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To: EDGES Group

From: Alan E.E. Rogers

Subject: High band results using Blade antenna

The high band blade antenna has been in operation since 23 July 2015 using a well calibrated receiver. In this memo I limit the data studied to a range of day 204 through 237.

1] Examples of data from a single day

Figure 1 shows the residuals to 1 term fit vs Galactic Hours Angle (GHA). Daytime data is clearly strongly influenced by the Sun. Figures 2 and 3 show the spectra for 2 hour averages when the Sun is 10 degrees below the horizon. A 1 term fit for scale of a spectral index of -2.5 is removed without beam correction in Figure 2 and with beam correction in Figure 3. Figures 4 and 5 show the residuals to a 2 term fit without and with beam correction. The second term in fit is the slope of the spectral index. The best fit spectral index is given in table 1.

GHA	-2	0	2	4	6	8	10
w	-2.41	-2.38	-2.43	-2.50	-2.56	-2.56	-2.56
w/o	-2.58	-2.62	-2.57	-2.47	-2.50	-2.54	-2.53

Table 1. Best fit spectral index with and without (bottom row) beam correction.

GHA	-2	0	2	4	6	8	10
w	267	200	195	120	76	67	139
w/o	276	182	192	132	77	60	134

Table 2. RMS is fit of 5 physical terms with and without (bottom row) beam correction.

Figures 6 shows the residuals to a 5 term polynomial fit. Figure 7 shows the residual spectra to a 5 term fit for the physical functions scale, spectral index, gamma, ion-absorption and ion-emission. In both cases beam correction makes little difference to the residuals. However the residuals using the physical functions are lower especially at GHA=0 at the transit of the Galactic center. The source of the dip at 130 MHz and rise at 115 MHz at GHA=2h appears to be in the sky but could be RFI. Some of the structure is also in the receiver calibration and/or S11 measurements. This will be discussed in later sections.

2] Comparison with Fourpoint antenna

GHA	-2	0	2	4	6	8	
	1.4	5.1	2.1	4.0	3.4	1.6	FP
	1.8	2.1	1.1	0.5	1.3	1.3	FP corrected
	1.7	4.4	1.8	2.4	2.2	1.4	Blade
	1.8	1.4	0.7	0.4	0.8	1.0	Blade corrected

Table 3 RMS residuals in K 2 term fit

In the case of a 2 term fit to scale and spectral index the rms residuals of the blade are lower than the Fourpoint at all night time GHA except at – 2 hours. Applying a correction using FEKO generally makes an improvement at all GHA except at – 2 hours. With more terms the rms residuals for the blade and Fourpoint become more similar and the improvement with beam correction becomes smaller.

Figures 8 and 9 show the residual spectra for 8 days with a 6 term fit for the Fourpoint and Blade respectively at –2 hours GHA. At this GHA the systematics which remain in the residuals appear to be almost the same for the 2 antennas.

3] Measurement of spectral index (beta) and curvature of spectral index (gamma)

GHA	Beta	Gamma	T150 (k)	rms (mK)
-2	-2.51	0.04	769	1062
0	-2.48	0.03	837	755
2	-2.52	0.01	761	584
4	-2.56	-0.01	552	311
6	-2.56	0.07	340	213
8	-2.54	0.10	265	165

Table 4 Spectral index and gamma from 2015_217 100-195 MHz. 1-sigma errors in spectral index and gamma are 0.01 and 0.03 respectively.

These results are obtained from a 3 parameter fit to scale, beta and gamma using $f^{-2.5}$, $f^{-2.5}(\log f)$ and $f^{-2.5}(\log f)^2$ where *f* is normalized to 150 MHz. Unfortunately gamma is very highly correlated with ionosphere absorption so adding a fourth parameter to include ionosphere absorption leads to very large errors in the determination of all four parameters. However the effect of the night time ionosphere on the determination of gamma is less than 0.01. It is noted that while the values of beta determined here are in reasonable agreement with those in Figure 10 of Oliveira-Costa et al. (2008). The values of gamma from EDGES are quite difference from the values of Oliveira-Costa which lie in the range around -0.1 outside the Galactic plane and around -0.2 in the Galactic plane. One possible reason (already discussed in memo 160) is that much of the data used by Oliveira was obtained during the daytime when the ionosphere absorption tends to drive gamma negative. The results for other days are within one sigma of those on day 217. In addition results in table 5 below from the Fourpoint are similar

GHA	Beta	Gamma	T150 (k)	Rms (mK)
-2	-2.50	0.06	782	1238
0	-2.47	0.06	858	1264
2	-2.51	0.03	756	1020
4	-2.54	0.01	542	715
6	-2.53	0.11	334	552

Table 5 spectral index and gamma from Fourpoint 2015_190.

4] Data from days 204 through 237

Figure 10 shows Galaxy down/up ratios after removal of a 3-term polynomial. Days 219, 220, 231, 232 have anomalous spectra and will be eliminated from further analysis. Some other days have already been removed owing to obvious weather problems. An examination of the residuals of the down/up ratio spectra after the removal of a lower order polynomial provides a good measure of data quality for each day. Figure 11 shows the Galaxy down/up ratios after removal of a 3-term polynomial and the removal of the days with anomalous spectra. The spectra have been corrected for beam chromaticity using FEKO with the minor changes to the sky discussed in memo 160.

	Down/up			Down			Up		
# terms	A	B	C	A	B	C	A	B	C
3	25	25	975	165	174	75	440	400	658
4	24	24	164	52	51	50	195	206	225
5	21	21	20	51	50	50	176	178	180

Table 6 Residuals in mK

Table 6 shows the rms residuals for the Galaxy down/up spectra after removal of a 3,4 and 5 term polynomial. Case A is using FEKO correction with modified sky map, Case B uses the Haslam map with constant spectral index of -2.5 and case C is without beam correction. At 5 terms beam correction slightly degrades the results. Figures 12 and 13 show the Galaxy down and up residual spectra respectively. Galaxy up data is all nighttime data within 4 hours of the transit of the Galactic center and Galaxy down data is within 4 hours of GHA=9hr. Nighttime is taken to be when the Sun is more than 10 degrees below the horizon. The residuals clearly show that characteristics expected from receiver calibration or S11 errors.

	Down/up			Down			Up		
# terms	A	B	C	A	B	C	A	B	C
3	50	290	1022	89	80	155	260	290	392
4	33	48	177	80	75	64	260	287	319
5	23	21	17	28	27	27	110	113	115

Table 7

Table 7 shows the rms residuals after subtracting 23 ps from the S11 of the antenna. This change in S11 lowers the rms in the Galaxy up, Galaxy down and the Down/up ratio for the 5 term residuals. A further improvement in rms can be made by limiting the range of Galaxy up spectrum to avoid the region at -2 hrs from transit of the Galactic center.

5] Estimate of EoR limits

a) Effect of adding an EoR signature

Figures 14, 15 and 16 the residuals to the "Down/up" ratio, Galaxy "down" and Galaxy "up" spectra after removing a 5 term polynomial. The 5 plots from top to bottom are:

a) Standard processing of days 204 through 237 with some days excluded.
b) After subtracting 23 ps from the antenna S11.
c) Same as b after limiting the integration from 4 to 2 hours from the GHA of 9 hr and 0 hr.
d) Same as c after adding 100 mK Gaussian EoR signature of half power full width of 10 MHz at 130 MHz
e) EoR signature moved to 160 MHz.

Comments:

a) While the down/up spectra are the flattest a 10 MHz wide EoR signature is more detectable in the Galaxy down spectrum. Wider EoR signatures are more detectable in the down/up spectra.
b) The Galaxy up spectra are dominated by a systematic which is most likely instrumental.
c) A limit of 100 mK EoR Gaussian of a width less than or equal to 10 MHz between 115 and 180 MHz with very small probability of error. A significant reduction of systematics is still required to get 30 mK.

Notes on Galaxy down/up ratio method

Memo 48, 555 and 146 describe methods of using "Galaxy Up" and "Galaxy Down" data to reduce the effects of errors in receiver calibration and antenna S11 errors on the detectability of an EoR signature. The 2 competing techniques are the "difference" method in which a scaled version of the Galaxy Up spectrum is subtracted from the Galaxy down spectrum and the Galaxy down/up ratio method. In the ratio method the ratio Galaxy down spectrum is divided by the Galaxy up spectrum and the result multiplied by value of the Galaxy up spectrum at 150 MHz. The ratio method was chosen here as it gave slightly better results. Various methods of how to best utilize the Galaxy up and down data are still under study.

