MASSACHUSETTS INSTITUTE OF TECHNOLOGY
HAYSTACK OBSERVATORY
WESTFORD, MASSACHUSETTS 01886

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Telephone: 617-715-5533
Fax: 781-981-0590

To: EDGES Group

From: Alan E.E. Rogers

Subject: Noise and fine frequency structure in EDGES data and simulations

1] Introduction

Verification of the absorption reported in Nature requires checking for a consistent absorption over the full range of GHA. Checking the results from the MRO in a range of GHA more than 6 hours from GHA = 12 is subject to a larger noise level owing to the larger sky temperature along with larger systematics due to S11 and calibration errors as well as larger beam chromaticity all of which increase at least in proportion to sky temperature. In the case of the beam effects the increase may be even greater. The check for absorption amplitude over GHA for lowband 1 data from 2016_251 to 2017_095 is given and discussed in memo 246. The detectability of an absorption with significant flattening, which has fine frequency structure, is made easier using more than 5 terms to remove the foreground and systematics. 6 terms was chosen in memo 246. More than 6 terms lowers the SNR that can be obtained due to a greater sensitivity to the noise and resolution of the absorption profile. For other datasets, which have less data or larger fine structure in the S11 data or beam effects it may be harder to verify the absorption closer than 8 hours from the transit of the Galactic center. For example, recent lowband2 data taken with antenna oriented at 42 degrees azimuth has “ripple” in the antenna S11 data which can be corrected assuming it is the result of I/Q crosstalk in the VNA as discussed in memo 333 but even with correction there are still questions of the quality of the S11 data.

This memo explores the effects of noise and filtering of the S11 and beam chromaticity further. While it is known that the beam data has noise and accuracy issues (see memos 231, 258 and 277) it is not clear at what point too much filtering removes real beam effects and real structure in the antenna S11.

2] Simulations of beam filtering

Figure 1 shows the residuals to a 5-term physical fit to data that is simulated for 1 hour blocks for low2-45 with 12-term polynomial filtering of the beam processed without any filtering of the beam. The plot is for a soil conductivity of 2e-2. Table 1 summarizes the results for other cases.

Soil conductivity S/m	average of rms K	GHA for no detection	comments
2e-1	0.025	21	
2e-2	0.045	1,15,21,23	Plot in Figure 1
2e-3	0.070	0,1,5,15,19,20,21,22	
2e-2	0.035	1	Proposed 48x48m
Infinite PEC	0.002	none	

Table 1. Results for different soil and ground planes.

The GHAs for which an absorption amplitude less than 0.1 or greater than 1 K is detected when an absorption 0.5 at 78 MHz, width 19 MHz and tau=7 was added to the simulation or equivalently a “false” detection is made when no absorption is added.

3] Simulations of S11 filtering

Figure 2 shows the residuals to a 5-term physical fit to data that is simulated for 1 hour blocks for low2-45 with antenna S11 from low2-45 fit with a 12-term polynomial and processed with the “filtering” of a 9-term polynomial.

S11 change	Average of rms K	Range of absorption	comments
9-term filter	0.034	0.48 to 0.59 K	plot in Figure 2
30 ps in S11	0.030	0.47 to 0.49 K	
0.1 dB in S11	0.052	0.52 to 0.54 K	

Table 2. Effect of excessive filtering of antenna S11

The effect of using fewer than 12-terms to filter the antenna S11 results in systematic error. Unlike the filtering of the beam the systematic errors due to antenna S11 filtering and other instrumental errors like an error in calibration load resistance and others in memo in table 1 of memo 332 result in a spectral error that whose amplitude scales with sky temperature. Also, unlike beam errors which are reduced by averaging over GHA the instrumental errors are not reduced by averaging.

4] Noise effects

The noise in the spectra from 4 hour blocks of low2-45 data taken on 2020_120 is shown in Figure 3. The rms noise is 100 mK at 75 MHz for a 4 hour block at GHA=12 hours. The rms increases in proportion to the sky temperature with frequency and with GHA. Looking at longer averages it is seen to decrease with the square root of time so that a rms noise of 10 mK at 75 MHz is reached in 400 hours. Checking the absorption profile using a 4 hour block each day requires 100 days to get the rms noise to 30 mK as the sky is about 3 times brighter at GHA=0 hours. In addition, 6 terms are needed to remove the foreground and systematics. The following results are obtained from low2-45 2020_055 to 140.

