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To: EDGES group

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Subject: Simulations of the chromatic effects of reflections from the rock below the soil

A two layer ground model is needed for reflections from the rock below the lunar regolith and the permafrost below the soil in the arctic and antarctic. The effects of these reflections are studied for a lunar orbit in memo 279 and on the surface of the moon in memo 422.

The basic mechanism for the chromatic effects on the antenna beam is due the subsurface reflection which is delayed and interferes with the antenna beam surface reflection, creating a frequency-dependent ripple effect on the antenna's beam. Beam chromaticity arises from the coherent interference of the signals received from the sky directly and those received by the EDGES antenna response up from below. The response below the horizon can be reduced by adding a ground plane as large as needed as simulated in memo 422. Owing to the cost of a ground plane this memo only considers using an antenna directly on the ground. While a raised ground plane might be lower cost the effects of the layer of air are considered in memo 436. In this case a third layer has to be added to model the beam.

These effects are simulated using a FEKO model of the EDGES-3 antenna on a two infinite layers of dielectric using the parameters in table 1. The site was lat = -26.7 lon = 116.5 and 1 hour blocks over 24 hours of GHA using the Haslam sky map corrected to the frequency of the simulated data using a spectral index of -2.5 and antenna azimuth of 90 degrees for the EDGES antenna. The EDGES 2018 21-cm result with centered at 78 MHz with width of 19 MHz depth of 0.5 K and tau = 7 was added to the sky.

layer	dielectric	conductivity S/m
soil	3.0	2e-5
rock	8.5	2e-2

Table 1. Soil and Rock parameters

Table 2 shows the average rms residuals in avrms with 5-terms removed for each 1 hour block and the rms residuals of all 24 1 hour blocks in rmsav.

The first entry in table 2 shows the relatively small effect of a depth of 20 cm of soil and in this case the added absorption can be recovered with the parameters listed in table 3. In this case a result can be obtained without beam correction. In all other cases beam correction is needed and may require high accuracy knowledge and uniformity of the depth, dielectric and conductivity as discussed in memo 295. The accuracy the soil depth needed is simulated using a soil depth of 1.0m and beam corrected with a soil depth of 1.1m whose avrms and rmsav values are listed in table 2. The change in soil depth of only 10% results in significant change in residuals. If the beam for soil depth of 1m is used to simulate the data and beam for soil depth of 1.1m is used to correct the data a reasonable result for the 21-cm absorption can be obtained but only with a reduced frequency range and using 6 loglog terms.

Depth of the soil m	avrms K	rmsav K	Frequency range	comments
0.20	0.09	0.003	52-105	
0.50	4.0	1.2	52-105	
1.0	6.59	1.6	52-105	
1.1	2.37	0.43	52-105	
2.0	55	16	52-105	
5.0	117	34	52-105	
5.1	114	33	52-105	
10.0	86	18	52-105	
20.0	166	16	52-105	
10.0	167	15	52-105	rock 2e-8
10.0	58	13	52-105	soil 2e-4
10.0	0.97	0.19	52-105	soil 2e-3

Table 2. Simulations of data results for different soil depths

The last entry in table 2 shows that high soil conductivity of 2e-3, which might be present at some wet saline soils on earth attenuates the reflections from the rock below. Monsalve et al. have studied effects of beam chromaticity on the MIST global 21-cm system in the arctic. Multilayer models of the ground with total layer thickness up to about 100 cm have been made by Spinelli et al. 2022 for the LEDA array located at Owens Valley California which include ground planes up to 10mx10m needed for adequate performance.

fcen MHz	SNR	amp K	width MHz	rms1 mK	rms2 mK	case
77.7	54	0.36	18.7	67	14	soil depth 20 cm 52-105 MHz
78.1	54	0.74	21.2	54	13	depth 1.0 – 1.1 m 60-98 MHz
77.4	46	0.53	20.6	54	11	added rms threshold of 0.4 K

Table 3. 21-cm absorption search. rms1 and rms2 are the residuals prior and after fitting the 21-cm

Adding a 0.4K rms threshold in the second case removes the spectra from with the highest residuals from the average which drops the rms2 residuals from 13 to 11 mK. This removes the data with the strongest reflections coming Galactic center in the range 23 to 1 hours GHA.

