EDGES MEMO #345

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To: EDGES Group

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Subject: Simulations and tests of scattering effects vs Galactic Hour Angle

Memo 344 provided examples of how scattering effects from objects at some distance from the antenna can be distinguished from other systematics from the variation with Galactic Hour Angle (GHA). It may be possible to correct for scattering effects if the objects producing the scatter can be modeled in FEK0 and then used in the beam correction using a map with sufficient angular resolution to match the structure in the beam which results from the scatter.

The effects of scattering from the electronics hut were first studied in memo 194. Simulations were made in memo 206 and ripples from the electronics hut are seen in the 2015/2016 lowband data shown in Figure 1a of memo 206 at GHA = 19 and 20 hours.

Large residuals in lowband2 data at GHA = 20 hours were studied in memo 341 but adding structures seen in photographs to the FEKO model have not reduced the residuals. This could be due to inaccurate "guesses" of the location and details of the scattering objects. This memo looks at the potential of removing the scattering effects in current data.

Table 1 shows the average rms residuals from simulations of low2-45 on a PEC ground plane with a 1x1x0.5m (LxWxH) metal cube with bottom 0.2m off the ground centered 17m from the antenna. The simulations are done with different sky maps. The "point" map replaces the 408 MHz map with a single pixel of 2.3e6 K at the Galactic Center and 18 K in all other pixels and the 10deg map has a gaussian of 10 degrees FWHM with peak of 2.6e3 K at the Galactic center plus 18 K in all pixels. The values in K being chosen to give a value close to the same as the Haslam and Guzman maps scaled to 75 MHz and convolved with the beam at GHA = 0 and 12 hours.

scatter location	point map	10deg gaussian map	Haslam 408 MHz map	Guzman 45 MHz map
no scat bfit 12	0.32	0.32	0.17	0.14
17m Northwest	1.99	0.39	0.25	0.15
17m Southeast	2.45	0.46	0.29	0.16
no scat and no filt	0.36	0.32	0.17	0.14
17m Northwest	4.62	0.97	0.53	0.19
17m Southeast	2.68	0.41	0.32	0.16
30x30 bfit 12	1.78	0.76	0.22	0.18
30x30 no filt	2.36	0.93	0.29	0.20

Table 1. Average rms residuals in deg K for 5 physical terms removed 19:00 to 23:50 in 10 min steps.

These results illustrate how a sky map with low resolution, like the 45 MHz map with 5 degrees resolution with have low correlation with fine structure in the antenna beam which results from the scatter and will not predict the results of the scatter effects in real data even if the scattering is correctly modeled in FEKO. For example, the scatter from an object 17m or about 60 ns from the antenna produces a ripple period of 17 MHz which changes phase by 140 degrees of phase at 75 MHz for a change of only 5 degrees in the sky. See memo 340 for details of scatter which effectively acts as an adding interferometer. Basically the sky map used for convolution with the beam has to match the true sky with sufficient angular resolution to match the angular detail in the beam. In the simulation results shown in Table 1 the point map may have sufficient resolution but has a width for the Galactic center that is too narrow and results in residuals from the scatter which are much larger than would be observed in reality. On the other hand, the 45 MHz Guzman map may predict lower residuals than would be observed because it may not completely resolve the Galactic Center region.

The smoothing of the beam with a 12 term polynomial in the first 3 entries also reduces the effects of scattering but may be needed to reduce fine frequency scale inaccuracies in the beam models. The entries labeled "no scat" are for the lowband antenna on an infinite PEC ground plane while the entries labeled "30x30" are for the lowband antenna on the 30x30m perforated ground plane with soil dielectric 3.5 and conductivity 4e-2 S/m. In this case there is scattering from the edges of the ground plane which may require a map with higher angular resolution than provided by the Haslam 408 MHz map to be accurately modeled in the beam correction.

Figures 1 and 2 compare the Northeast and Southeast side by side for comparison. Note the main difference is that the scatter from the Northeast structure shows a frequency shift of the features to higher frequencies for increasing GHA which may be present in the lowband2_45 data shown in Figure 3.

Simulations of a metal lid to a fiber cable pit box which is located 28m southeast of the low2-45 antenna using the same parameters as in table 1 with scatterer at 28m gives an rms of 0.18 K

using the Haslam map and no filtering. The scattering effects can be increased by increasing the size of the metal box but the frequency shift of the features is to lower frequencies for increasing GHA. The weak scattering from a metal box that is already larger than the pit cover and extends to 0.7m in height makes it unlikely that the pit lid is the source of the high residuals seen in the low2-45 data shown in Figure 3.