GHA	Amplitude K	SNR
00	0.40	4.2
04	0.24	3.1
08	0.37	6.5
12	0.30	7.5
16	0.69	15
20	0.24	1.5

Table 3. Absorption vs GHA from low2-45 data using 7-term polynomial with fixed center and width of 78 and 19 MHz and fixed tau = 6 and soils conductivity 2e-2 S/m.

5] Comparison of low1 and low2-45

Figure 4 shows the 5-term residuals from physical model for 1-hour blocks of data at each GHA along with a grid search for the best fit absorption using the average over all GHA and fixed tau=7. Some tests have been made using the average of the rms residuals with 5 physical terms removed from 52 to 95 MHz for each GHA as a metric. The lowest average rms of 137.3 mK is found for the following parameters:

S11 filtering	9-terms 50 – 100 MHz
Beam filtering	12-terms 50 – 100 MHz
Antenna azimuth	42 +/- 1 degree
Soil conductivity	4e-2 S/m

6] General conclusions

a) Beam chromaticity

Some filtering of the beam is needed to remove “ripple” in the beam correction. A 12-term polynomial over 50 – 100 MHz is adequate. The beam chromaticity increases by more than the increase in sky temperature near transit of the galactic center. There is also an increase around GHA = 14 when the galactic plane is at the zenith again 10 hours before the Galactic center transits at the MRO. Beam correction using soil conductivity of 4e-2 S/m is found to minimize the average rms in the low2-45 data residuals.

The beam chromaticity effect are reduced by averaging over GHA. The absorption grid search obtained from an average over all GHA shown in the lower plots of Figure 3 are in reasonable agreement with the Nature result for both low1 and low2-45.

b) Systematics

The residuals to instrumental systematics have a shape whose amplitude scales with sky temperature and do not average down with GHA so that an accurate absorption measurement is best made in the GHA range with the lowest sky temperature but systematics can be identified by analyzing data over the full range of GHA.

