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To: EDGES group
From: Alan E.E. Rogers
Subject: Summary of EDGES-3 results from the WA from 2023

The EDGES-3 global 21-cm antenna with its internal electronics was installed at the WA in November 2022 on the new 48x48m welded mesh ground plane. The details of the installation are described in memo 406. A resonance at a level of about 0.5K at 75 MHz was observed in the data from 2022:319 to 2023:006 (see memo 407) which turned out to be due to a resonant slot in the baseplate as suggested in memo 408. This resonant slot was eliminated by adding screws to the baseplate to shorten the length of any slots to move any resonances to frequencies up above the EDGES band.

After fixing the resonance in the baseplate good data was analyzed starting on day 54 of 2023. Automated receiver calibrations were made every few days and for processing used spectrometer calibration from day 210 for days 54 to 275 when the electronics were temperature controlled to 30C and the calibration from 2022 day 316 for days after 275 when the temperatures in the electronics were controlled to 35C. Owing to the high temperature in the hut during the summer and the inability of the temperature control to maintain 35C some data, especially during the day when the high temperature has been taken the electronics temperatures above 35C but this is not critical because most data taken during the day is not used owing to the RFI from solar activity.

The 21-cm absorption results are more sensitive to antenna S11 error than to receiver calibration error which is most sensitive to the LNA S11 (see memo 368 for details). A significant improvement in antenna S11 measurement accuracy was made on day 68 and used thereafter by averaging multiple cycles of shorter VNA calibration as described in memo 412. The antenna box separation was brought under better control following the installation of nylon parts to ensure a constant separation on day 275. The antenna S11 were made every day and the following sequence was used for this analysis:

days	S11 used
54-97	70
98-149	99
150-199	155
200-224	263
225-234	99
235-262	263
263-274	277
275-284	2022-316
285-364	286

Table 1 Antenna S11 used

The last antenna S11 file prior to the failure of the Fieldfox VNA was on day 308. However with the nylon parts in place the EDGES-3 antenna S11 should be as stable the EDGES-2 antenna S11 for which infrequent S11 was needed.

The results of a study of ground plane resonances studied in memo 412 for a range of Galactic Hour Angle (GHA) from 0 to 6.5 hours in 30 minute blocks from day 54 to 174 is extended to cover day 54 to 348 in Figure 1 which shows the residuals are similar for day 54 to 200 and from day 201 to 348 in the lower two plots with the upper left plot which averages over the full range of day 54 to 348. The upper right plot, for which there was no beam correction is a little different than the plot on the lower right especially at GHA below 2 hours. The overall conclusion is that there may still be additional slot resonances in the ground plane as discussed in more detail in memos 429 and 435.

Figures 3 and 5 of memo 432 compare an absorption search with and without beam correction which show that the beam chromaticity effects are not large and Figure 2 shows the residuals with 5 term loglog polynomial removed. It is noted that the fine structure in the beam correction in the 20 to 23 hr range of GHA is seen in the beam chromaticity using the Haslam map it is not seen in the data and not seen in the beam chromaticity using Guzman map. After a further analysis it was found that this is because when the Haslam map is scaled from 408 MHz to 60 MHz with a spectral index of -2.5 the point sources, which have a spectral index closer to -1.0, have their flux increased by a factor of 2 compared with the flux of these sources in the Guzman map which have flux closer to the actual flux since the map was made at 45 MHz. Simulations show that the most likely point source, whose flux is raised too high and produces the residuals in Figure 3 which are not observed in the data are from Centurus A NGC5128. Pagano et al. 2024 discuss accounting for map errors and they show the typical map errors in figure 5 of the paper. In practice most of the errors which have a spatial structure smaller than the scale of the structure in the antenna beam which is approximately given by the wavelength divided by the diameter of the ground plane have the largest effect on the beam chromaticity. The point sources which have the largest effect on the chromaticity are Cassiopea A for antenna sites in the northern hemisphere and Centurus A for sites in the southern hemisphere. Spectral data for these sources can be factored into the sky map by adjusting the temperature of the pixel at the location of the point source to obtain the correct flux in the EDGES frequency range. See Baars et al. for the source fluxes vs frequency and the table of coordinates in the Reeve Celestial Radio Source Map document.

