PACS spectroscopy flatfield correction

PICC-KL-TN-044

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1 Introduction

The PACS spectrometer absolute flux calibration relates the signal (V/sec) to flux density (Jy). This is done for every pixel at a few key wavelengths in the different spectral bands.

The signal to flux density conversion factors are tied to the differential signal from the internal calibration sources at the respective key wavelengths. The calibration files .spectrometer.calSourceFlux and spectrometer.relCalSourceFlux tabulate for every pixel the equivalent flux density of the calibration source: the flux density of a sky source delivering the same signal on the pixel as the internal calibration source. These calibration tables are determined from sky measurements of photometric standard stars with well known flux density. These standards only illuminate the central integral field modules, while the conversion is needed for all pixels. Therefore, we determine a correction for the presently tabulated calibration source flux densities to match the sky flatfield.

Until now, the internal calibration source measurement has not been applied for the signal-to-flux density scaling in the PACS spectrometer pipeline. Instead, the conversion factors tabulated in the spectrometer.nominalResponse calibration table are used. The values in the nominalResponse calibration table give a mean detector response for the whole mission, disregarding detector response drifts. Also these values are tied to the flux density of pointlike absolute flux calibration sources, seen only in the central module. We therefore also determine a flatfield correction to the nominalResponse calibration table.

2 Reference documents

2.1 Applicable documents

Number	***Document***
[AD1]	

2.2 Reference documents

Number	***Document***
[RD1]	
[RD2]	

3 Data log

3.1 Key wavelength measurements

B2A 60

1342186326 1342186551 1342186560 1342186563 1342186661 1342186680
1342186961 1342186974 1342186980 1342186983 1342187194 1342187211
1342188030 1342188945 1342189274 1342189953 1342191141 1342191150
1342192113 1342192118 1342192158 1342192976 1342196699 1342196866

B2B 75

1342186327 1342186534 1342186552 1342186559 1342186564 1342186662
1342186681 1342186962 1342186975 1342186981 1342186984 1342187195
1342187212 1342188031 1342188946 1342189275 1342189954 1342191142
1342191151 1342192114 1342192119 1342192159 1342192977 1342195499
1342196700 1342196867

B3A60

1342186328 1342186535 1342186553 1342186561 1342186565 1342186663
1342186682 1342186963 1342186976 1342186982 1342186983 1342187196
1342187213 1342188032 1342188947 1342189276 1342189955 1342191143
1342191150 1342192113 1342192118 1342192158 1342192978 1342195500
1342196699 1342196868

R1 120

1342186326 1342186551 1342186560 1342186563 1342186661 1342186680
1342186961 1342186974 1342186980 1342186983 1342187194 1342187211
1342188030 1342188945 1342189274 1342189953 1342191141 1342191150
1342192113 1342192118 1342192158 1342192976 1342196699 1342196866

R1 150

1342186327 1342186534 1342186552 1342186559 1342186564 1342186662
1342186681 1342186962 1342186975 1342186981 1342186984 1342187195
1342187212 1342188031 1342188946 1342189275 1342189954 1342191142
1342191151 1342192114 1342192119 1342192159 1342192977 1342195499
1342196700 1342196867

R1 180

1342186328 1342186535 1342186553 1342186561 1342186565 1342186663
1342186682 1342186963 1342186976 1342186982 1342186983 1342187196
1342187213 1342188032 1342188947 1342189276 1342189955 1342191143
1342191150 1342192113 1342192118 1342192158 1342192978 1342195500
1342196699 1342196868

3.2 Raster measurements

Neptune: 1342186678

4 Sky flatness at different chopper positions

The key wavelength measurements listed in section 3.1 are chopped-nodded range scans of flux calibration standards at the key wavelengths. In these measurements we have have selected the off-positions, and took per pixel the median of the detector signal in both nod positions. This delivers two response maps measured on the telescope at +/- 30" chopper position per measurement. Taking the median over all observations gives a median response map at +30" and -30" chopper throw.

The ratio between the two median telescope response maps measured at +30" and -30" chopper shows that the sky flats at the chopper positions are well reproduced. We summarise the mean of the ratios and the standard deviation on the ratios in Table 1. The ratio maps and histograms are depicted in figures 1 to 12.

Band / Key wavelength	***Mean ratio***	***Standard deviation***
B2A 60	0.991	0.009
B3A 60	1.012	0.008
B3B 75	1.004	0.009
R1 120	0.995	0.011
R1 150	1.026	0.011
R1 180	1.018	0.009

Table 1: Summary of the sky flatfield ratio measured at positive and negative small chopper throw.