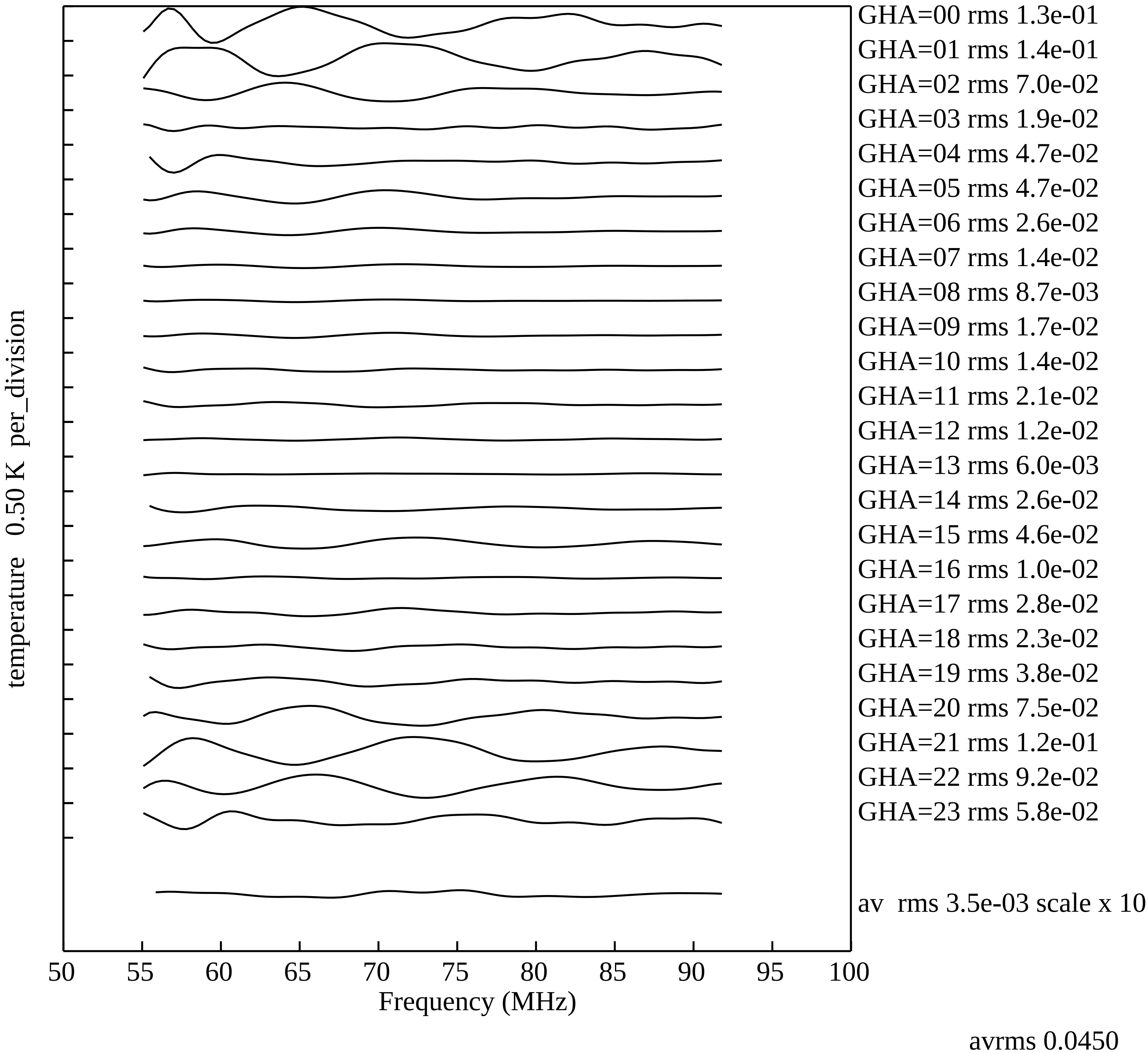

Figure 1. Simulation of the effect of beam filtering vs GHA.