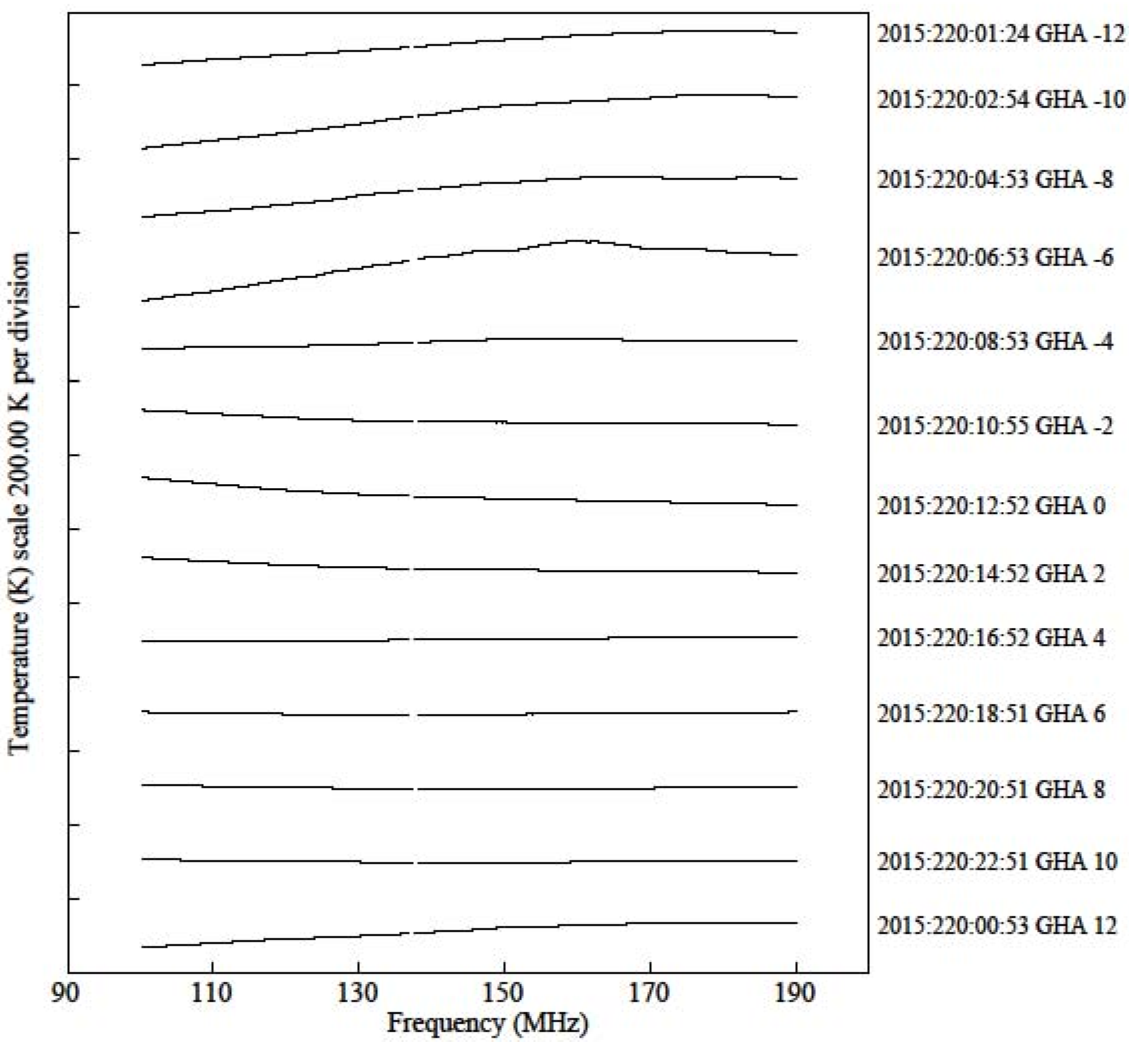

Figure 1. 1 term fit without beam correction.

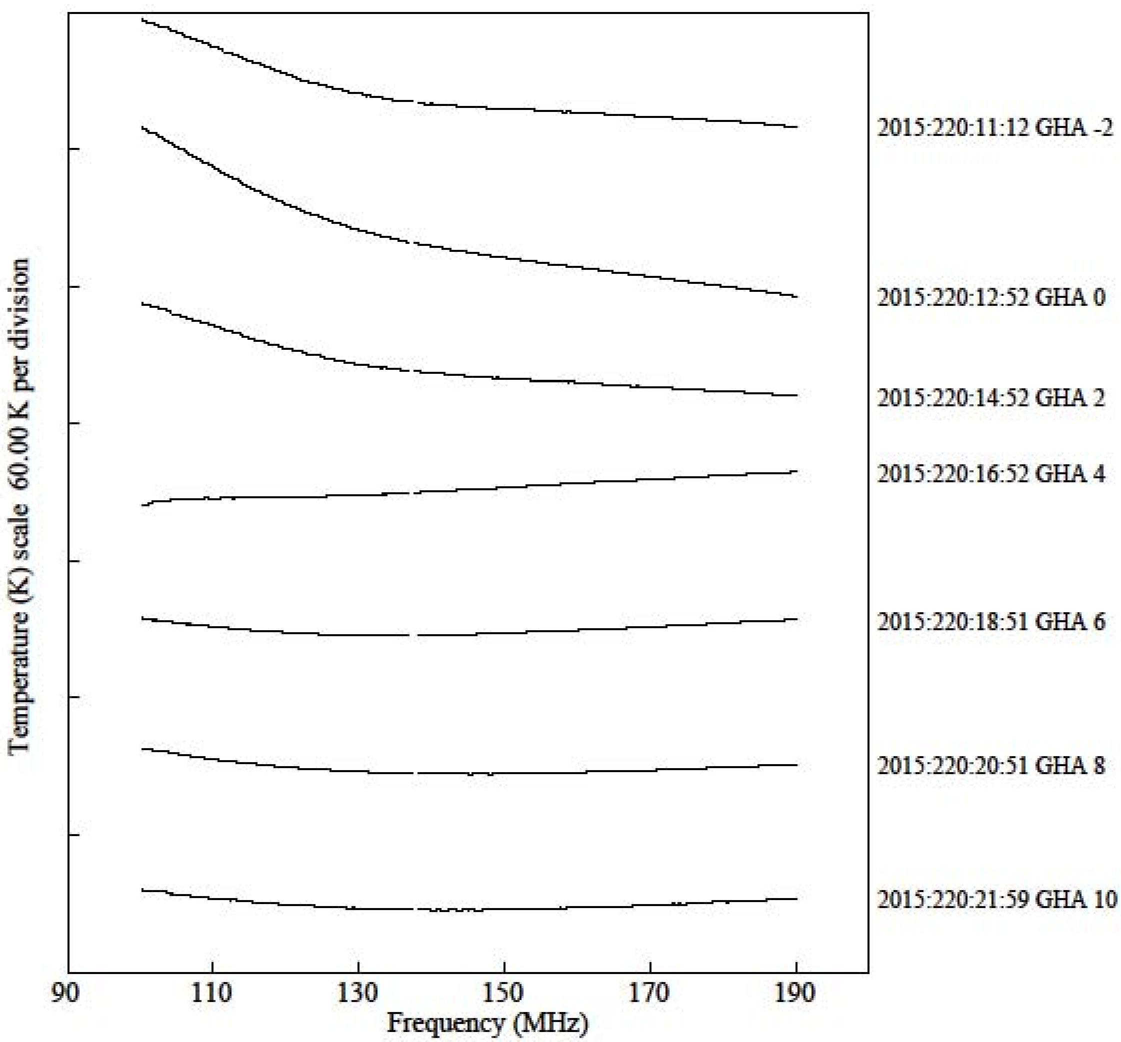

Figure 2. Nighttime 1 term fit without beam correction.