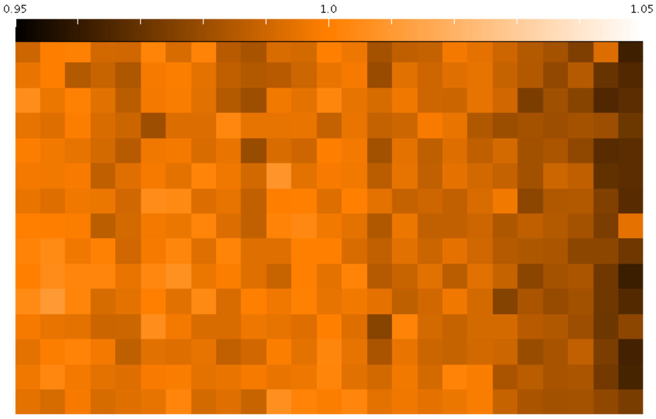

Figure 1: Ratio telescope response nod A/B B2A 60

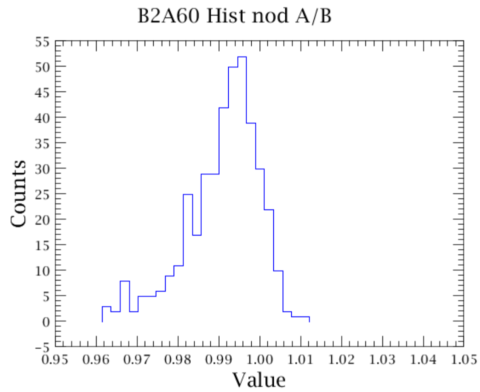

Figure 2: Histogram ratio telescope response nod A/B B2A 60

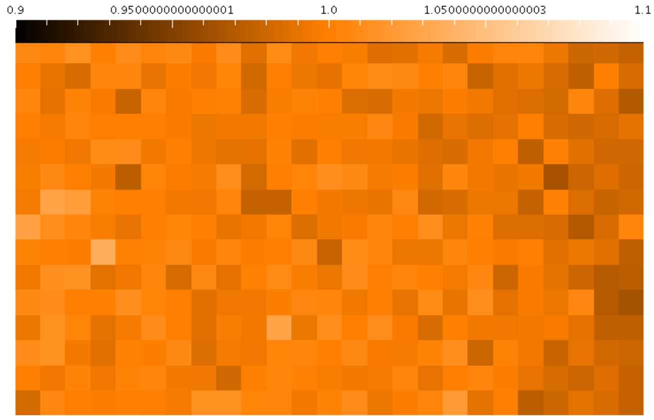

Figure 3 : Ratio telescope response nod A/B B3A 60

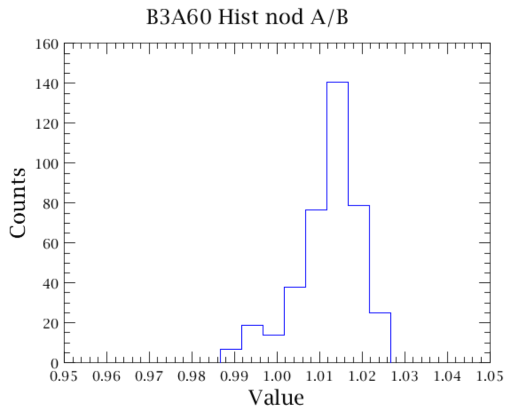

Figure 4: Histogram ratio telescope response nod A/B B3A 60

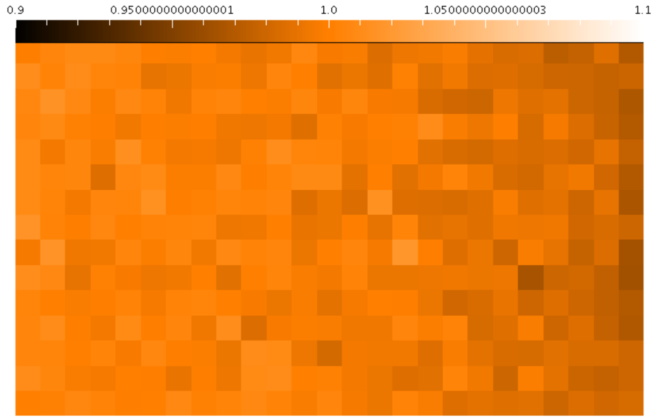

Figure 5: Ratio telescope response nod A/B B2B 75

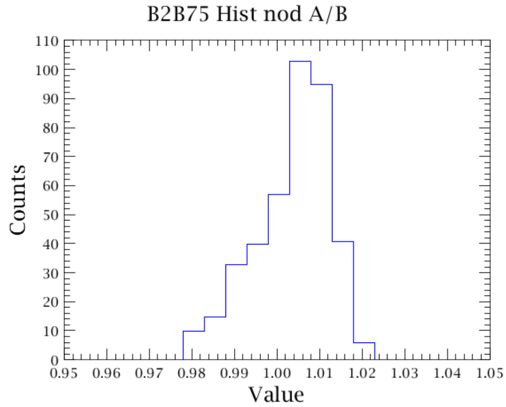

Figure 6: Histogram ratio telescope response nod A/B B2B 75

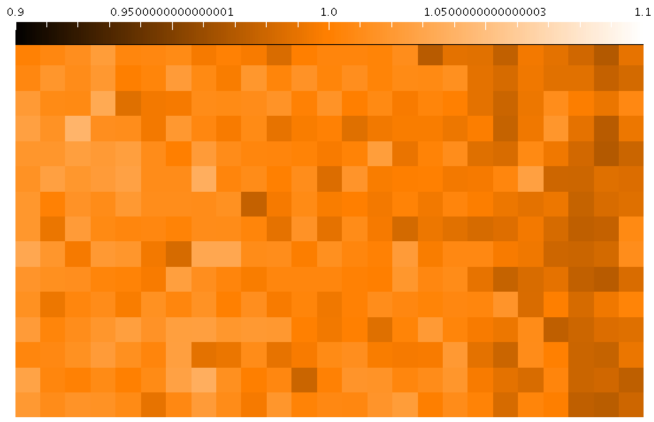

Figure 7: Ratio telescope response nod A/B R1 120

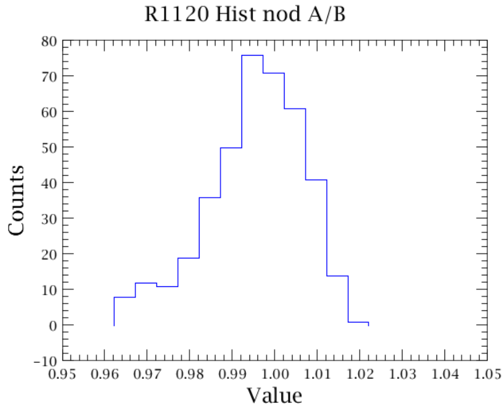

Figure 8: Histogram ratio telescope response nod A/B R1 120

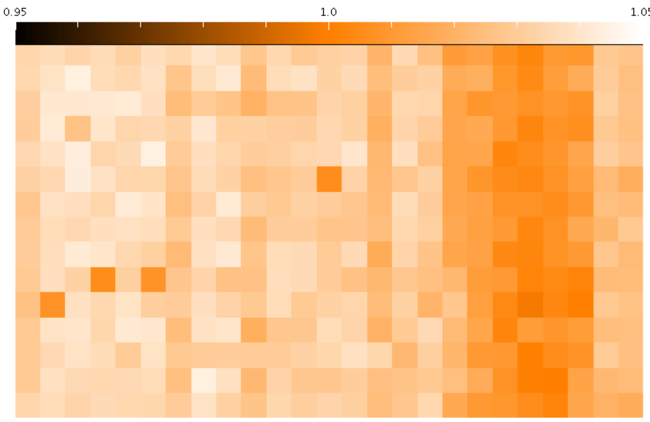

Figure 9: Ratio telescope response nod A/B R1 150

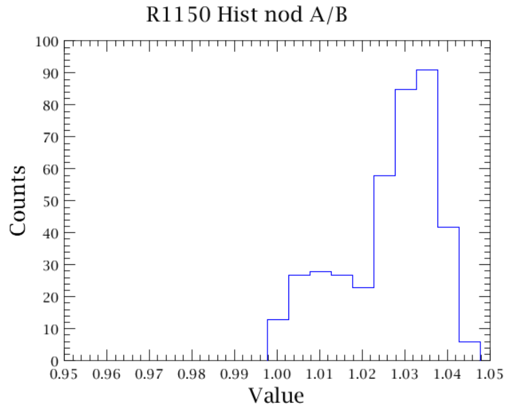

Figure 10: Histogram ratio telescope response nod A/B R1 150

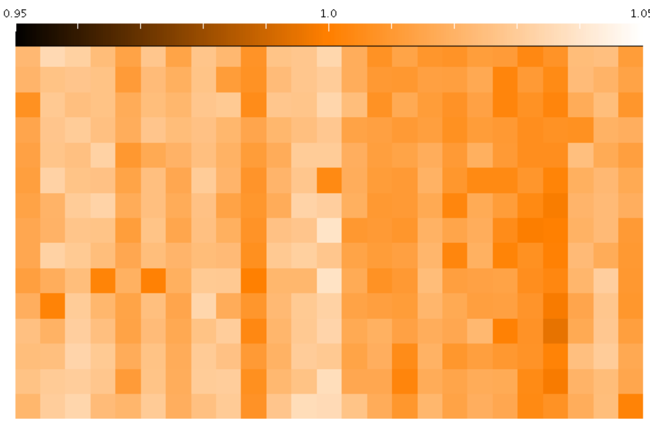

Figure 11: Ratio telescope response nod A/B R1 180

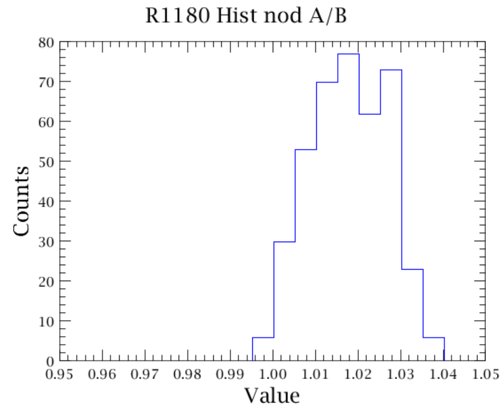

Figure 12: Histogram ratio telescope response nod A/B R1 180

5 Flatfield correction of nominalResponse

The key wavelength measurements listed in section 3.1 are chopped-nodded range scans of flux calibration standards at the key wavelengths. In these measurements we have have selected the off-positions, and took per pixel the median of the detector signal in both nod positions. This delivers two response maps measured on the telescope at +/- 30" chopper position per measurement. We have divided these response maps by the response map in the spectrometer.NominalResponse calibration table, and normalised the ratio so that the median of the ratio of all pixels is 1. This gives for every measurement at a prime key wavelength a flatfield correction for the nominalResponse calibration table. Subsequently, a median flatfield correction for the nominalResponse was obtained by taking the median over all observations and both nod positions for every pixel.