The possibility that these simulations underestimate the scatter of the lid because the Haslam map has insufficient resolution is possible but in this case the part of the sky that has to correlate cannot be the Galactic center region which is limited is peak brightness temperature by the absorption seen in the low frequency maps of Yusef-Zadeh et al. made at 74 MHz. The nearest compact source is Cygnus but while compact its flux density of about 3e4 Jy at 75 MHz is not sufficient to result in a larger scatter effect than in the simulation.

The region of the sky which results in the strongest scatter effects is the Galactic center region so that for a given antenna and scattering object the effects are larger in the southern hemisphere. Simulations for the lowband antenna on an infinite PEC ground plane at various sites are given in Table 2.

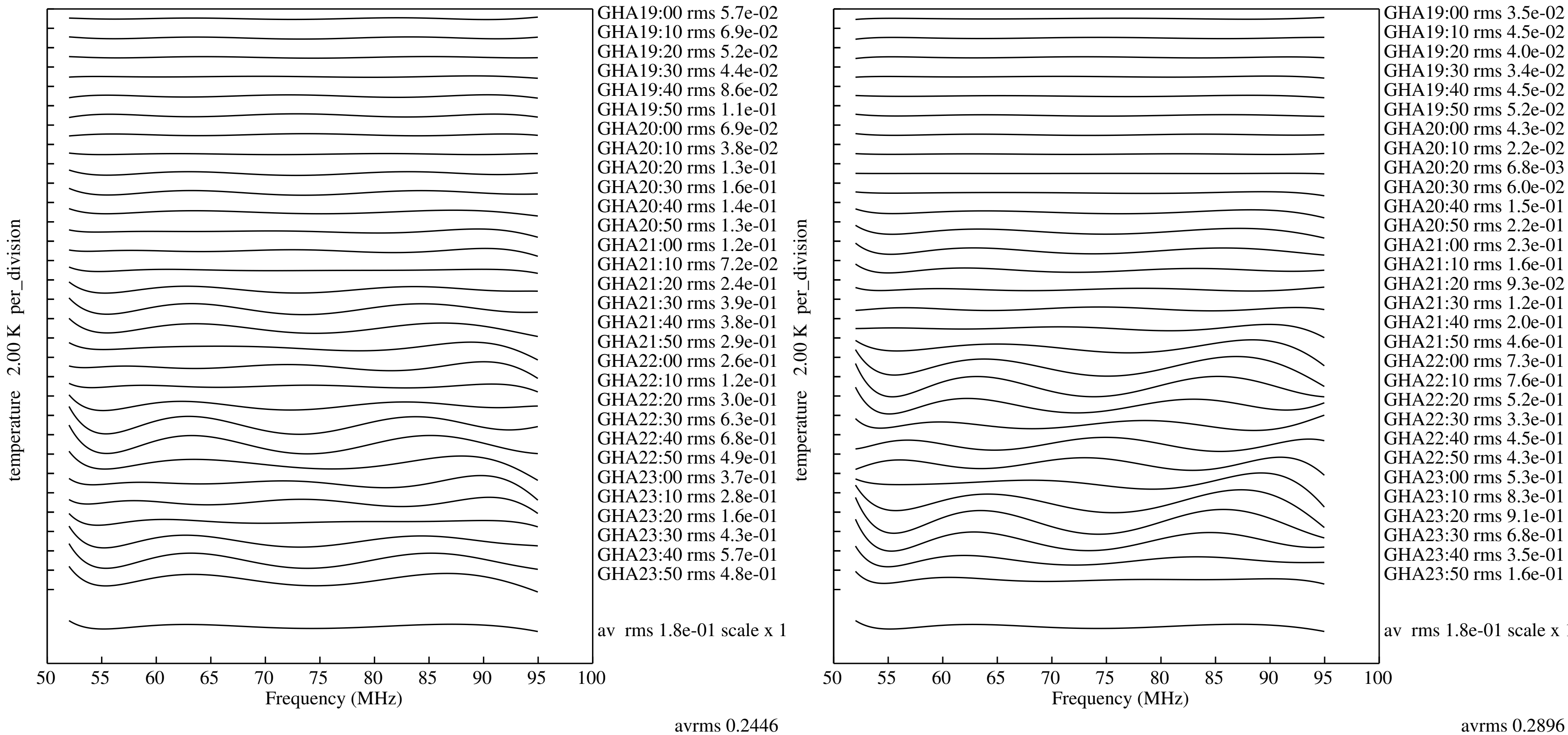
Site	Average rms over all GHA in 10 min bins (K)
MRO	0.20
Oregon	0.10
Baffin Island	0.07
South Africa	0.20

Table 2. Average rms for 5-physical terms removed 52-95 MHz from beam chromaticity plus scatter from 1x1x0.5m metal 17m from lowband antenna in direction perpendicular to line between the dipole antenna panels.