The search for the 21-cm absorption made from day 54 to 398 in Figure 2 of memo 432 is updated to cover day 54 to 351 with a change in the nrfi parameter from 4 down to 2 which makes a small improvement in SNR by reducing the number of frequency channels on either side of a channel which exceeds the RFI threshold that are weighted to zero. Figure 4 shows the results using the Haslam map on the left, the Guzman map in the middle and no beam correction on the right. In all cases a flattening of tau = 4 tends to produce a better fit with lower residuals than tau = 7. This is also true for the EDGES-2 data on EW baseline analyzed in memo 272 and the combined EDGES-2 low and midband data used in the analysis in memo 286.

There is some remaining RFI structure in the plots due to a limited ability to remove all the strong FM that is produced by reflections from satellites, the space station and meteor showers. These can be eliminated by reducing the FM band threshold in the acqplot function from maxfm 2000 to maxfm 200 but this severely limits the amount of available data so that a better solution is to lower the rfi threshold from 2.5 to 2.1 sigma and Figure 5 shows the reduced RFI effects which result in a drop in the rms following the absorption fit from about 20 mK in the plots in figure 3 to 17 mK in Figure 4. Figure 6 is a plot of the grid search on the same data as Figure 5 with the bandwidth extended to cover 55 – 104 MHz.

Figure 7 shows the estimates of the errors in the center frequency, width, depth of the absorption and flattening tau are made using delta Chi-squared boundaries (see memo 272 for details of the algorithms used) for the same data used in Figure 5. This method is based on Gaussian noise and does not account for additional errors in the parameters due to systematics.

In summary EDGES-3 data from the WA provides a good confirmation of the EDGES-2 results. More data and simulations should help gain a better understanding of the residuals at low galactic hour angles.

References:

Pagano, M., Sims, P., Liu, A., Anstey, D., Handley, W. and de Lera Acedo, E., 2024. A general Bayesian framework to account for foreground map errors in global 21-cm experiments. *Monthly Notices of the Royal Astronomical Society*, *527*(3), pp.5649-5667.

Baars, J.W.M., Genzel, R., Pauliny-Toth, I.I.K. and Witzel, A., 1977. The absolute spectrum of CAS A-an accurate flux density scale and a set of secondary calibrators. *Astronomy and Astrophysics, vol. 61, no. 1, Oct. 1977, p. 99-106.*, *61*, pp.99-106.