In figures 13 to 20 we show the median flatfield correction for the nominalResponse and the histogram of the correction factors for all pixels.

The standard deviation of the correction factors are listed in Table 2 . These give an indication of the magnitude of the average correction factors deduced.

We also list the flatfield for the secondary key wavelength at 120 for comparison with the Neptune raster measurement at that wavelength in section 9 . It is noted that this flatfield correction at the secondary wavelength is affected by uncertainties on the RSRF, and should not be applied to the NominalResponse calibration table.

Key wavelength	Standard deviation
B2A 60	0.052
B3A 60	0.058
B2B 70	0.065
R1 120 (secondary key)	0.171
R1 150	0.097

Table 2: Standard deviation on the nominalResponse flatfield corrections

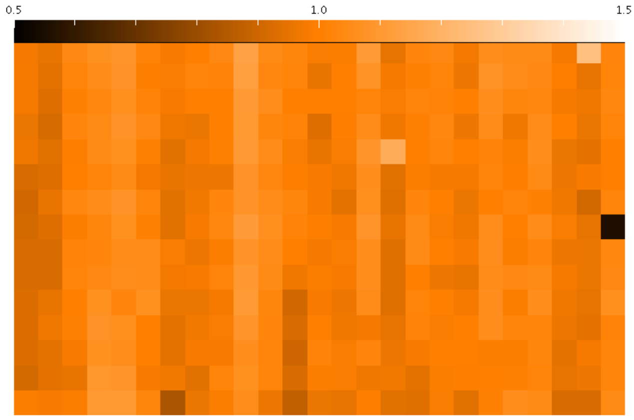

Figure 13: Flatfield correction of nominalResponse B2A 60

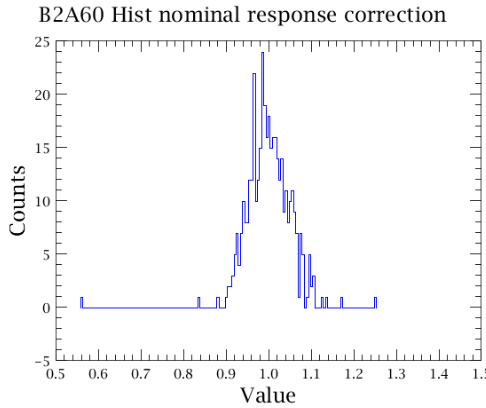

Figure 14: Histogram of the flatfield correction factors for nominalResponse B2A 60

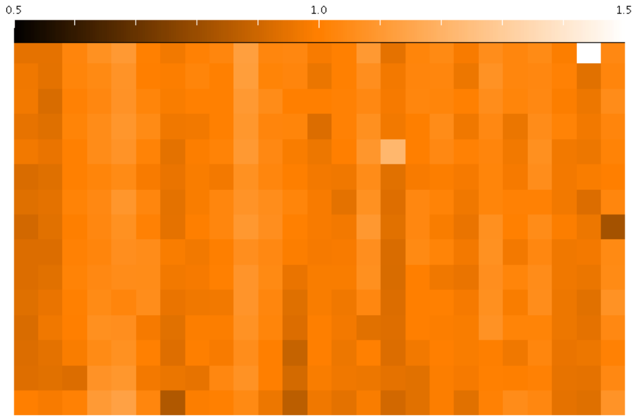

Figure 15: Flatfield correction of nominalResponse B3A 60

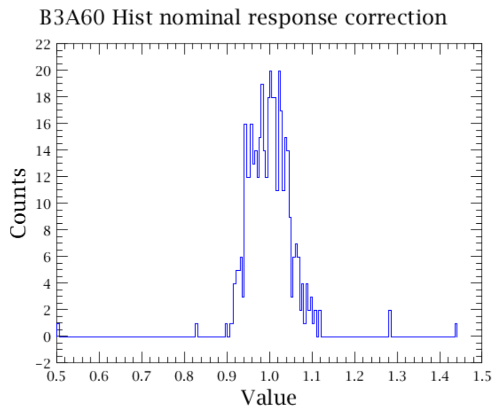

Figure 16: Histogram of the flatfield correction factors for nominalResponse B3A 60

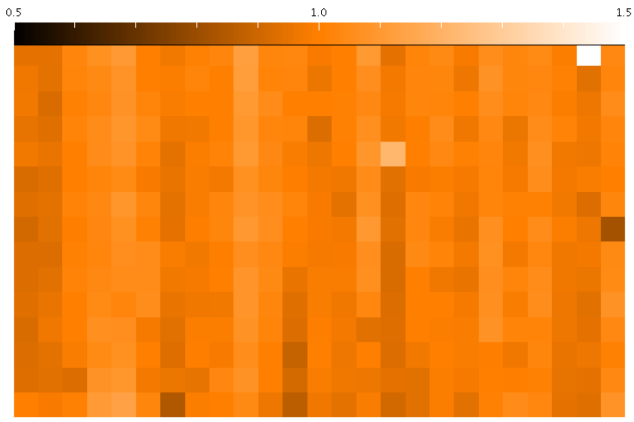

Figure 17: Flatfield correction of nominalResponse B2B 75

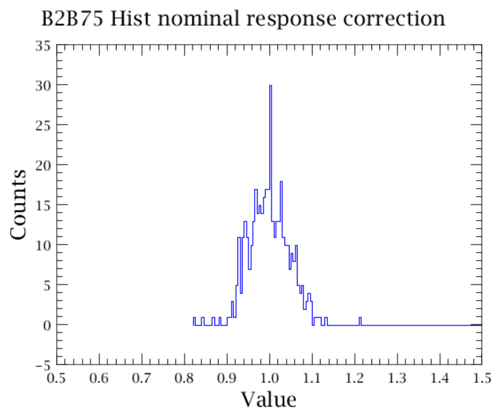

Figure 18: Histogram of the flatfield correction factors for nominalResponse B2B 75

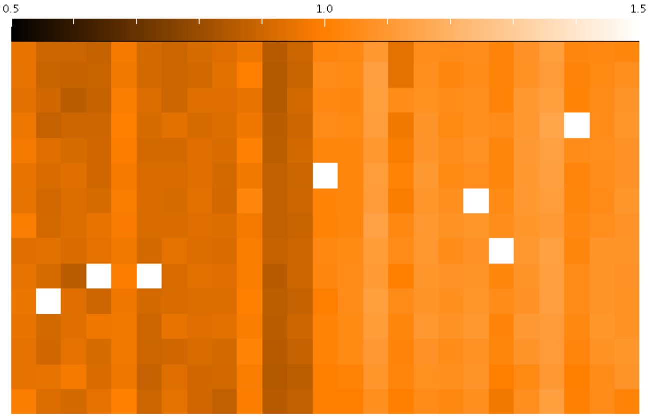

Figure 19: Flatfield correction of nominalResponse R1 120

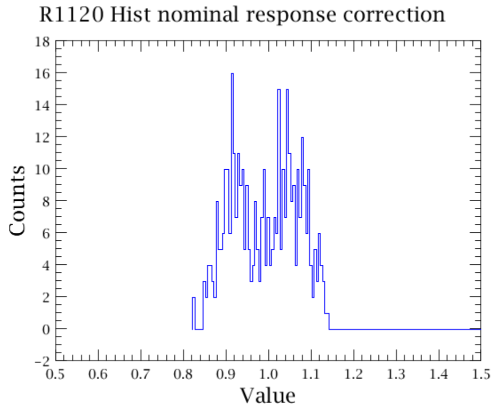

Figure 20: Histogram of the flatfield correction factors for nominalResponse R1 120