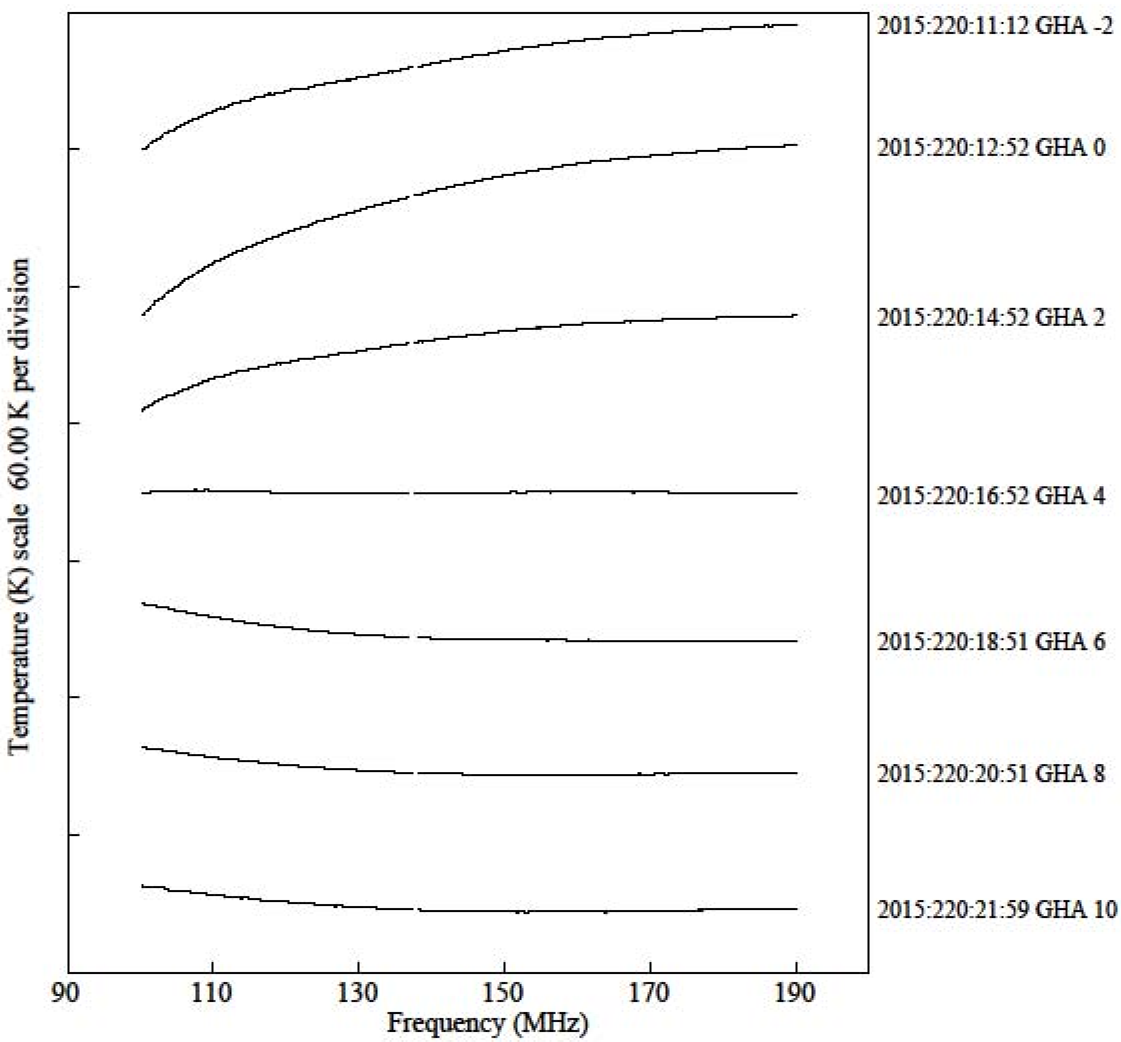

Figure 3. Nighttime 1 term fit with beam correction.

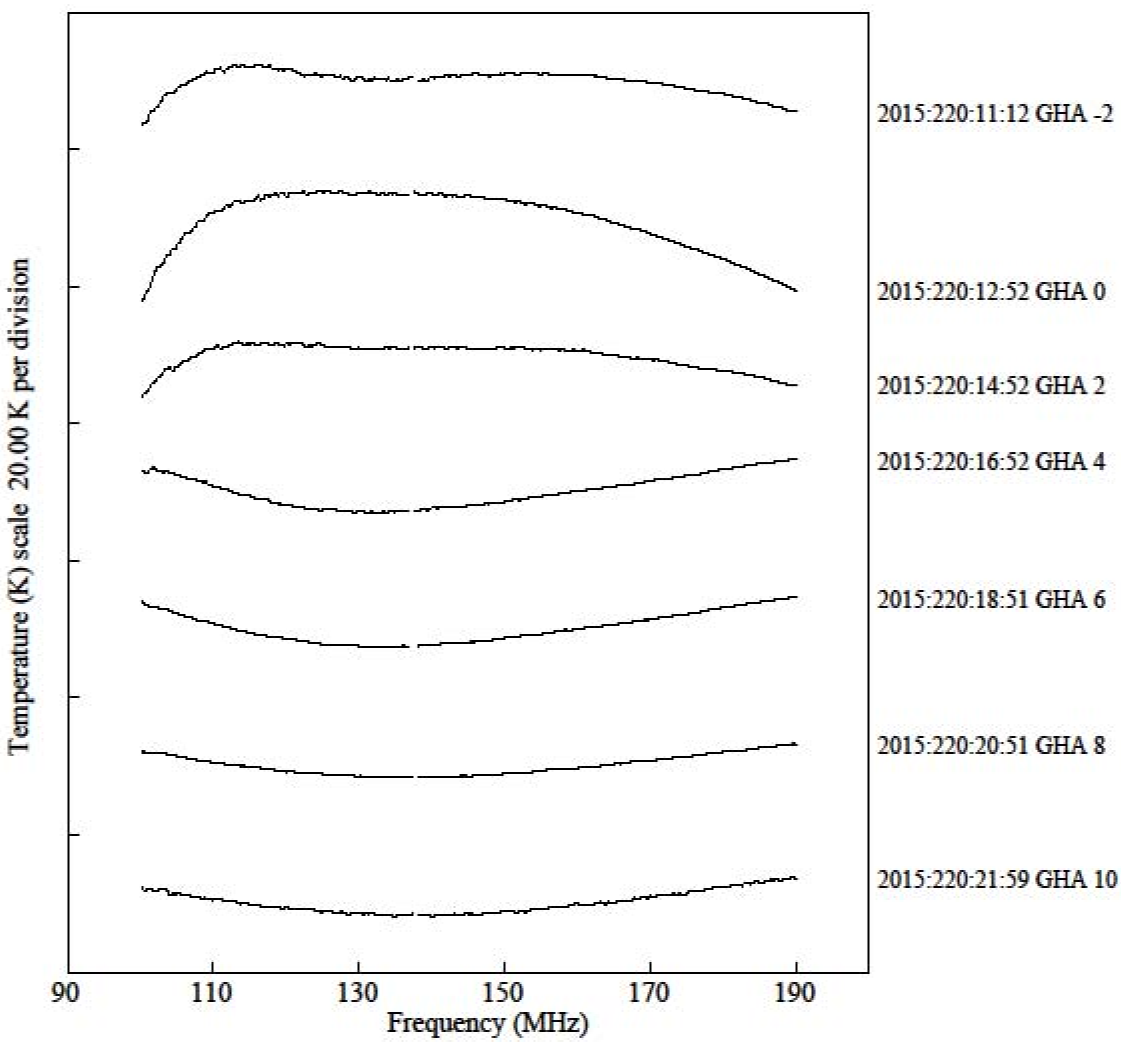

Figure 4. Nighttime 2 term fit without beam correction.