https://reeve.com/Documents/Articles%20Papers/Reeve_CelestialRadioSources.pdf

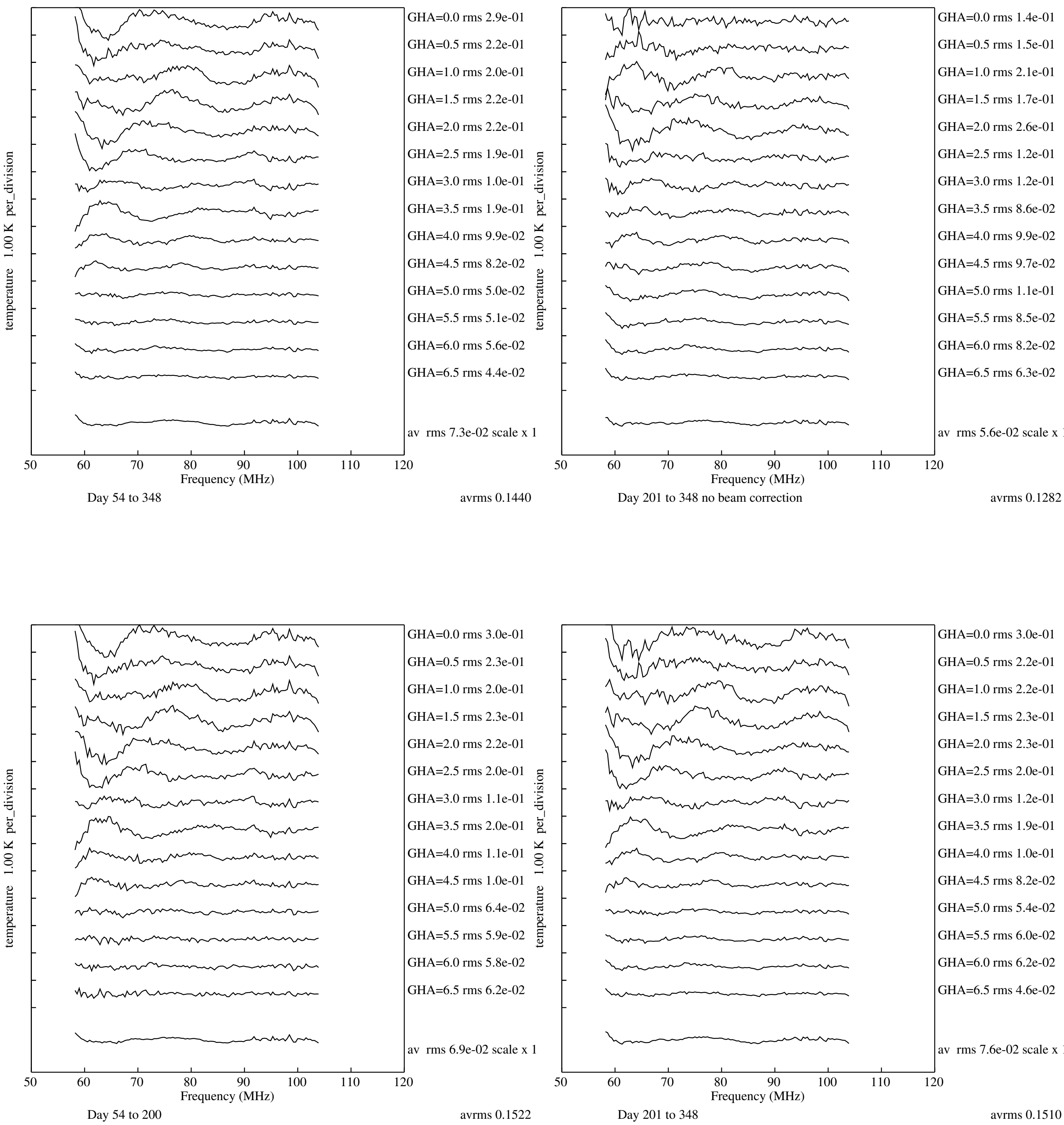

Figure 1. Residuals for 5-terms removed