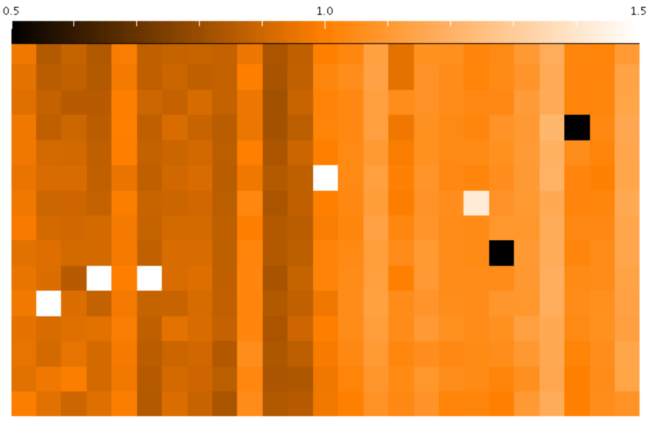

Figure 21: Flatfield correction of nominalResponse R1 150

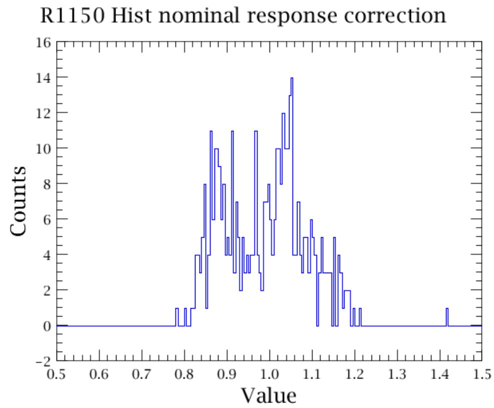

Figure 22: Histogram of the flatfield correction factors for nominalResponse R1 150

6 NominalResponse flatfield accuracies

In order to assess the accuracy of the flatfield in the nominalResponse calibration table before and after the corrections, we take the normalised telescope flatfields of the individual measurements as described above. The differences of these factors to 1 indicate how well the present nominalResponse would flatfield. The differences to the median correction factors derived in the previous section indicates how well the new, corrected nominalResponse would flatfield. The standard deviations on these differences give the old and the new flatfield accuracies using nominalResponse. They are tabulated in Table 3. Since we have 16 pixels in one module, the module-to-module flatfield will be a factor 4 better. As can be seen, the corrected nominalResponse should bring the module-to-module flatfield accuracy down to 1% in all bands. Histograms of the differences between the nominalResponse flatfield factors and flatfield factors derived in the individual measurements are shown in Figures for the old nominalResponse and the corrected version.

Band	Stddev/pix old	Stddev/mod old	Stddev/pix new	Stddev/mod new
B2A 60	0.066	0.017	0.039	0.010
B3A 60	0.072	0.018	0.043	0.011
B2B 75	0.072	0.018	0.037	0.009
R1 120	0.087	0.022	0.039	0.010
R1 150	0.100	0.025	0.040	0.010

Table 3 Standard deviations on differences between nominalResponse flatfield (before/after correction) and telescope flatfields determined in individual measurements

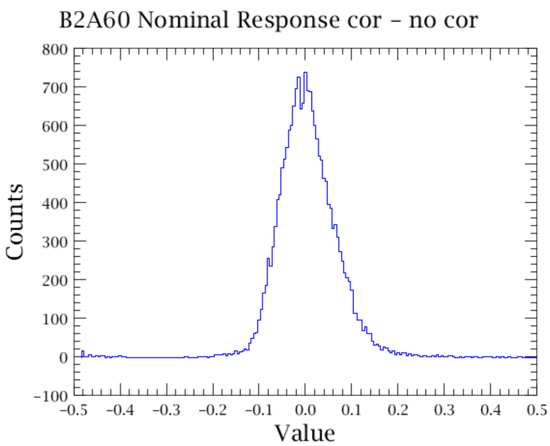

Figure 24: Histogram differences flatfield factors from individual measurements – factors old nominalResponse B2A 60

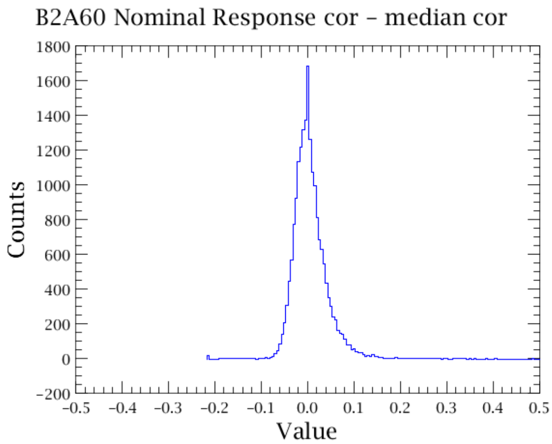

Figure 23: Histogram differences flatfield factors from individual measurements – median flatfield correction derived for nominalResponse B2A 60

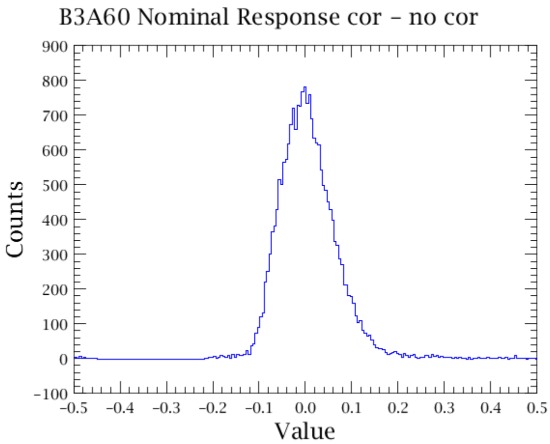

Figure 25: Histogram differences flatfield factors from individual measurements – factors old nominalResponse B3A 60

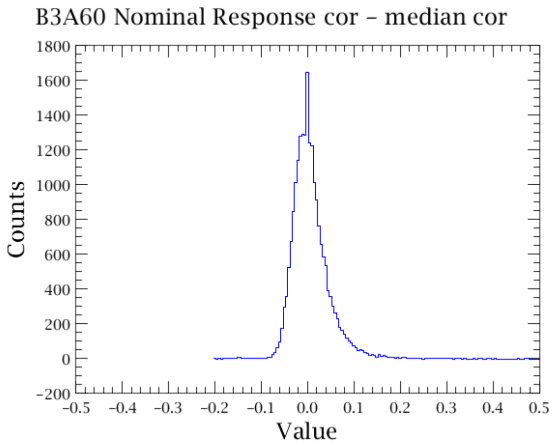

Figure 26: Histogram differences flatfield factors from individual measurements – median flatfield correction derived for nominalResponse B3A 60