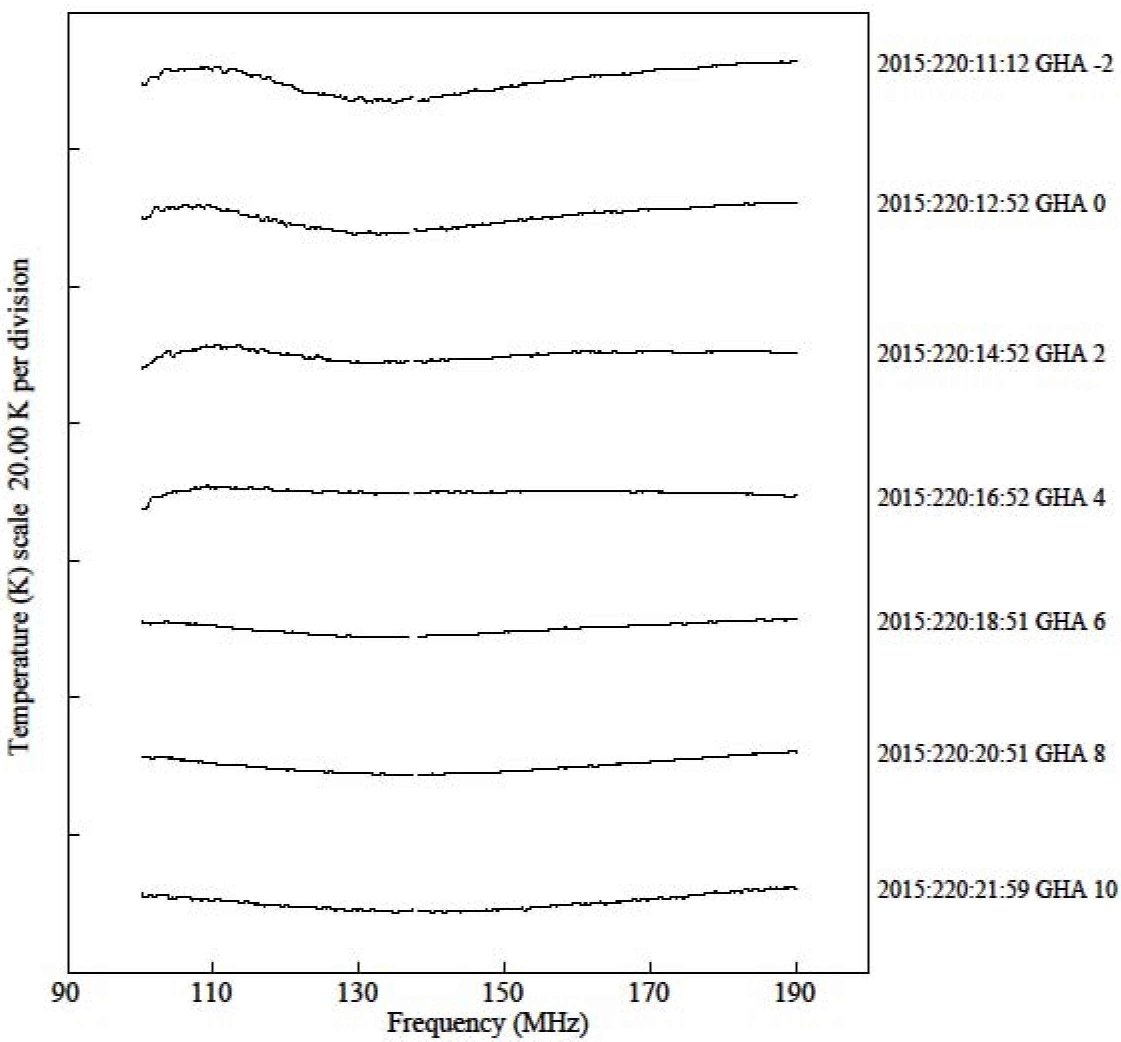

Figure 5. Nighttime 2 term fit with beam correction.

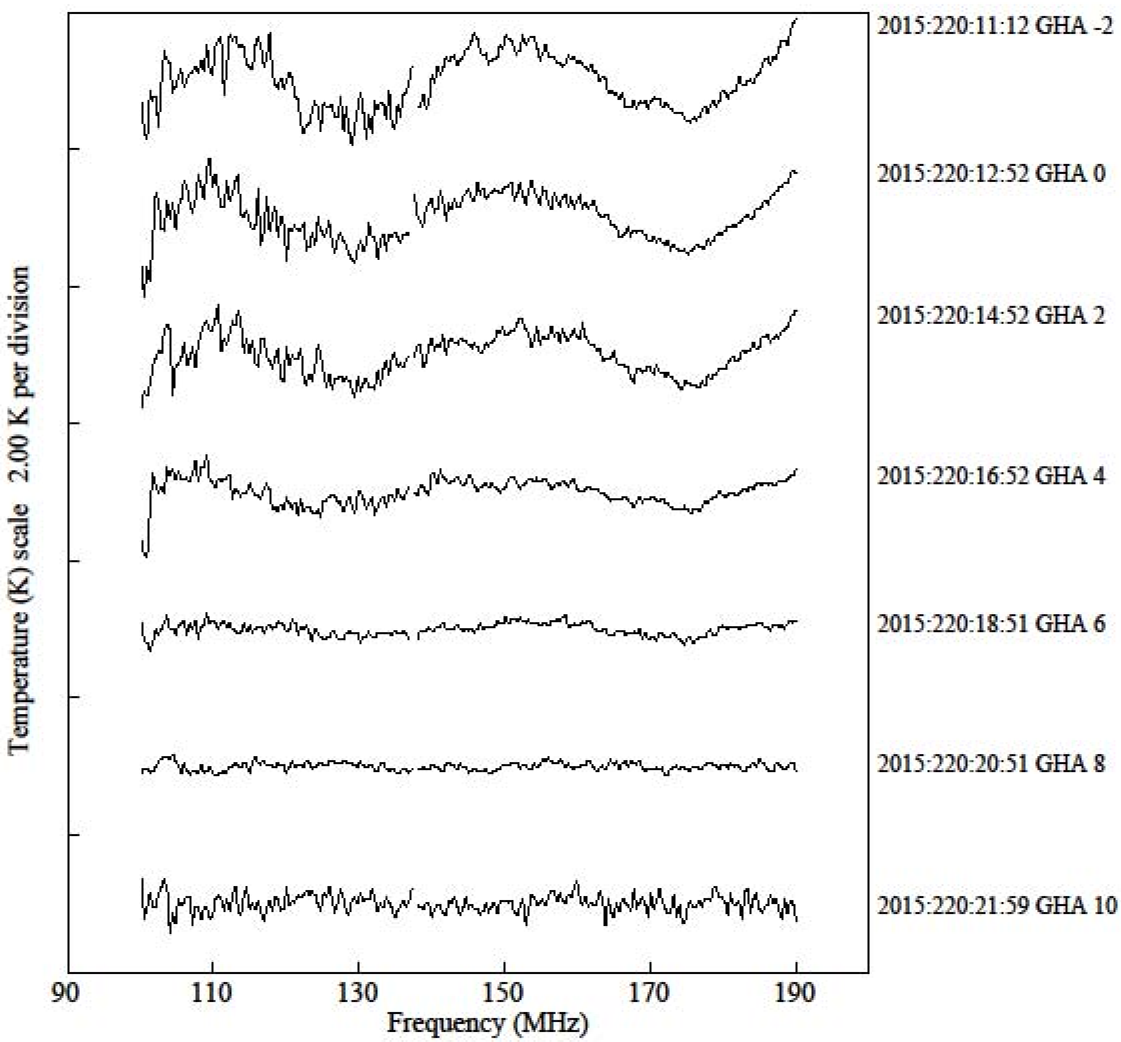

Figure 6. 5 term polynomial fit without beam correction.

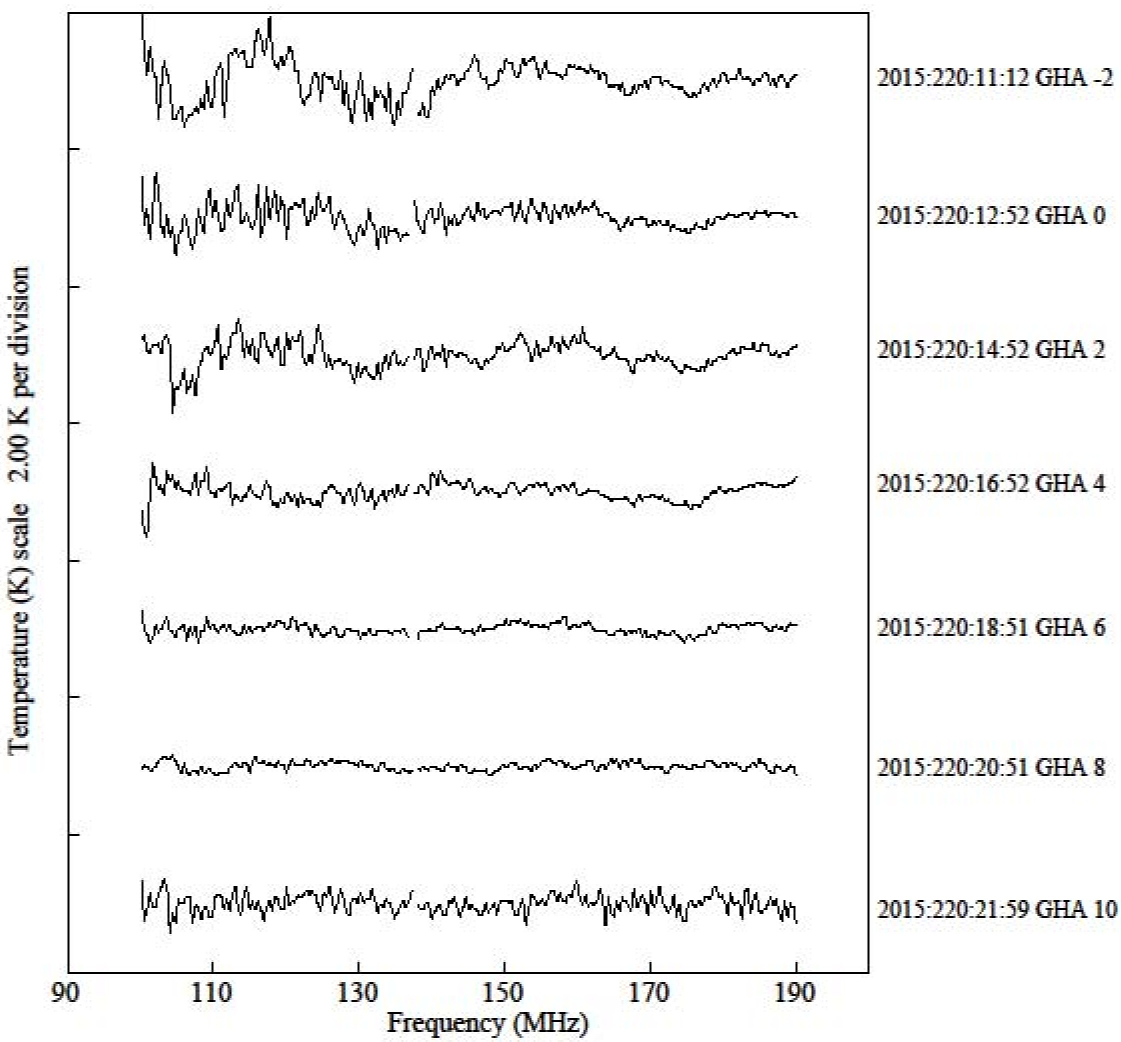

Figure 7. 5 terms fit using physical functions.