for 30 blocks of GHA

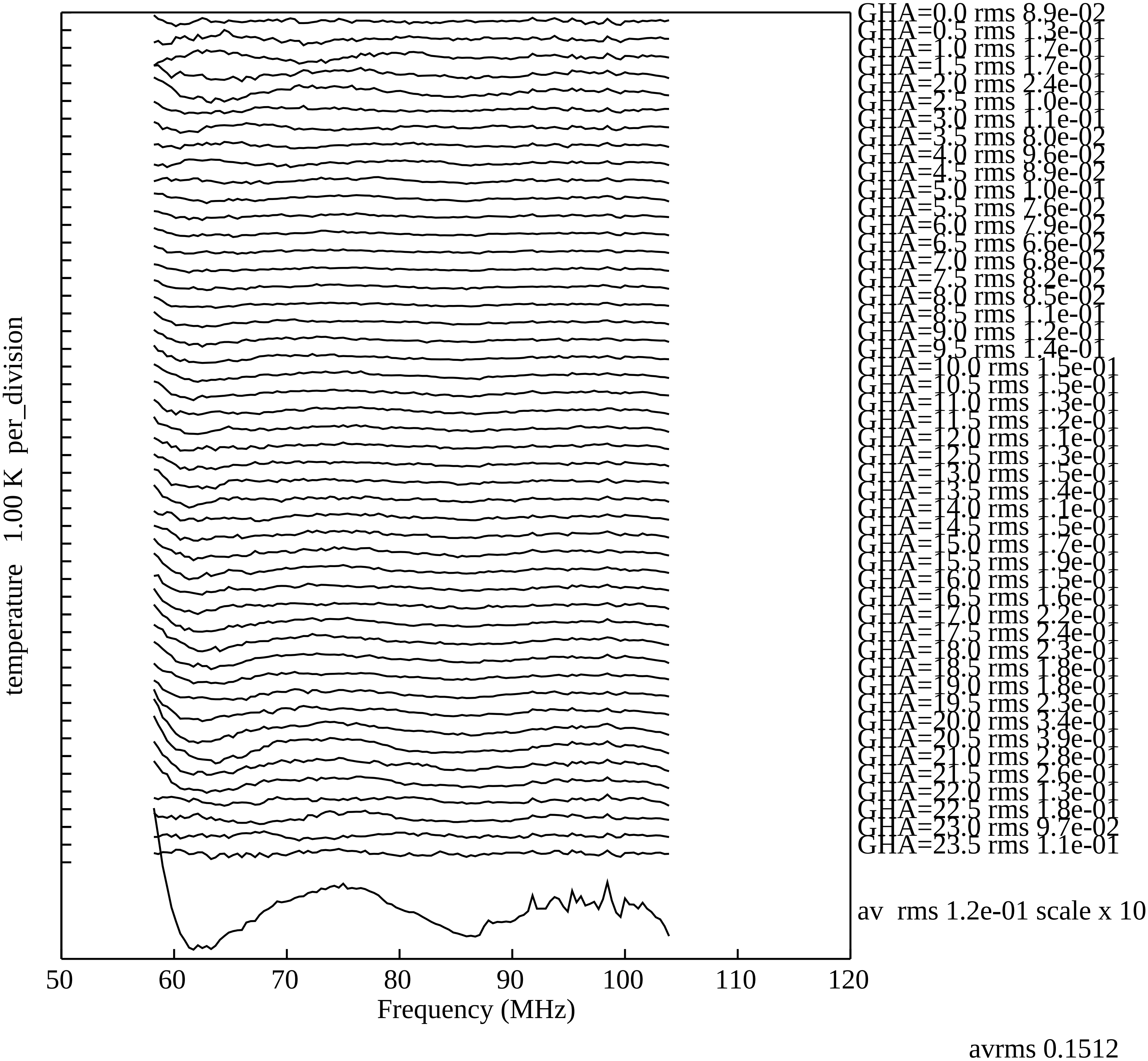

Figure 2. Residuals vs GHA for days 54 to 351 in 30 minute blocks without beam correction.