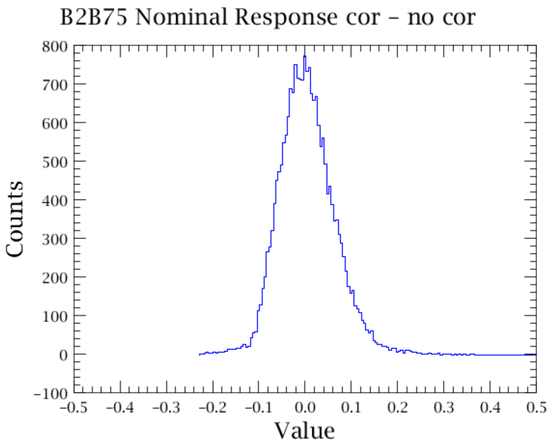

Figure 27: Histogram differences flatfield factors from individual measurements – factors old nominalResponse B2B 75

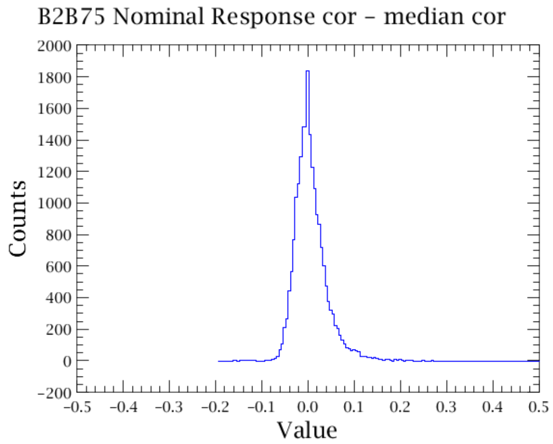

Figure 28: Histogram differences flatfield factors from individual measurements – median flatfield correction derived for nominalResponse B2B 75

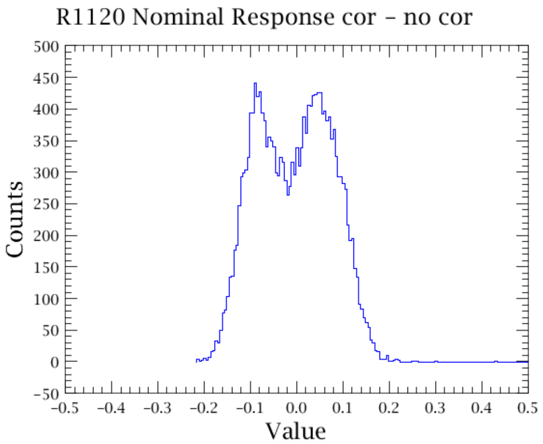

Figure 29: Histogram differences flatfield factors from individual measurements – factors old nominalResponse R1 120

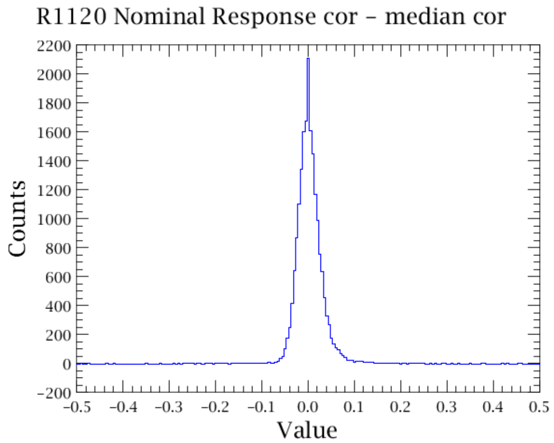

Figure 30: Histogram differences flatfield factors from individual measurements – median flatfield correction derived for nominalResponse R1 120

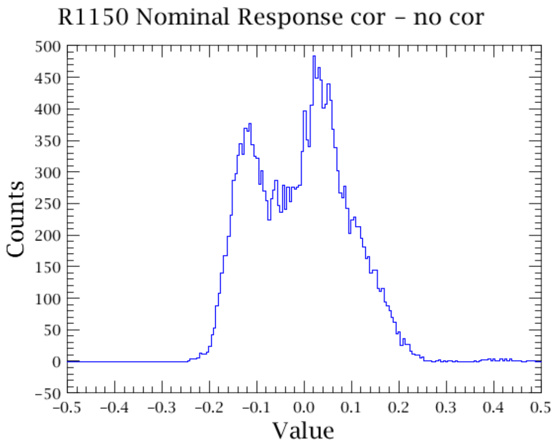

Figure 31: Histogram differences flatfield factors from individual measurements – factors old nominalResponse R1 150

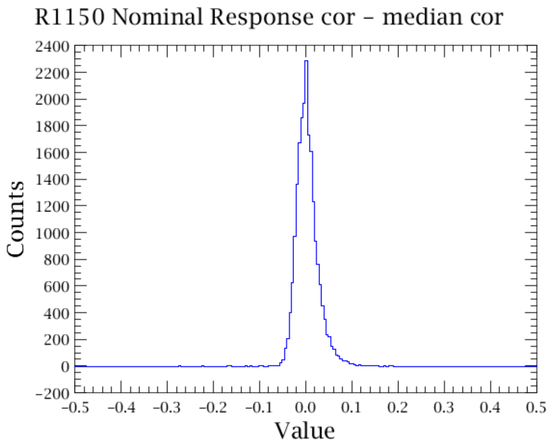

Figure 32: Histogram differences flatfield factors from individual measurements – median flatfield correction derived for nominalResponse R1 150

7 CalSourceFlux flatfield correction

For all the key wavelength measurements, the pipeline module specDiffCs was run on the internal calibration source measurement in the observation. This delivers a response calibration for every pixel at the key wavelengths, based on the calibration tables spectrometer.calSourceFlux and spectrometer.relCalSourceFlux. We divide the sky flat A and B by this response and normalise to the median of all pixels. This gives a flatfield correction to the calSourceFlux calibration table based on the flatfield measured on the sky. For every pixel, we take the median of this correction factor over all measurements. We refer to this as the median CS response flatfield correction.

The key wavelengths measured

In figures 33 to 40 we show the median flatfield correction for the CS response and the histogram of the correction factors for all pixels.

The standard deviation of the correction factors are listed in Table 4 . These give an indication of the magnitude of the average correction factors deduced.

Wavelength telescope flat	Key Wavelength CS	Standard deviation
B2A 60	B3A 60	0.169
B3A 60	B3A 60	0.207
B2B 75	B2B 75	0.213
R1 120	R1 180	0.206
R1 150	R1 150	0.12

Table 4: Wavelengths at which a telescope flat was measured, with key wavelength of the internal calibration source measurement that was measured in the observatin (and to which the flatfield correction applies) Third column gives the standard deviation on the calSourceFlux / relativeCalSourceFlux flatfield correctio factors found over all pixels.

