_A3	516.1	178.4	427.3	604.9	2.9
PLW_A4	513.9	176.6	425.1	602.6	2.9
PLW_C6	520.5	181.9	425.7	615.4	2.9
PLW_E5	513.0	177.4	423.9	602.1	2.9
PLW_E9	515.2	181.0	424.2	606.2	2.8

specification	363	114.0 +/- 12.7	306.0 +/- 3.1	420.0 +/- 12.3	3.18 +/- 0.45
		101.3 - 126.7	302.9 - 309.1	407.7 - 432.3	2.73 - 3.63
Pixel	λ_c (um)	$\Delta\lambda'$ (um)	λ_1' (um)	λ_2' (um)	R'
PMW_A1	359.1	109.7	305.6	412.5	3.3
PMW_A6	357.2	111.1	304.1	410.3	3.2
PMW_A7	358.8	108.9	306.5	411.1	3.3
PMW_B7	358.4	111.4	306.2	410.7	3.2
PMW_C3	361.2	112.0	307.5	415.0	3.2
PMW_C4	358.7	112.9	303.8	413.5	3.2
PMW_C5	357.4	112.0	304.4	410.4	3.2
PMW_C6	362.5	105.6	309.7	415.3	3.4
PMW_D2	364.3	113.7	308.7	419.9	3.2
PMW_D4	358.9	111.9	305.2	412.5	3.2
PMW_F1	358.0	113.7	303.5	412.6	3.1
PMW_G1	359.4	113.3	303.7	415.0	3.2
PMW_G2	357.3	111.5	303.2	411.4	3.2
PMW_G2_al	357.8	111.9	304.1	411.6	3.2
PMW_G10	361.8	114.4	308.0	415.6	3.2

specification	250	83.4 +/- 8.8	208.3 +/- 2.1	291.7 +/- 8.5	3.00 +/- 0.39
		74.6 - 92.2	206.2 - 210.4	283.2 - 300.2	2.61 - 3.39
Pixel	λ_c (um)	$\Delta\lambda'$ (um)	λ_1' (um)	λ_2' (um)	R'
PSW_A8	247.1	76.6	209.3	285.0	3.2
PSW_A9	247.1	77.8	209.1	285.2	3.2
PSW_B8	247.7	76.0	209.6	285.9	3.3
PSW_B9	249.8	83.0	209.0	290.5	3.0
PSW_C10	248.2	76.3	210.3	286.0	3.3
PSW_D10	247.5	83.6	206.2	288.7	3.0
PSW_D11	251.5	85.5	210.1	293.0	2.9
PSW_E9	249.9	81.9	208.2	291.5	3.0
PSW_E10	248.0	80.7	207.8	288.2	3.1
PSW_E12	248.0	83.0	207.3	288.8	3.0
PSW_F12	248.4	78.9	210.1	286.7	3.2
PSW_G12	249.0	84.2	208.4	289.7	3.0
PSW_G13	249.4	95.3	209.6	289.3	2.6
PSW_G13_a	247.2	81.2	205.8	288.7	3.0
PSW_G14	248.3	80.9	207.5	289.1	3.1
PSW_H5	248.0	80.1	208.4	287.7	3.1
PSW_H12	249.4	84.2	206.3	292.4	3.0
PSW_H13	250.9	84.8	209.5	292.3	3.0
PSW_H13_a	249.9	84.4	208.7	291.0	3.0
PSW_H14	248.7	83.0	207.4	289.9	3.0
PSW_H14_a	249.4	83.6	208.3	290.6	3.0
PSW_H15	247.9	80.9	207.3	288.5	3.1
PSW_J4	246.8	76.2	209.3	284.3	3.2
PSW_J5	247.9	78.5	209.4	286.3	3.2
PSW_J12	247.8	81.3	207.7	287.9	3.0
PSW_J13	248.9	81.3	208.9	288.8	3.1
PSW_J13_a	248.3	81.1	208.4	288.2	3.1
PSW_J14	248.6	79.7	209.2	288.0	3.1