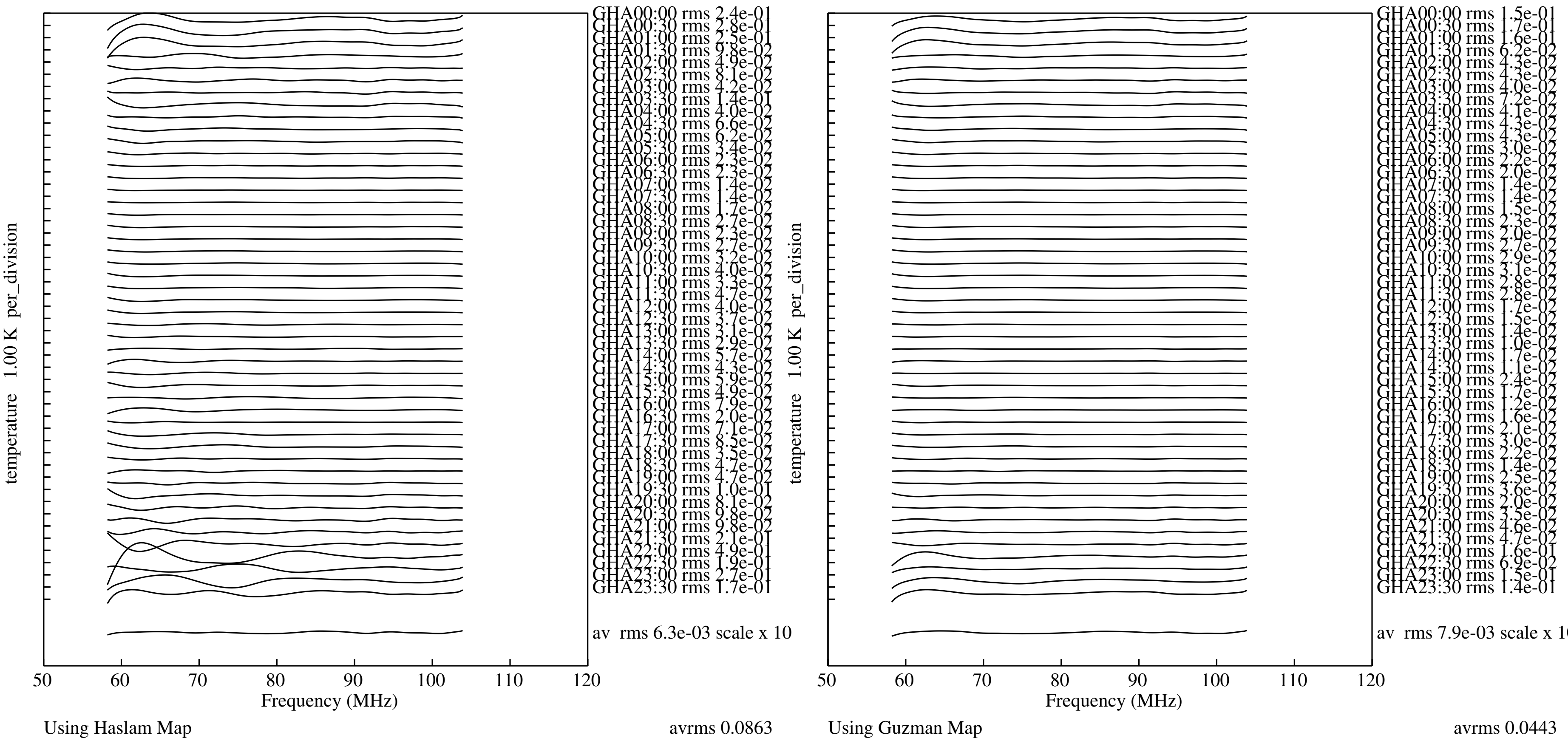

Figure 3. Beam chromaticity with 5-terms removed using Haslam map on left and Guzman map on right.