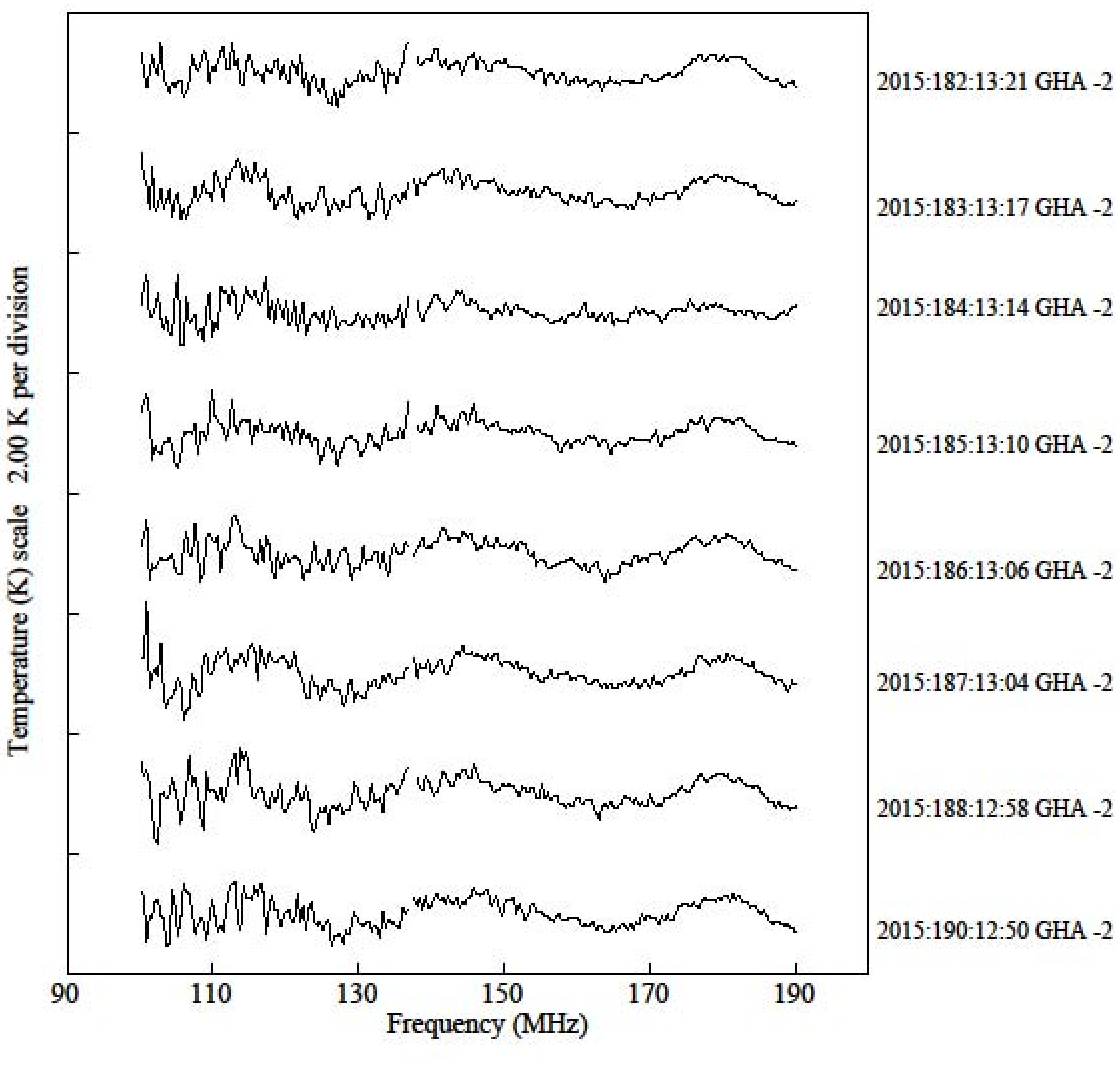

Figure 8. 6 term poly fit to Fourpoint.

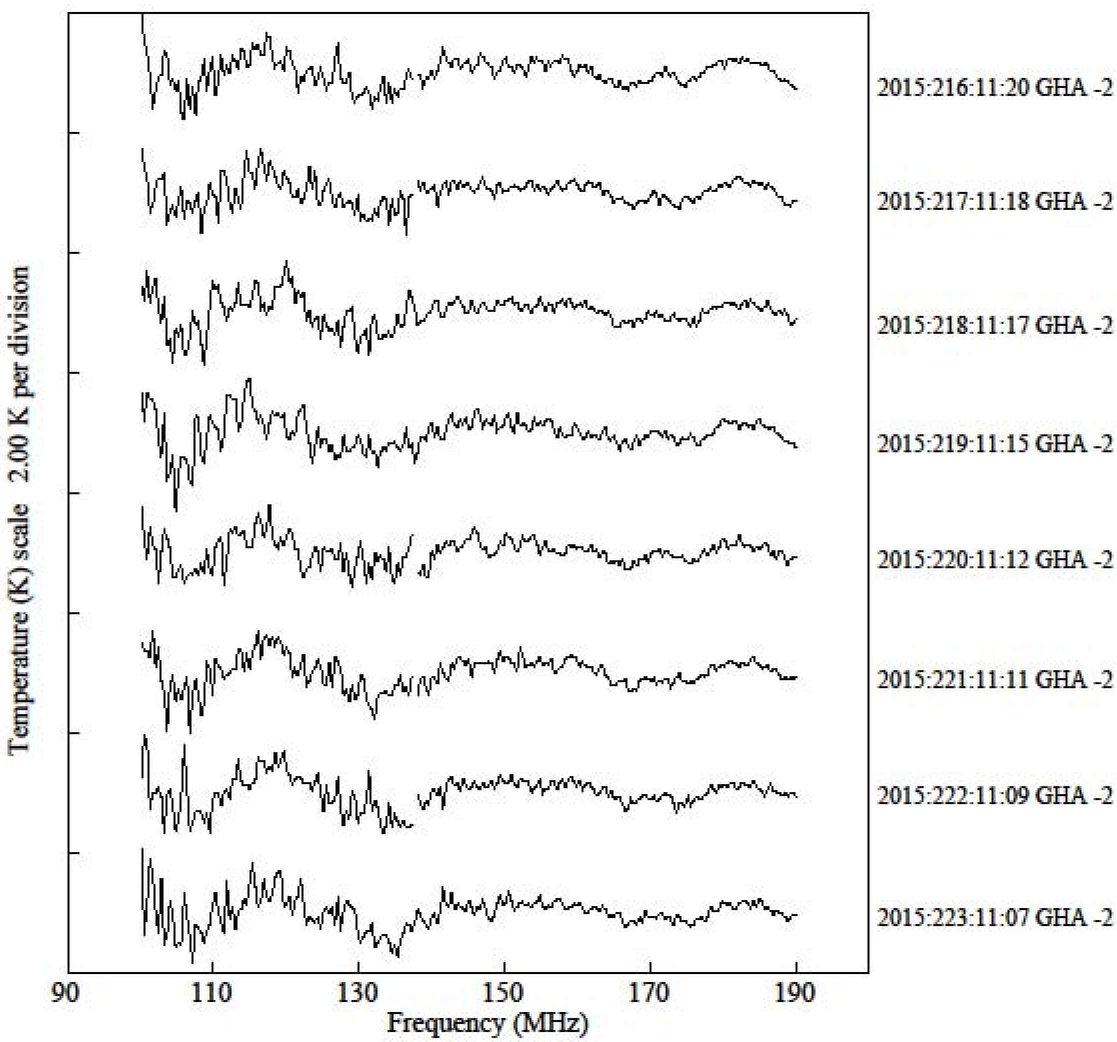

Figure 9. 6 term poly fit to Blade.