In summary scattering effects are probably the limiting factor in obtaining 21-cm absorption parameters over the full range of GHA. Simulations show that it would require a very accurate and high resolution sky map to be able to remove scattering effects from objects further than about 10 meters from the antenna even if the scattering objects can be accurately modeled in the antenna beam. The solution may be to locate the antenna on a flat ground plane of at least 50x50m or larger and in addition undertake the removal of potential scattering objects out to 50m from the antenna. While there is still a possibility that some shielding of the antenna might be possible to allow a smaller ground plane none has been found so far that can provide such shielding without introducing scatter or loss with significant spectral structure.

Reference:

Yusef-Zadeh, F., M. Wardle, D. Lis, S. Viti, C. Brogan, E. Chambers, M. Pound, M. Rickert (2013), 74 MHz Nonthermal Emission from Molecular Clouds: Evidence for a Cosmic Ray Dominated Region at the Galactic Center, *J. Phys. Chem. A*, 117, 39, 9404–9419. https://doi.org/10.1021/jp311240h



Figures 1. The residuals for scatter from the Northeast on the left and Southeast on the right for case of 12 term polynomial smoothing of the beam using the Haslam map as in Table 1.

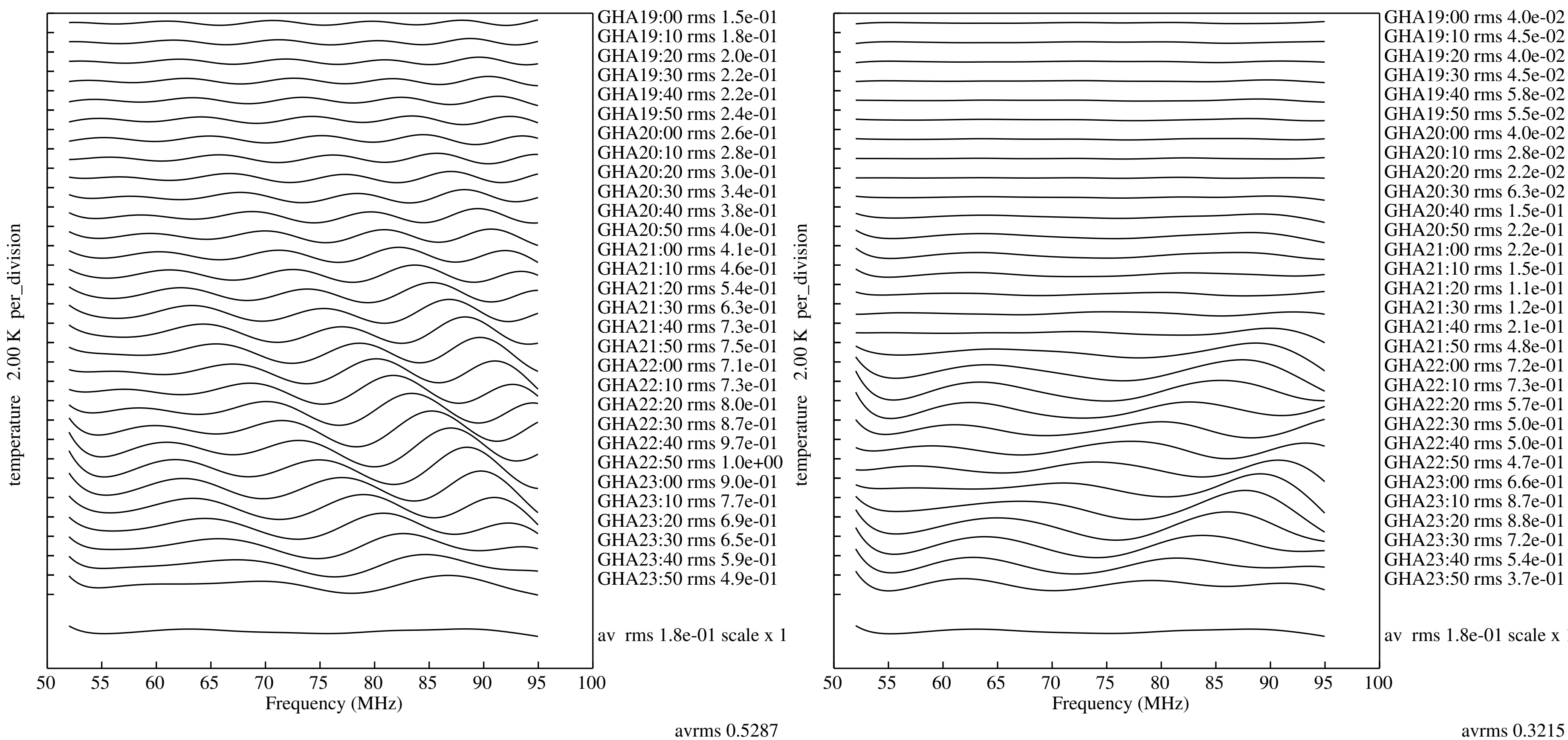


Figure 2. The residuals for scatter from the Northeast on the left and Southeast on the right for case of no smoothing of the beam using the Haslam map as in Table 1.