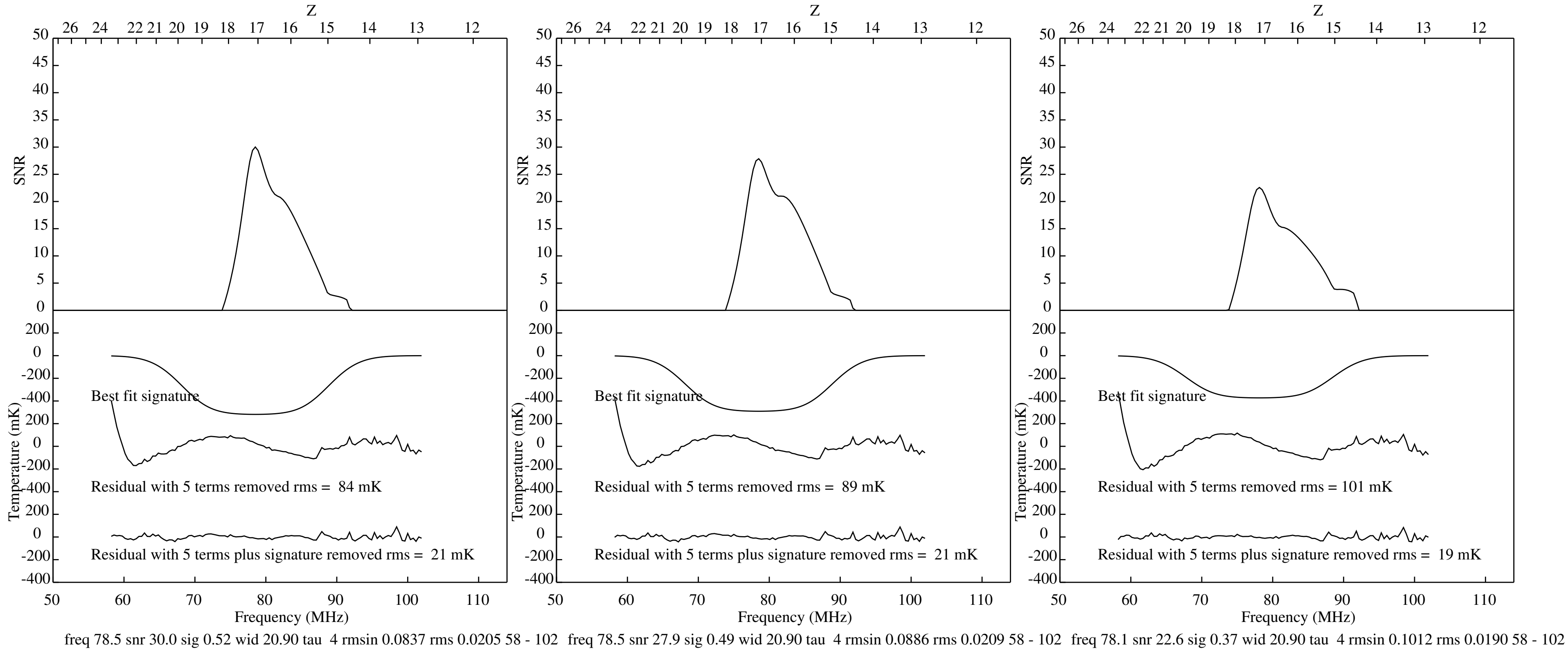

Figure 4. Grid search for 21-cm absorption using 5 loglog terms and fixed tau = 4 and one hour blocks from 06 to 18 GHA.

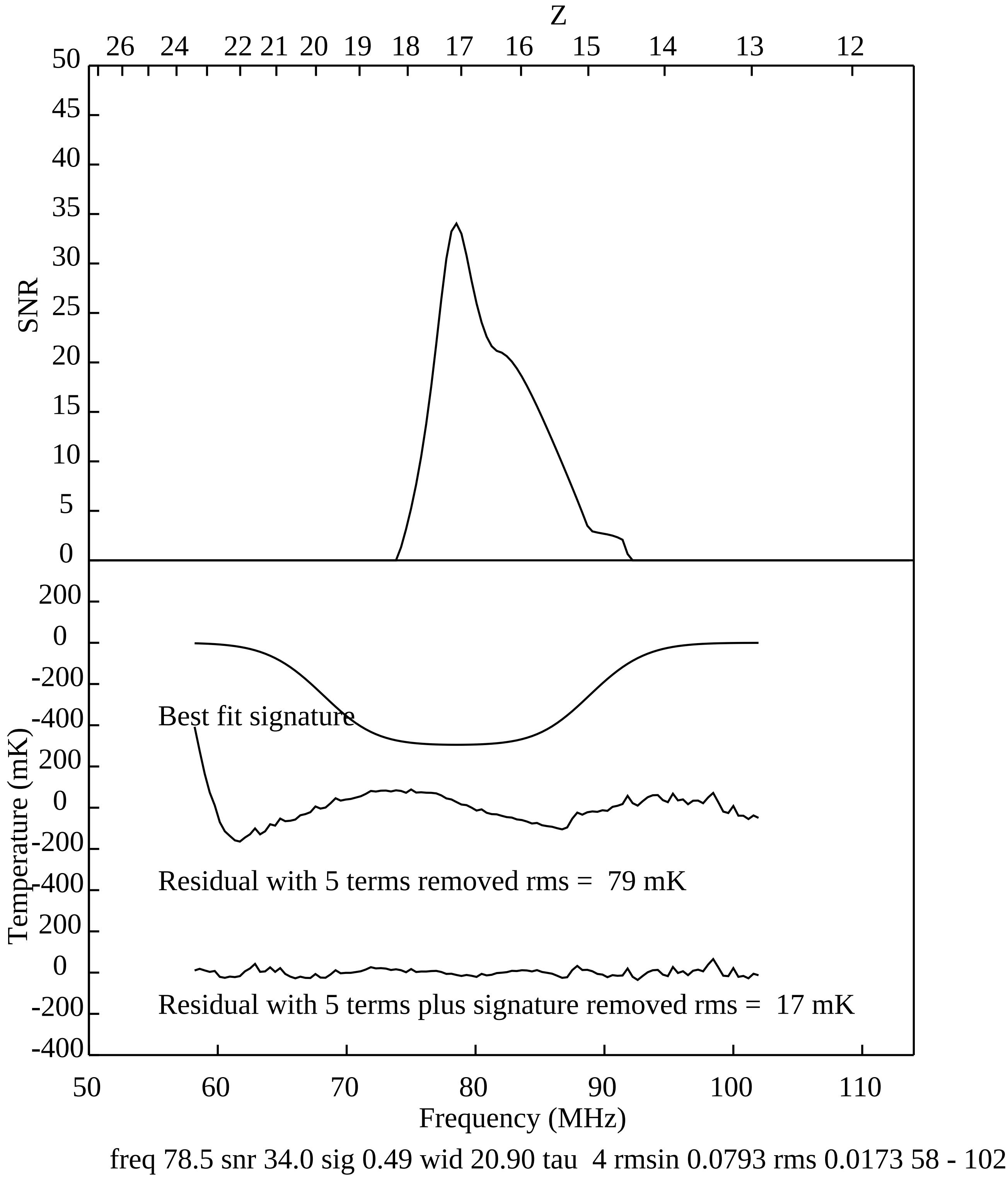

Figure 5. Grid search for day 54 to 360 with rfi detection threshold reduced from 3.5 to 3.1 sigma.