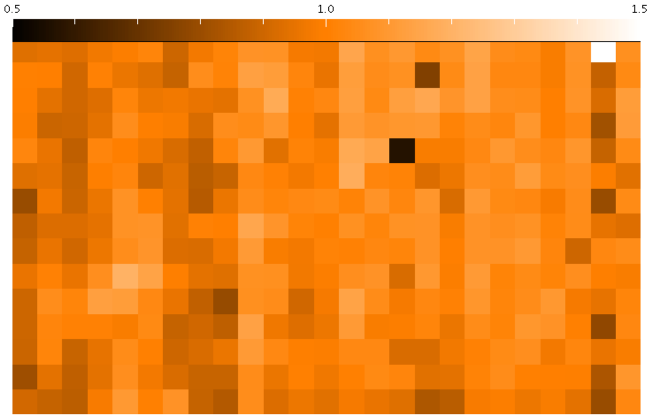

Figure 33: Flatfield correction of CS Response B2A 60

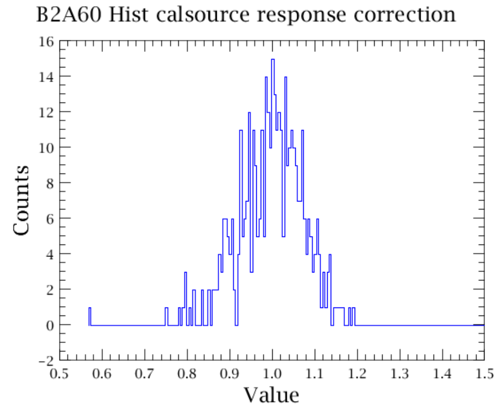

Figure 34: Histogram flatfield correction of CS Response B2A 60

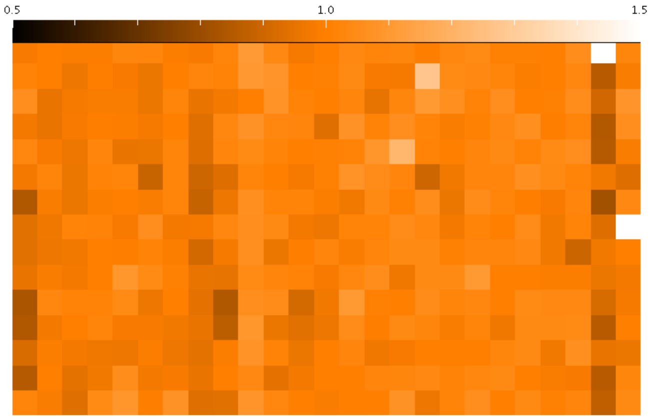

Figure 35: Flatfield correction of CS Response B3A 60

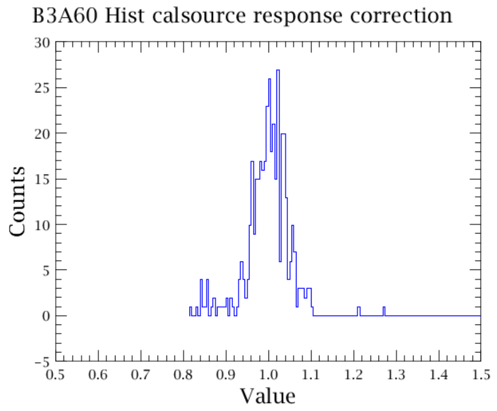

Figure 36: Histogram flatfield correction of CS Response B3A 60

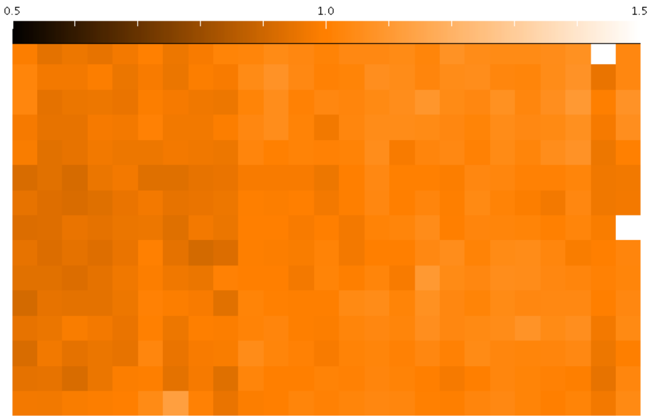

Figure 37: Flatfield correction of CS Response B2B 75

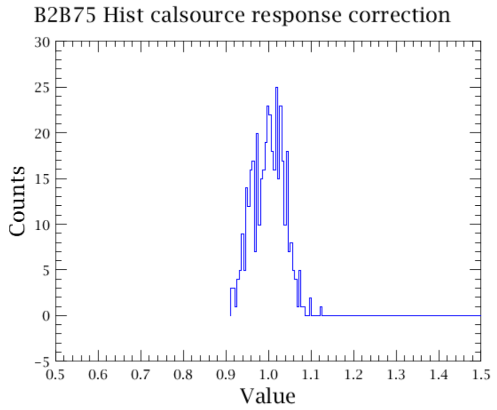

Figure 38: Histogram flatfield correction of CS Response B2B 75

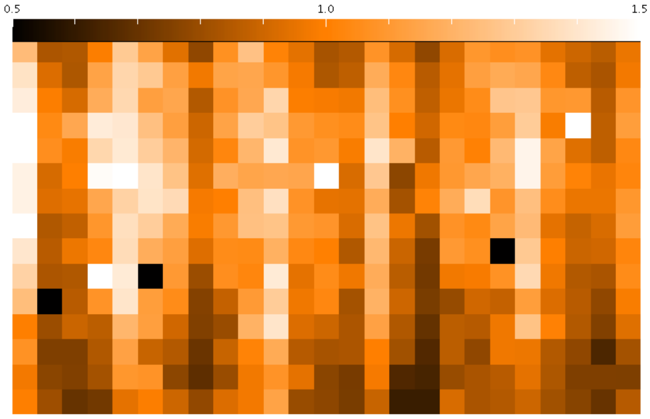

Figure 39: Flatfield correction of CS Response R1 120

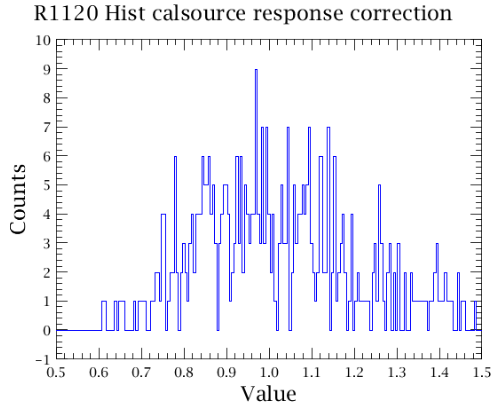

Figure 40: Histogram flatfield correction of CS Response R1 120

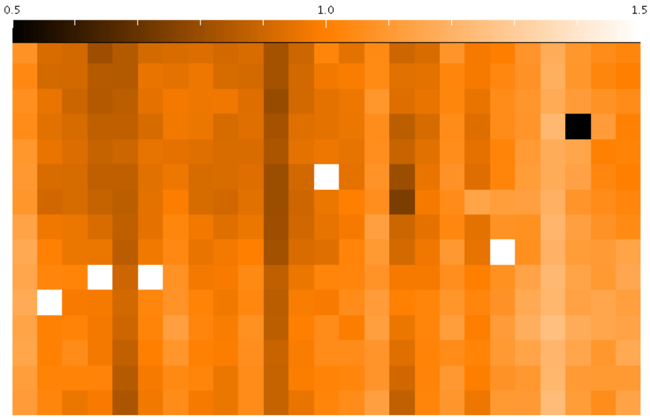

Figure 41: Flatfield correction of CS Response R1 150

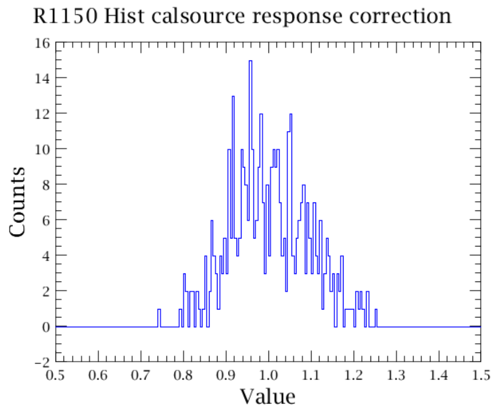

Figure 42: Histogram flatfield correction of CS Response R1 150

8 CalsourceFlux flatfield accuracy

From every measurement we have derived two flatfield corrections to the present CS response calibration tables, based on the off position in nod A and nod B. In order to assess how well the median flatfield corrected CS response would perform on an individual measurement, we compare the median CS response flatfield correction to the CS response flatfield corrections derived from the indiviual measurements. The differences of these factors to 1 indicate how well the present calSourceFlux with the internal calibration source measurement in the observation would flatfield. The differences to the median correction factors derived in the previous section indicate how well the new, corrected calSourceFlux with the internal calibration source measurement in the observation would flatfield. The standard deviations on these differences give the old and the new flatfield accuracies using the calibration block and the calSourceFlux calfile. They are tabulated