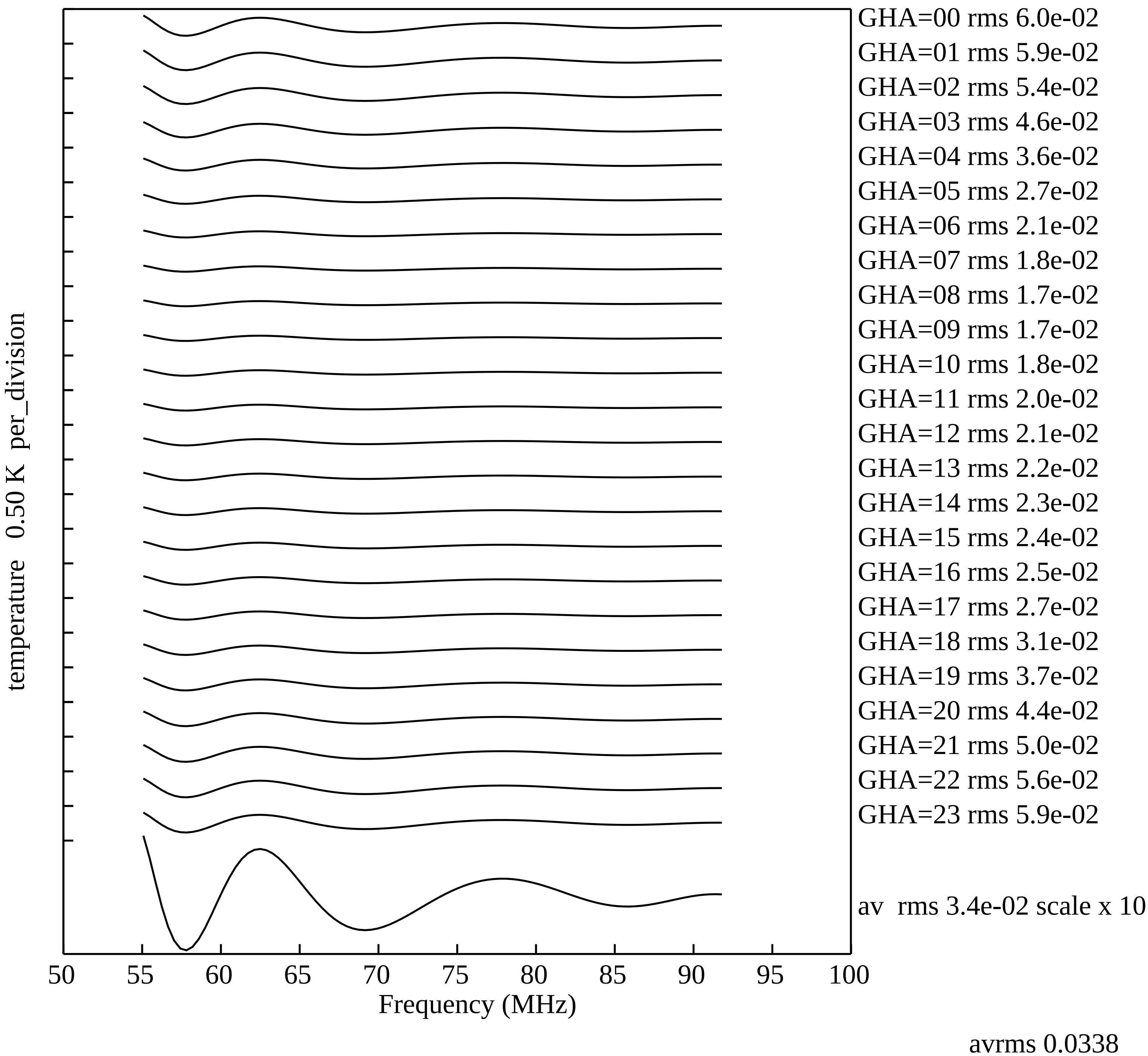

Figure 2. Simulation of the effect of systematic error in S11 or calibration vs GHA.

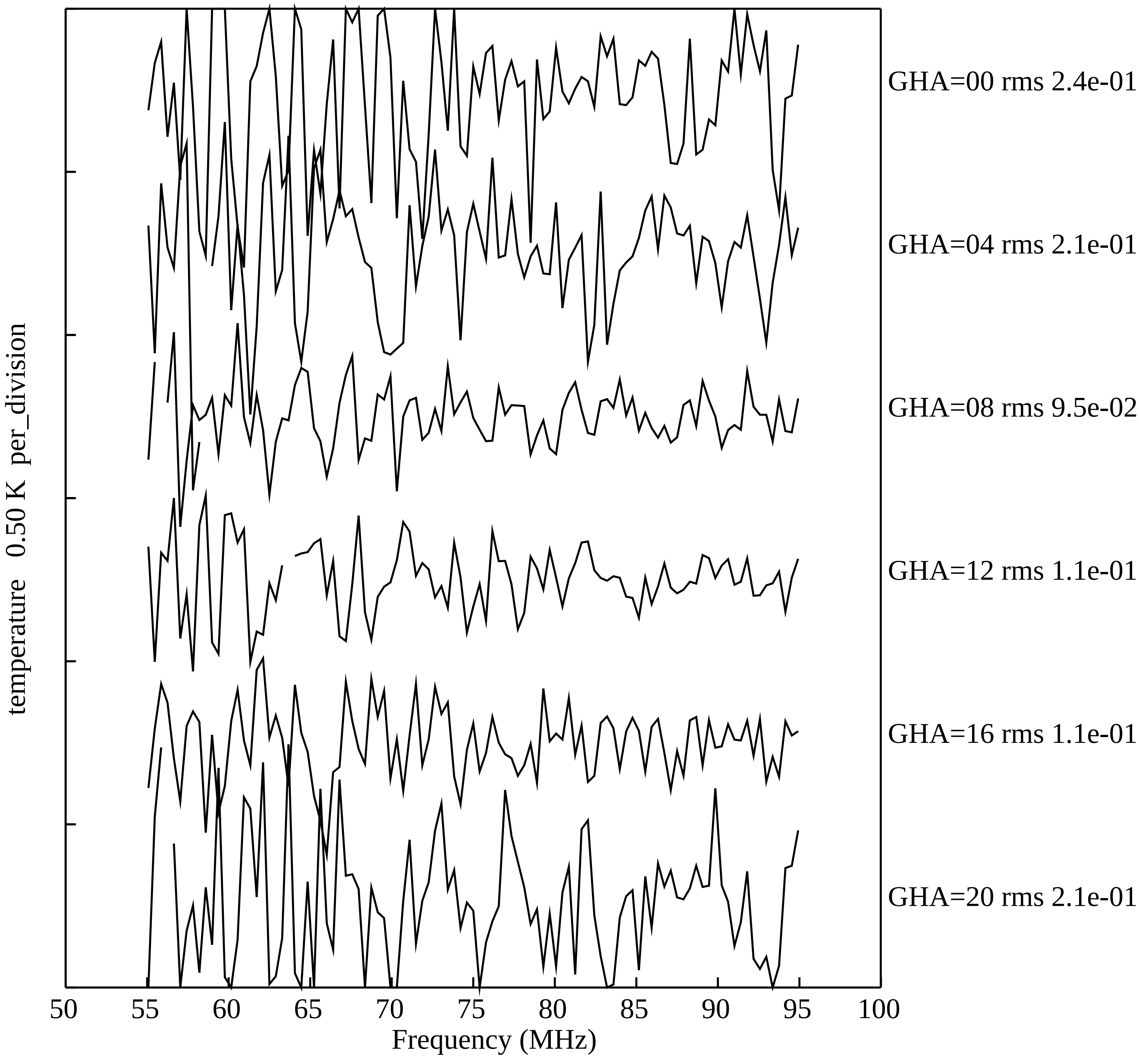

Figure 3. Observed noise in 4 hour blocks of low2-45 data vs GHA.