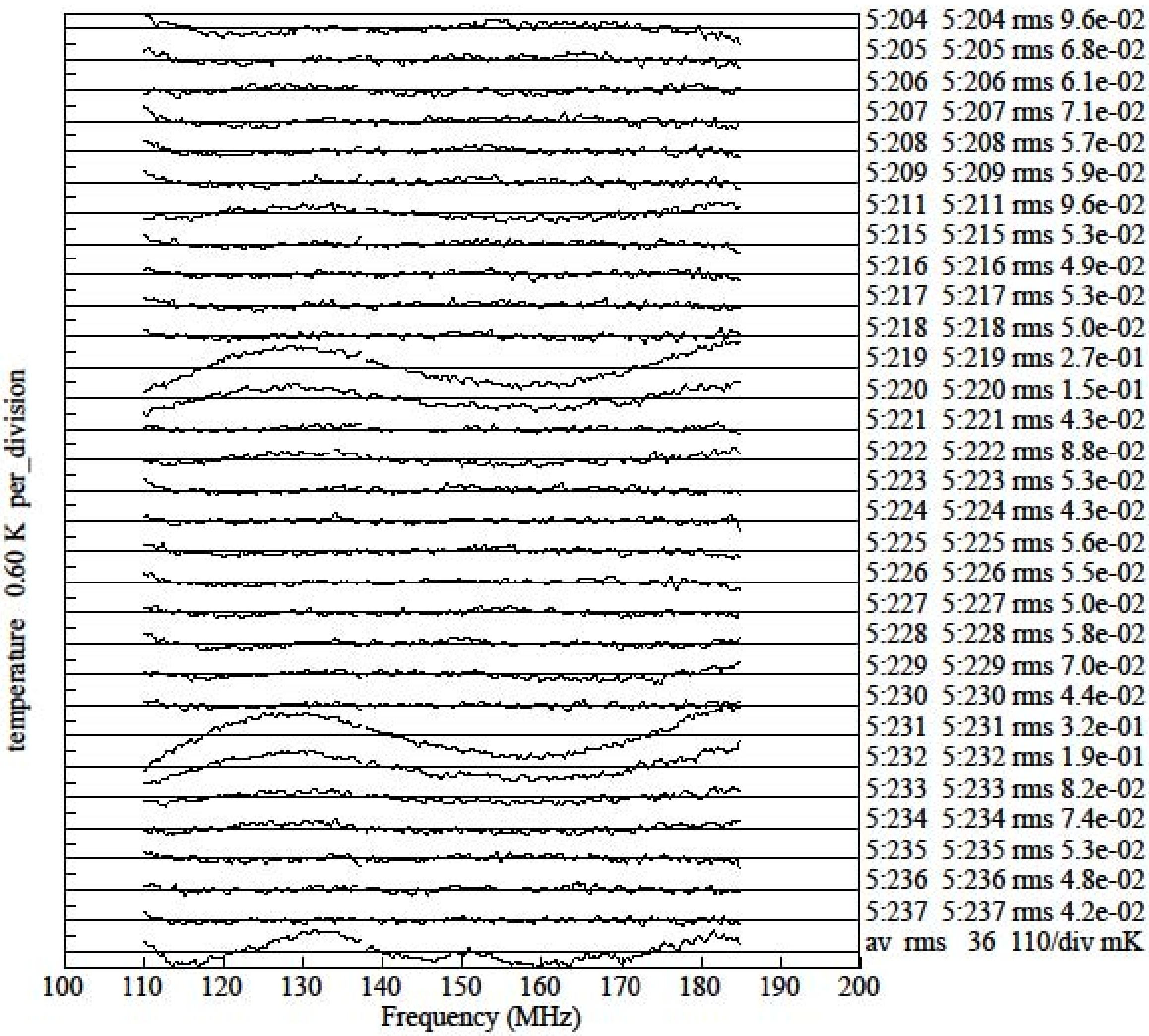

Figure 10. Galaxy down/up ratio spectra showing days 219, 220, 231, 232 have anomalies. Note the change of scale for average.

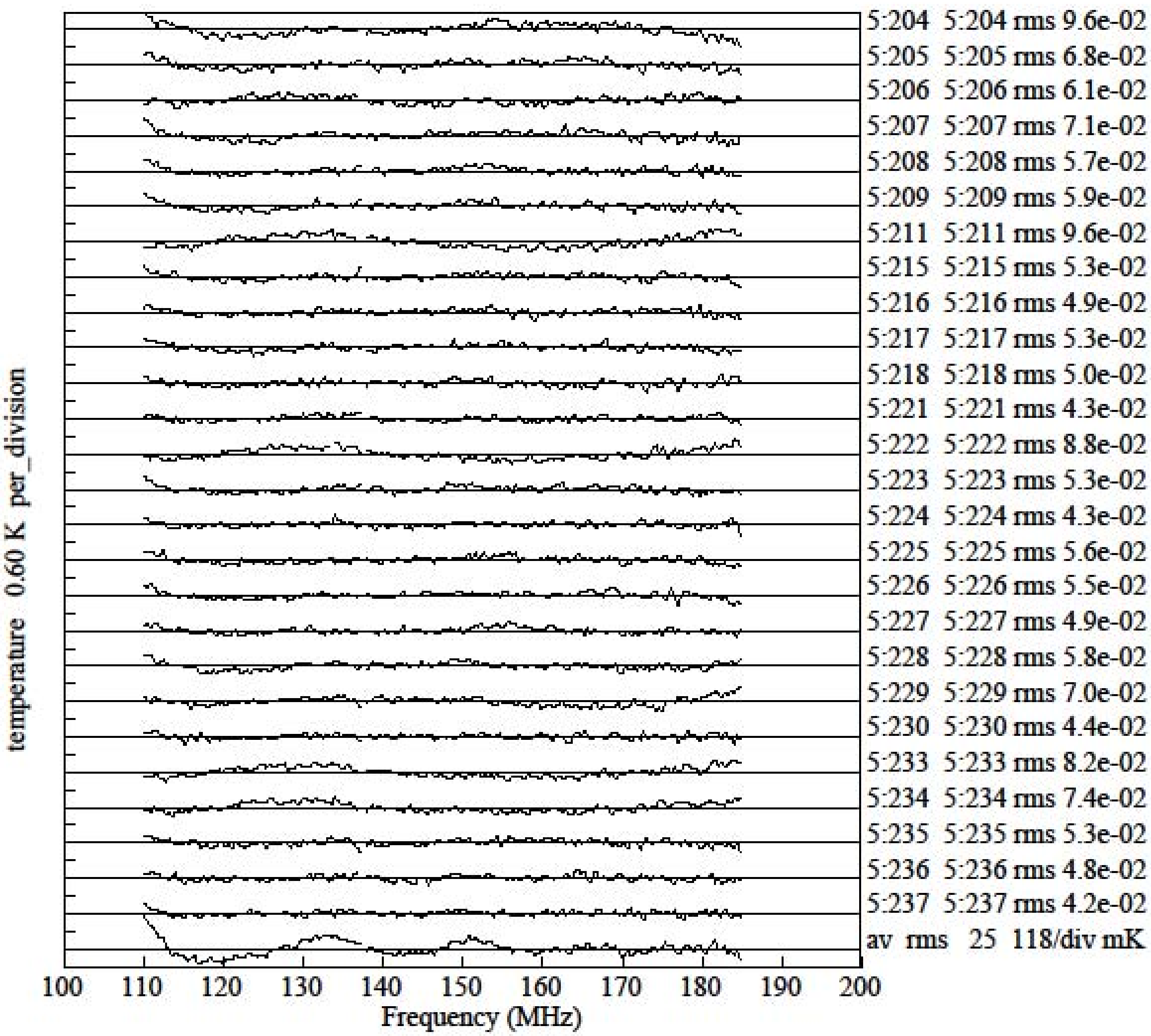

Figure 11. Galaxy down/up ratio spectra after removal of anomalous days.