in Table 5. Since we have 16 pixels in one module, the module-to-module flatfield will be a factor 4 better. As can be seen, the corrected calSourceFlux should bring the module-to-module flatfield accuracy down to 1-3% in the diffferent bands. Histograms of the differences between the calSourceFlux flatfield factors and flatfield factors derived in the individual measurements are shown in Figures for the old and the corrected version of the calSourceFlux.

Band	Stddev/pix old	Stddev/mod old	Stddev/pix new	Stddev/mod new
B2A 60 (key B3A)	0.113	0.028	0.084	0.021
B3A 60	0.092	0.023	0.081	0.020
B2B 75	0.061	0.015	0.045	0.011
R1 120 (key 180)	0.223	0.056	0.125	0.031
R1 150	0.103	0.026	0.067	0.017

Table 5 Standard deviations on differences between calSourceFlux flatfield (before/after correction) and telescope flatfields determined in individual measurements

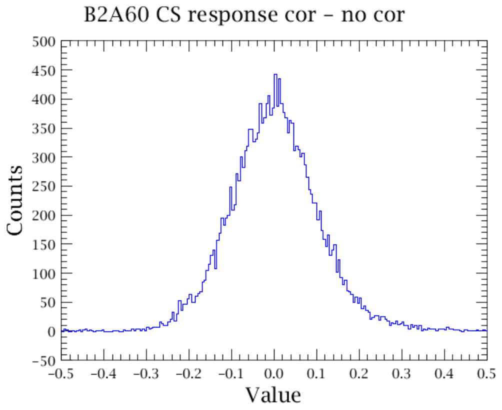

Figure 43: Histogram differences flatfield factors from individual measurements – old factors CalSourceFlux B2A 60

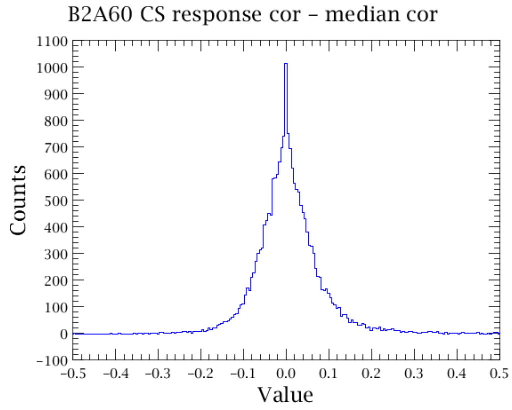

Figure 44: Histogram differences flatfield factors from individual measurements – median correction factors CalSourceFlux B2A 60

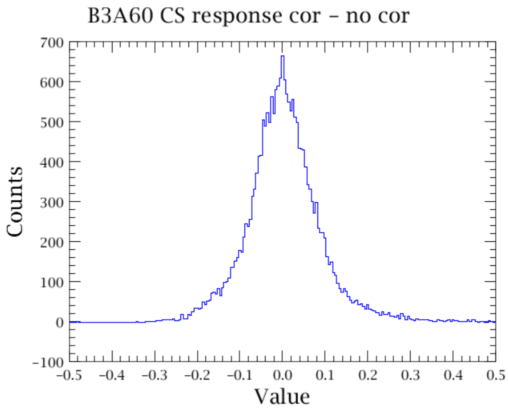

Figure 45: Histogram differences flatfield factors from individual measurements – old factors CalSourceFlux B3A 60

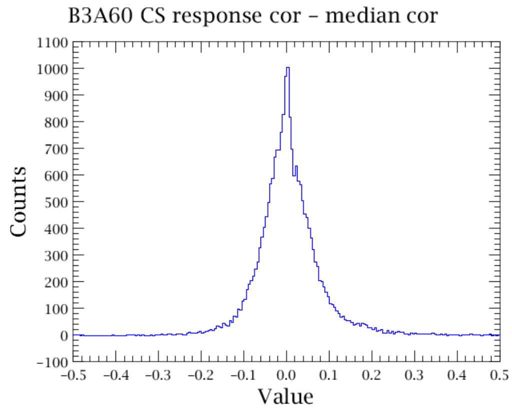

Figure 46: Histogram differences flatfield factors from individual measurements – median correction factors CalSourceFlux B3A 60

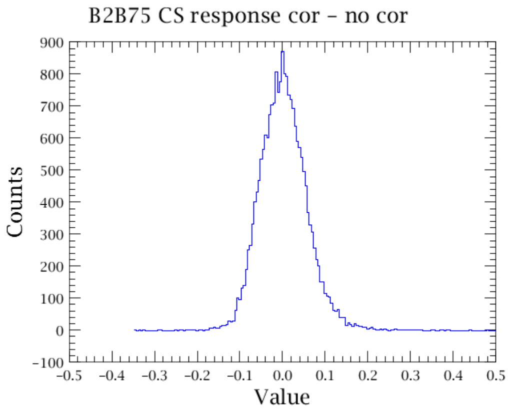

Figure 47: Histogram differences flatfield factors from individual measurements – old factors CalSourceFlux B2B 75

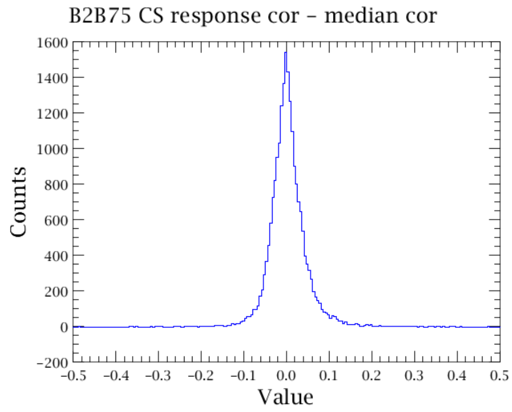

Figure 48: Histogram differences flatfield factors from individual measurements – median correction factors CalSourceFlux B2B 75

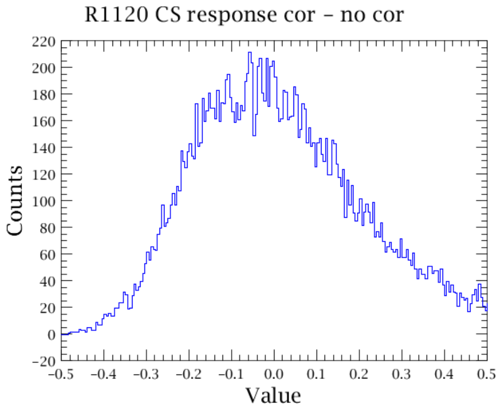

Figure 49: Histogram differences flatfield factors from individual measurements – old factors CalSourceFlux R1 120