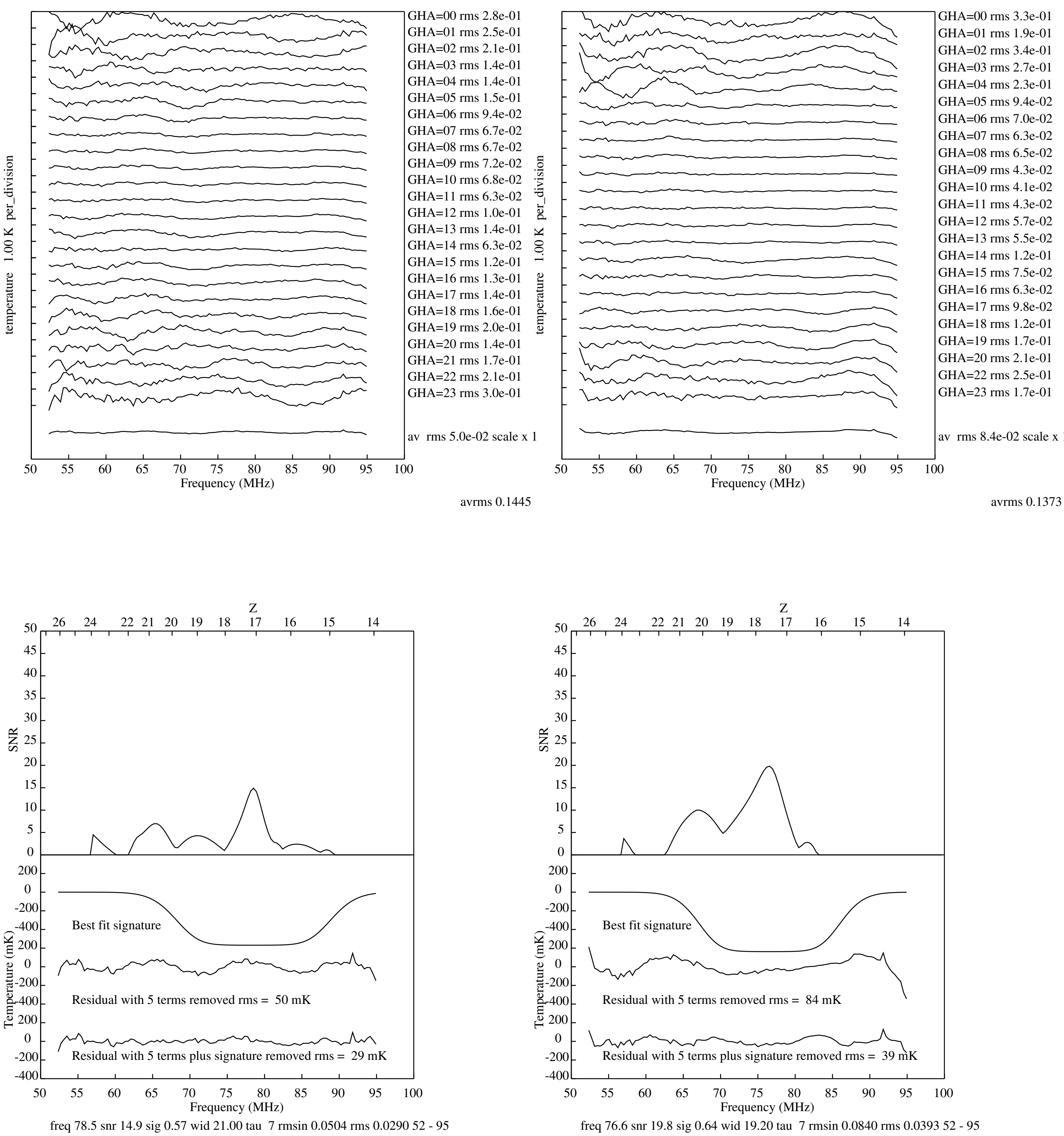

Figure 4. Comparison of low1 on the left and low2-45 data on the right.