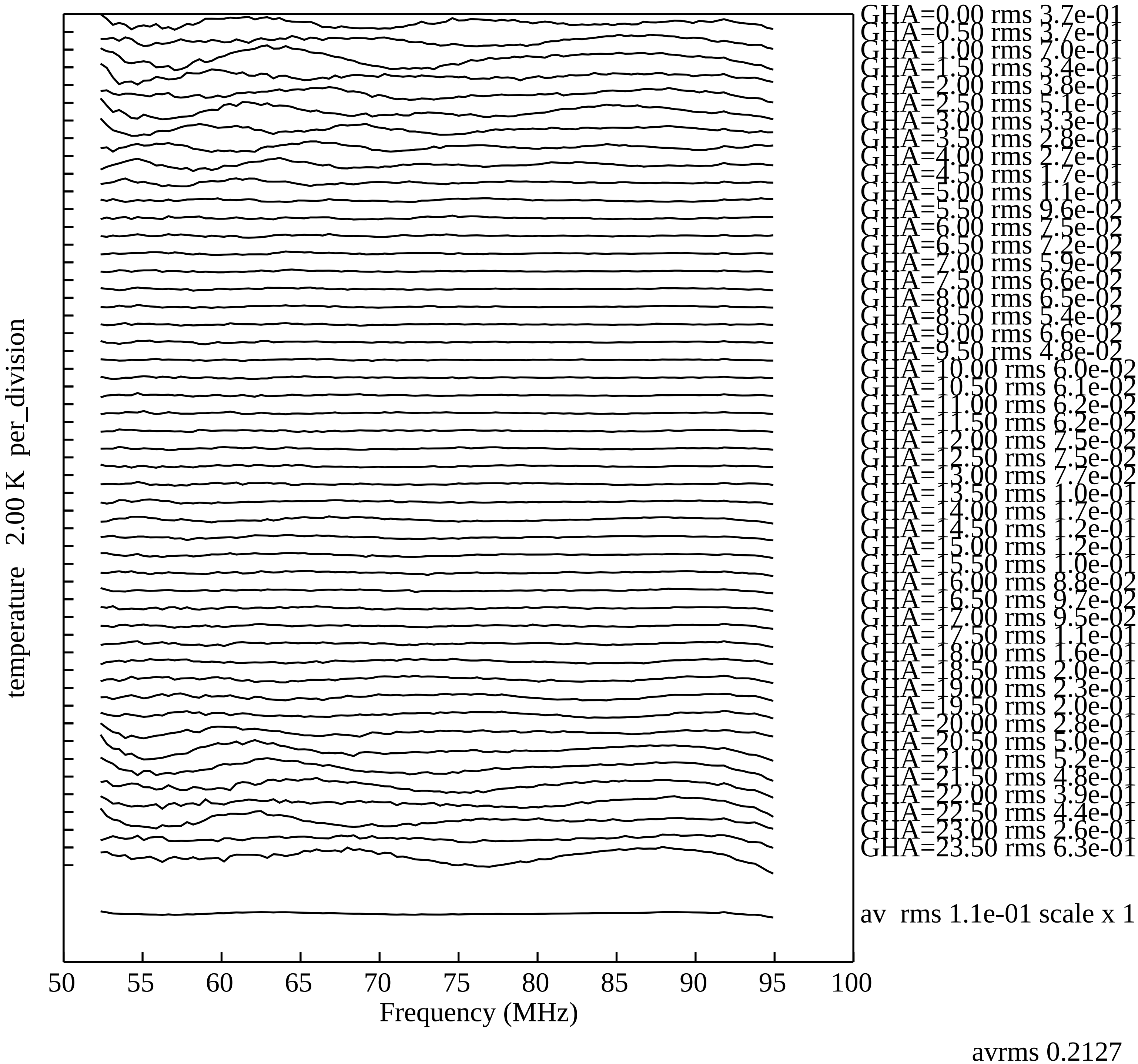


Figure 3. Residuals of lowband2_45 data with 5 physical terms removed vs GHA in 30 min bins for days 2020_050 to 2020_140.