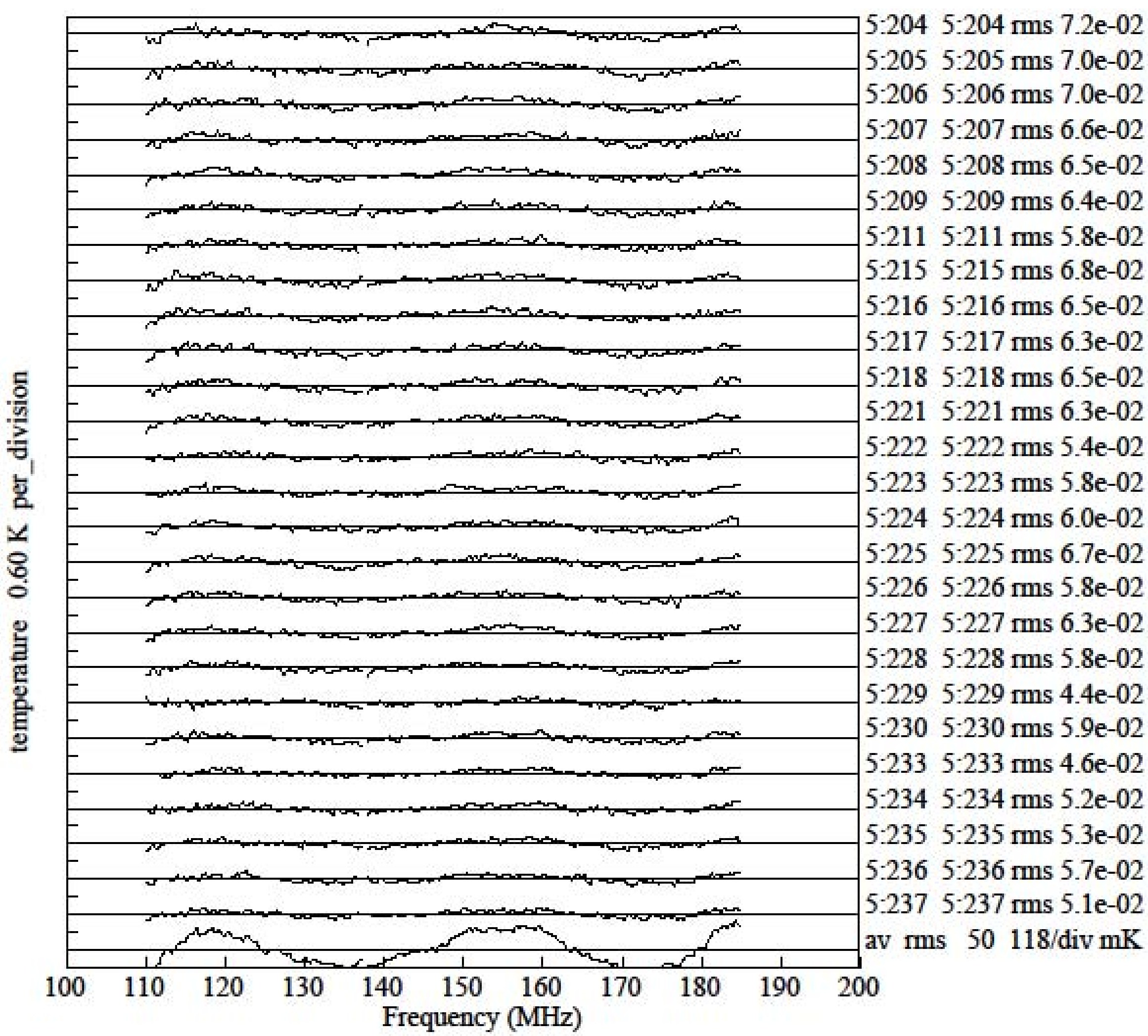

Figure 12. Galaxy down residual spectra with a 5 term poly removed.

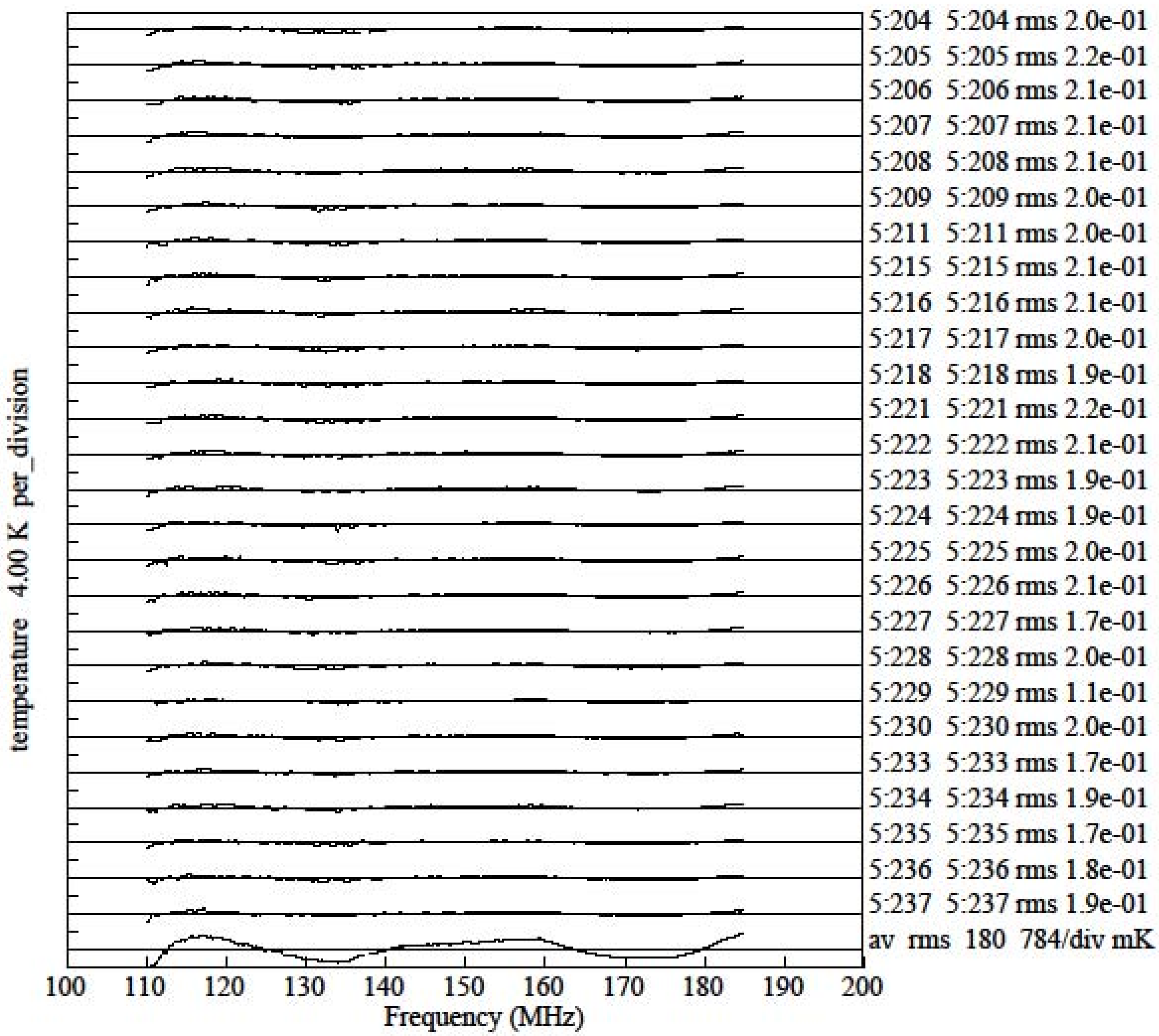

Figure 13. Galaxy up residuals. Note scale change.