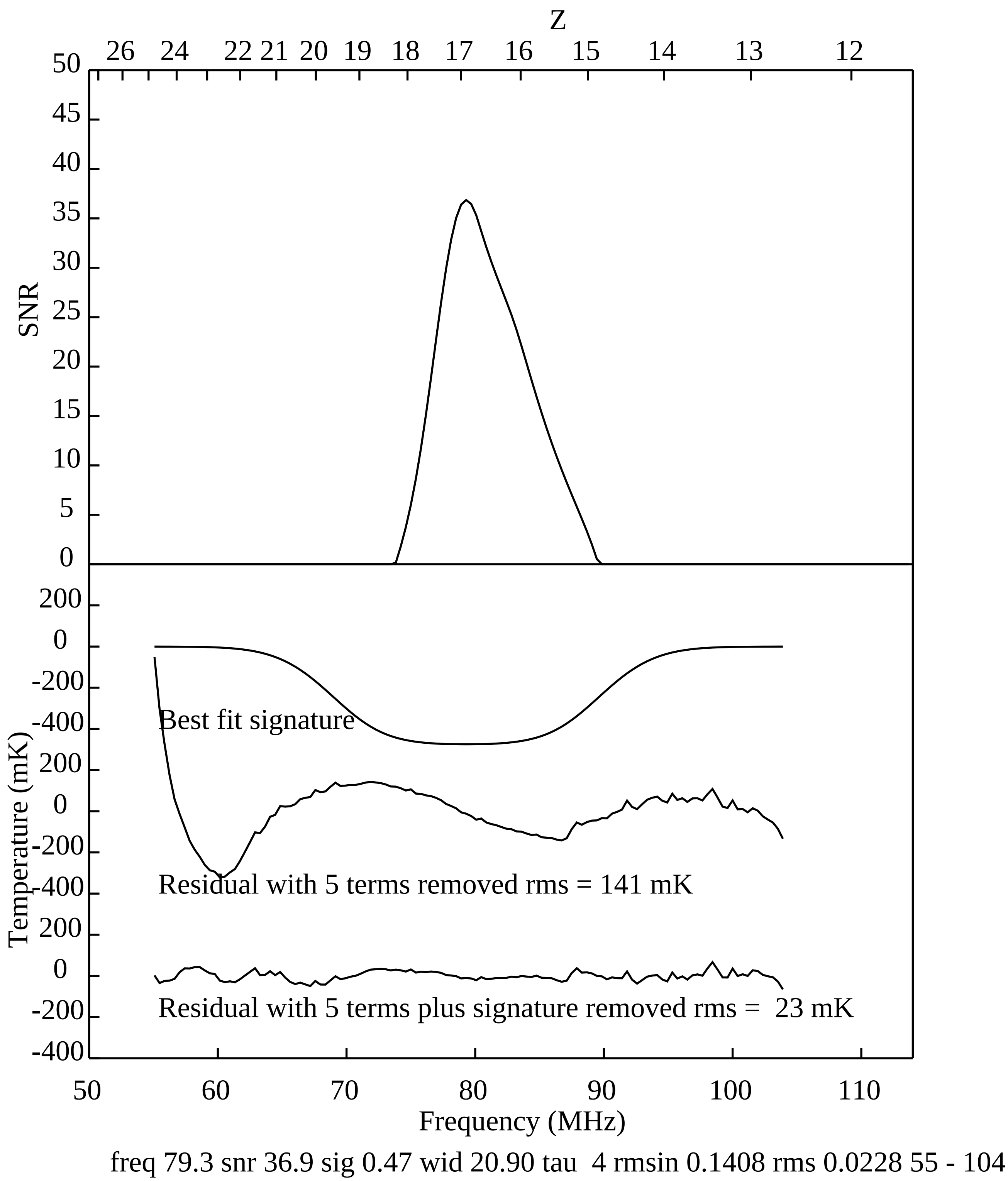

Figure 6. Grid search for day 54 to 360 bandwidth extended to cover 55 – 104 MHz.