Summary

This study, which does not consider the spectral structures of the loss which are relatively smooth compared with the beam chromaticity. The effects of loss are considered in memos 88, 187, 239, 258, 263, 27, 280, 290, 294, 370, 375 and 395. While it might be possible to model the loss and beam chromaticity well enough in the arctic and antarctic where the depth of the soil is under 50 cm to avoid the need for a ground plane. These simulations show that it probably will not be possible to get good enough data on the global 21-cm cosmology using an antenna on the moon without a ground plane or a reflector to shield the antenna from the reflections from below. Independent simulations are needed to test the conclusion based on these simulations that a ground plane will be needed for global 21-cm cosmology on the moon.

References:

Simulating the Detection of the Global 21 cm Signal with MIST for Different Models of the Soil and Beam Directivity Raul A. Monsalve *et al* 2024 *ApJ* 961 56

Antenna beam characterization for the global 21-cm experiment LEDA and its impact on signal model parameter reconstruction Spinelli et al. MNRAS 515, 1580–1597 (2022)

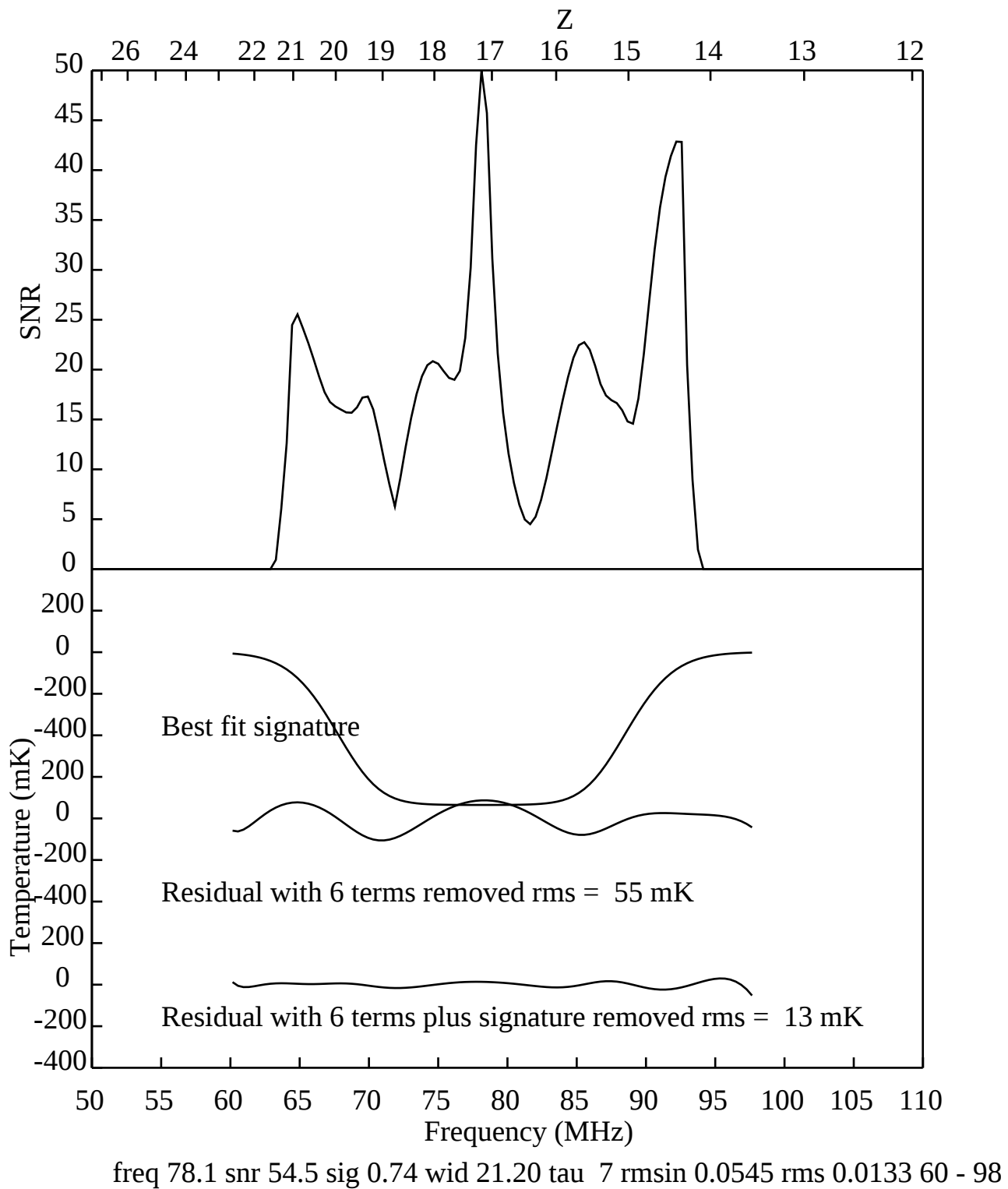


Figure 1. Global 21-cm search for the second case in table 3.