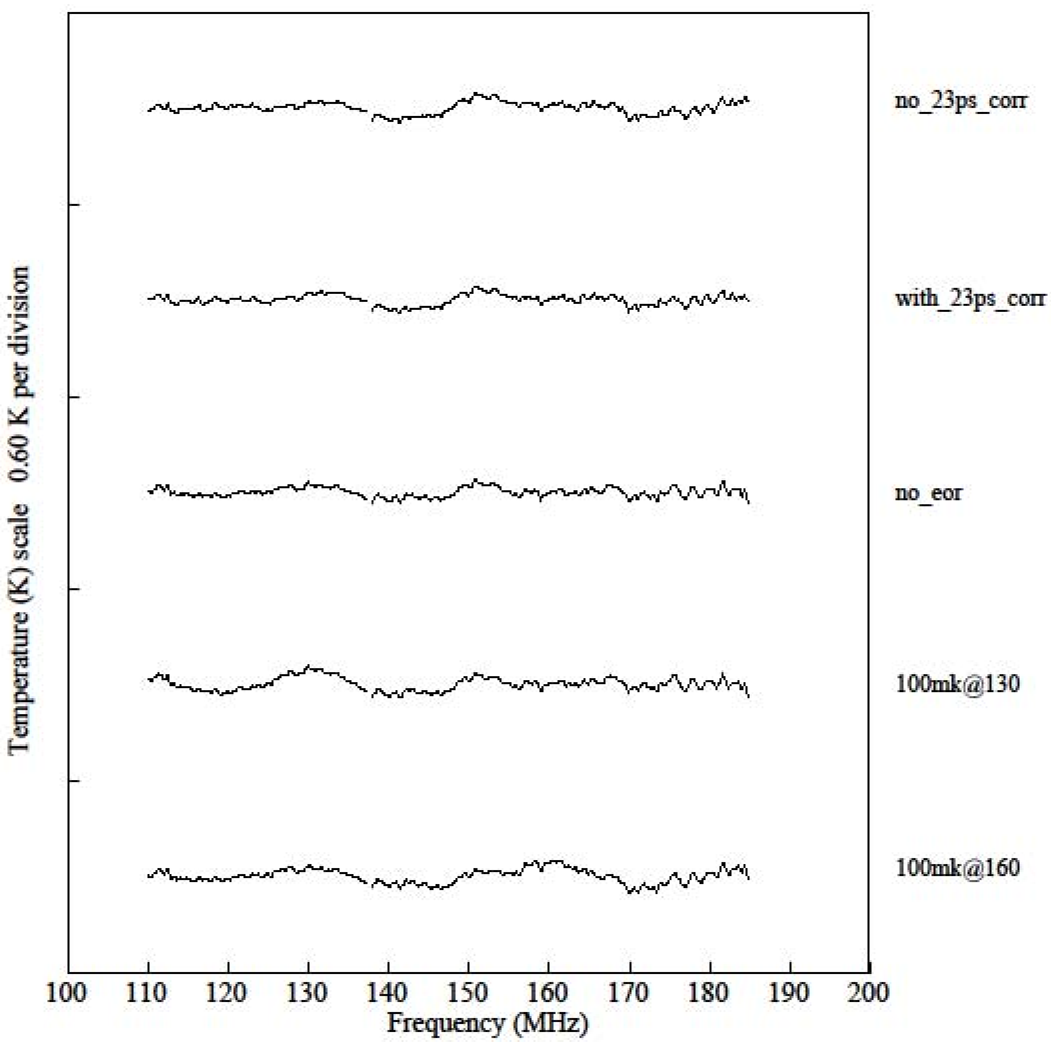

Figure 14. Galaxy Down/up ratio spectra with 5 terms removed. A 100 mK Gaussian EoR signature of 10 MHz half power full width has been added to the data in the bottom 2 spectra.

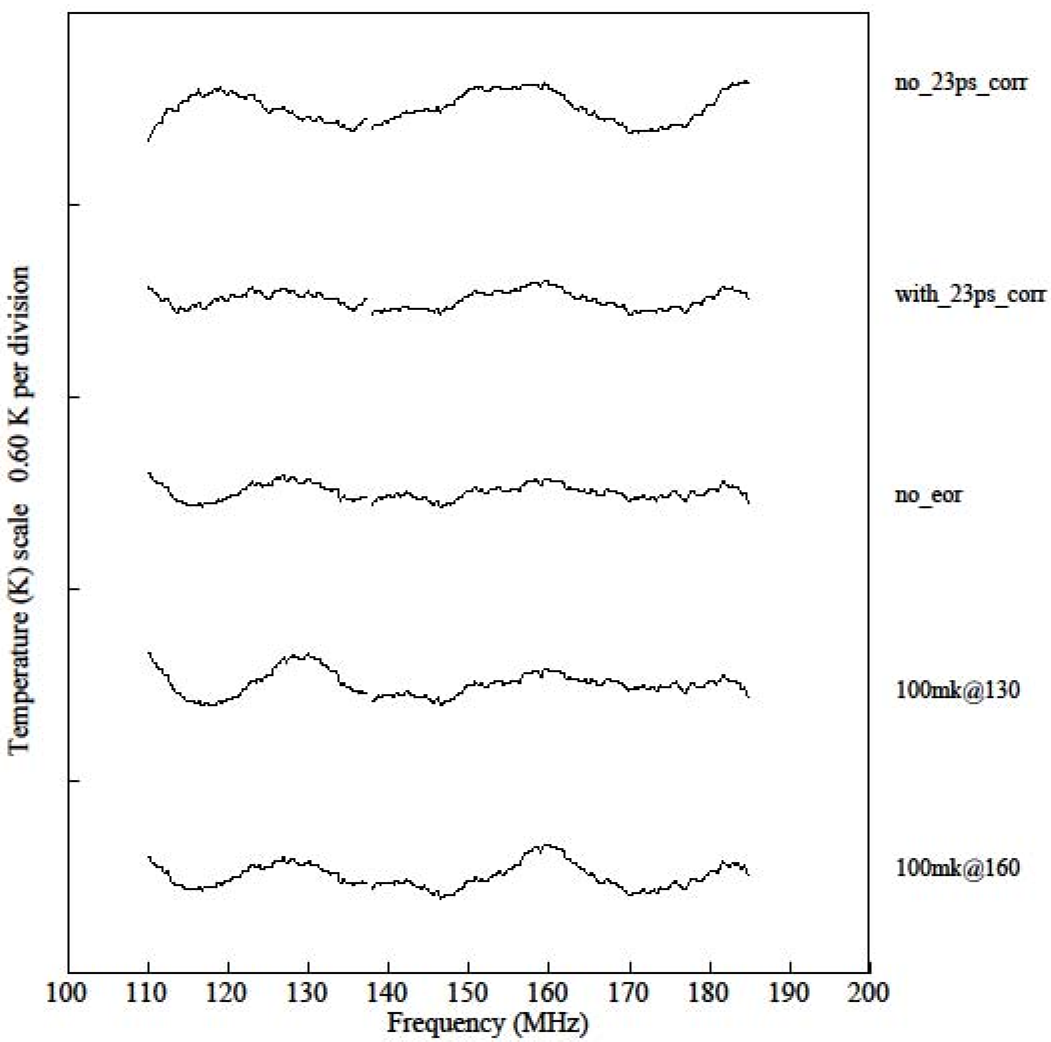

Figure 15. Galaxy Down with 5 terms removed.

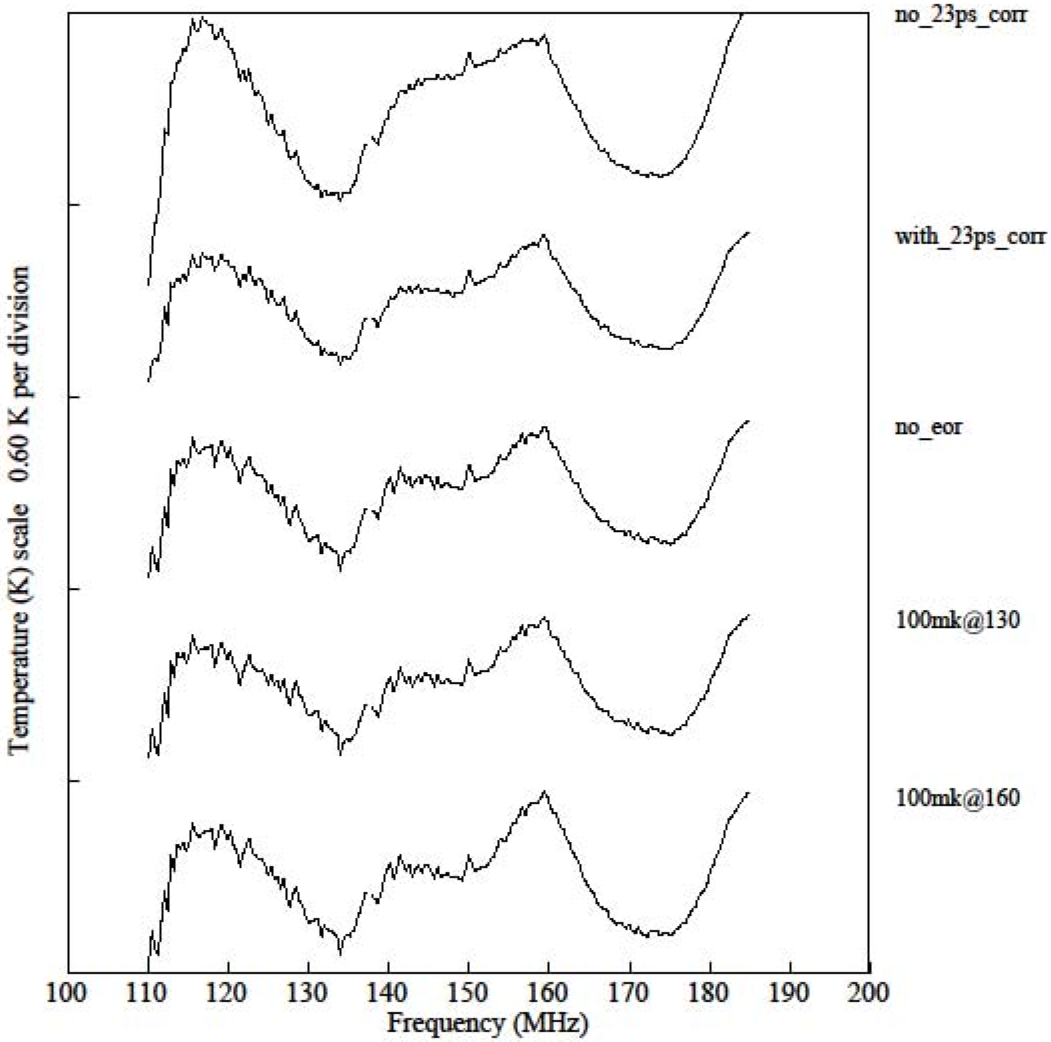

Figure 16. Galaxy up with 5 terms removed.