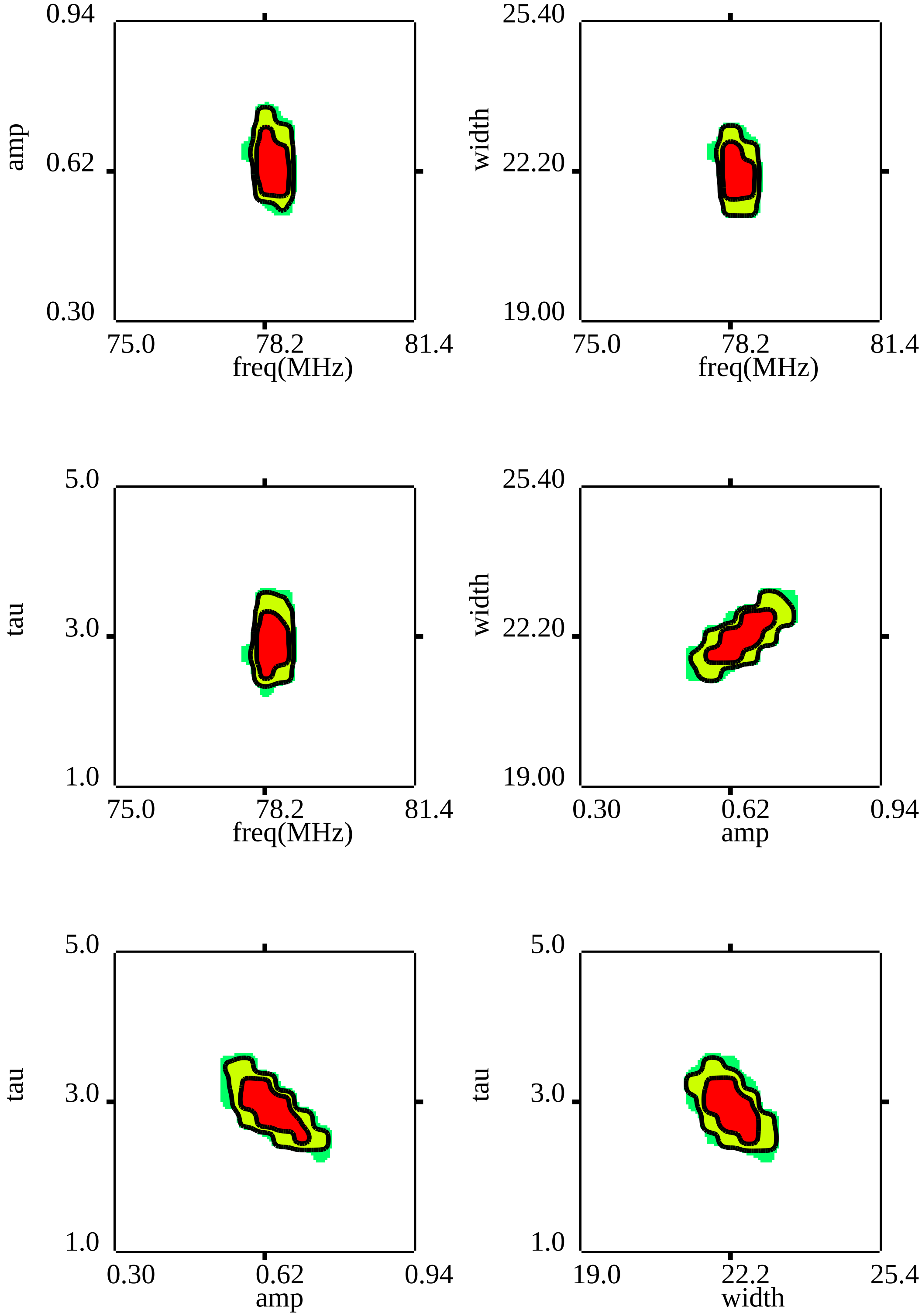

Figure 7. Delta Chi-squared boundaries errors for grid search shown in figure 5.