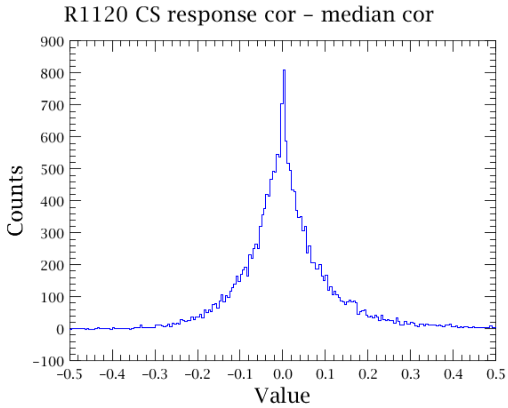

Figure 50: Histogram differences flatfield factors from individual measurements – median correction factors CalSourceFlux R1 120

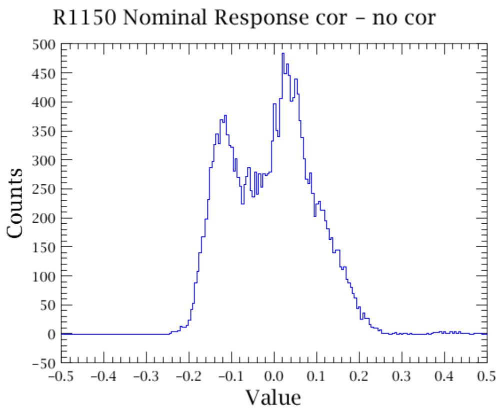

Figure 51: Histogram differences flatfield factors from individual measurements – old factors CalSourceFlux R1 150

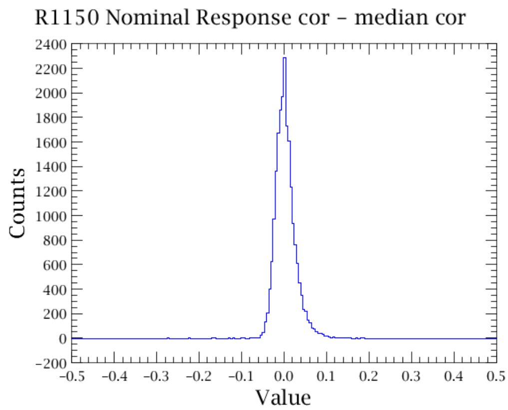

Figure 52: Histogram differences flatfield factors from individual measurements – median correction factors CalSourceFlux R1 150

9 Comparison to Neptune beam maps

Helmut Feuchtgruber produced flatfield maps from a 40x40 neptune beam map observation. This measurement was executed with the grating fixed with the blue order selection filter in position A. The grating position corresponded to a wavelength close to 62um (B2A) and 124um (R1).

Helmut fitted the peak and the width (area) of the beam in the resulting 40x40 map in every spectral pixel. Multiplying the fitted peak and width (area) gives a flatfield that should be similar to the inverse of the nominalResponse flatfield correction that we have derived above, since the Neptune maps were processed with the absolutely scaled RSRFs. The response in nominalResponse corresponds exactly to the response in these legacy absolutely scaled RSRFs.

The flatfields based on the Neptune beam maps are shown in Figure 54 and 55. Comparing these to the nominalResponse flatfield corrections shown in Figure 13 and 19, we see a qualitative agreement (low / high response pixels are similar in both the telescope flats and the Neptune flats), but the flatifeld correction factors obtained from the Neptune rasters are much more spread. This is currently not understood.

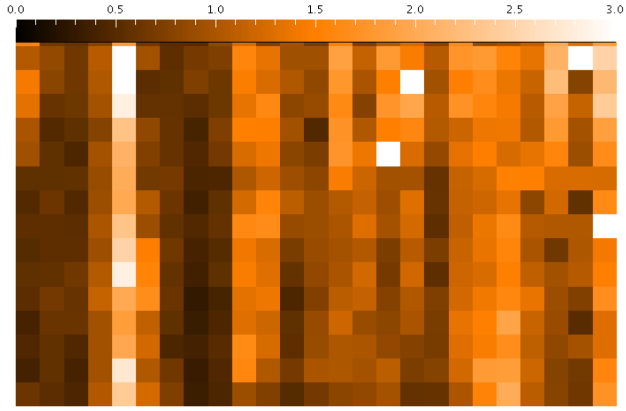

Figure 53: B2A flatfield from Neptune raster observations

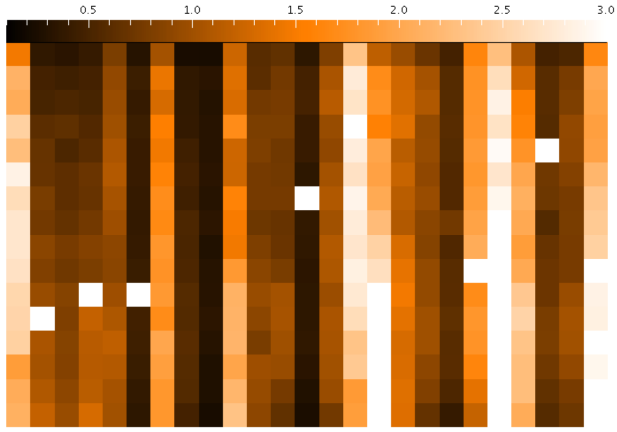

Figure 54: R1 flatfield from Neptune raster observations

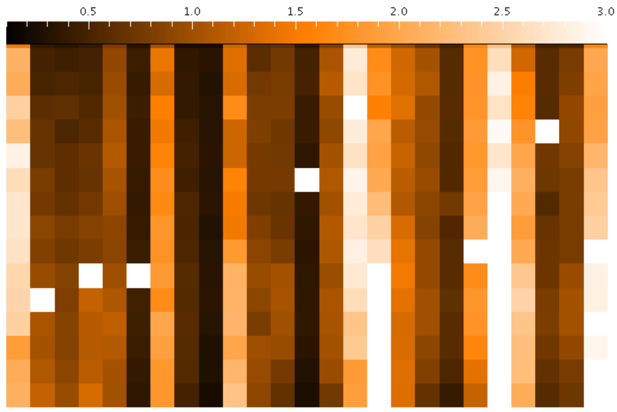

Figure 55: R1 flatfield from Neptune raster observations

10 Implementation in calibration files

10.1 Update of NominalResponse

The median nominal response flatfield corrections were applied to the NominalResponse FM version 2:

response_new = response_old * median flatfield correction

Additionally, we have incorporated the approximate flux correction factors listed in version 1.1 of the PACS Spectroscopy performance and calibration document (PICC-KL-TN-041):

response_new_new = response_new *1.3 (blue bands)

response_new_new = response_new *1.1 (red band)

The resulting calibration table is NominalResponse FM version 3

10.2 Update of CalSourceFlux

The median calsource flux flatfield correction factors were applied to the CS1 and CS2 fluxes in calSourceFlux FM version3

calSourceFlux_new = calSourceFlux_old / median CS flatfield correction

The resulting calibration table is calSourceFlux FM version 4.

Note that no key wavelength measurements on the calibration sources are available at the key wavelength of CS2, that will stay unaltered in the calfile.

The update of the relCalSourceFlux calibration file could be done based on the ratios of the median signal over all calibration blocks done in the mission at the different key wavelenths.