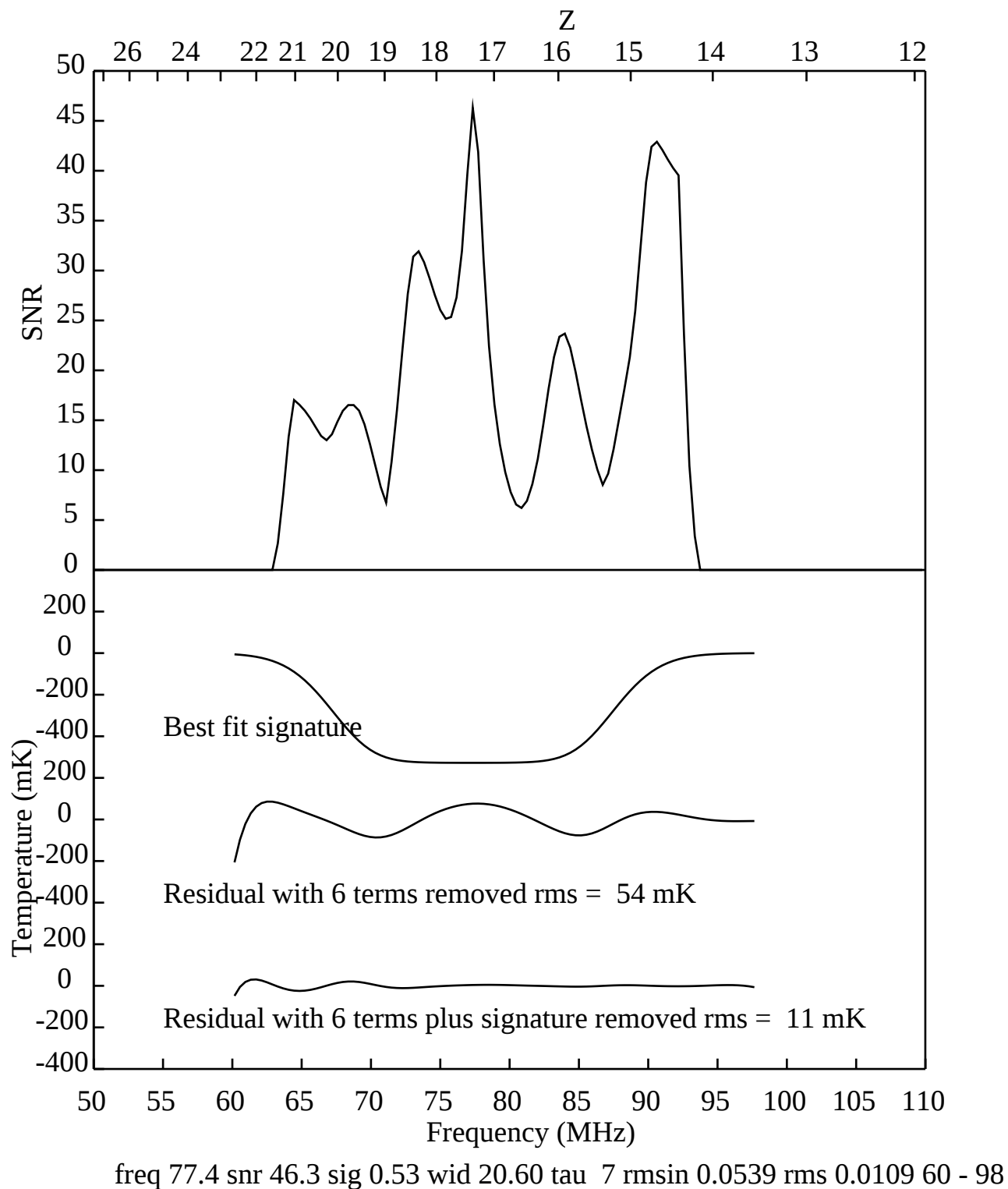


Figure 2. Search results for the second case in table 3 with 0.4K threshold.