EDGES MEMO #352

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To: EDGES Group

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Subject: Sensitivity of low2-45 averaged over GHA to systematics

The lowband-2 data oriented at 45 degrees relative to the 30x30m ground plane, which corresponds to an azimuth of 42 degrees, from 2020 day 56 to 2021 day 21 averaged over GHA provides an important test of instrumental systematics because beam effects tend to average out. In this memo the data is averaged over GHA = 6 to GHA = 18 hours using one 12 hour block for each day. This makes it easier to separate effects of errors in the beam and the sky maps which are strongly dependent on GHA from errors in receiver calibration, loss estimates and errors in the measurement of the antenna S11.

error source	amp K	SNR dB	center MHz	width MHz	rms mK	comments
Nature signature	0.50		78	19		nominal Nature params
reference	0.57	34.1	78.5	19.3	21	No beam correction
No I/Q correction	0.63	34.6	78.5	18.1	27	No I/Q cross-talk corr.
No balun loss	0.40	24.1	78.1	21.9	15	
Beam correction	0.71	33.1	78.5	18.8	29	using Haslam map
Beam correction	0.67	33.7	78.5	18.9	27	using Guzman map
Ant S11 +0.1dB	0.90	29.1	78.1	18.4	45	
Ant S11 -0.05dB	0.43	21.9	78.5	20.4	21	
Ant S11 -0.1dB	0.15	13.3	84.4	10.0	25	different signature
Ant S11 +100ps	0.90	27.0	78.1	18.2	50	
Ant S11 +40ps	0.40	14.8	77.7	21.8	30	diff. signature at -50ps
Ant S11 -100ps	1.06	24.8	75.4	29.9	27	different signature
LNA S11 +0.1dB	0.67	33.1	78.5	18.9	27	
LNA S11 -0.1dB	0.49	31.0	78.5	19.9	18	
LNA S11 +100ps	0.90	27.0	78.1	18.2	50	
LNA S11 -100ps	0.74	18.4	74.6	29.9	25	different signature
LNA S11 -50ps	0.45	16.8	78.1	21.1	27	

Table 1. Effects of changes to the best fit parameters of 21-cm absorption fit to amplitude, center frequency and width for fixed tau = 7 using 5 physical terms 55 – 95 MHz. The 6 th. column is the rms residual following the removal of the absorption and 5 physical terms for the foreground. The comment "different signature" is a result outside the 99% confidence limits in the Nature paper (2018). It is possible

to “recover” the Nature signature in those cases by increasing the number of terms or reducing the frequency range.

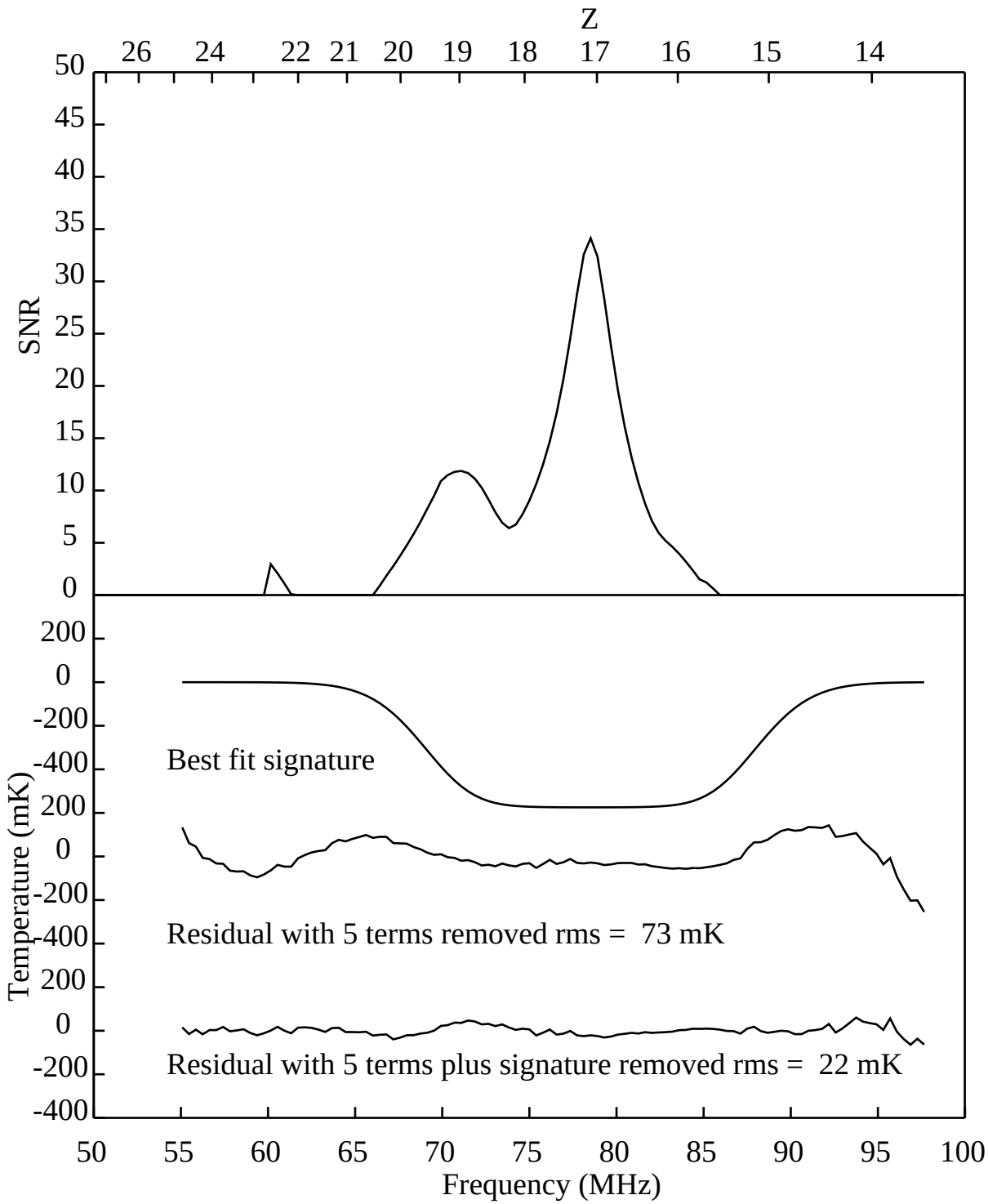
The very high sensitivity to VNA measurement error is a large source of concern in the EDGES system for the measurement of the global 21-cm signature. The reason is VNA measurement error can introduce a change in the fine frequency structure scale of the calibrated whereas other systems with an electrically small antenna can rely on the smoothness of the antenna S11 which can then be modeled without the need for such accurate VNA measurements. Table 1 shows that when averaged over GHA the sky map and beam correction have small effects. The beam averages over a very large area of the sky makes the effects of different spectral index and curvature in individual regions of the sky average out so that the only fine scale frequency structure could come from recombination lines in the galactic plane which have been separately studied in memo 261 and found to be too weak to contribute significantly. Simulations show that fine frequency scale in the beam are introduced by scattering (memo 348) and antenna defects, like those of a lack of flatness (memo 337) in the ground plane which is part of the antenna. This fine scale structure in the beam results in frequency structure in the spectrum when convolved with the sky but these effects tend to average out over 24 hours of GHA.

An especially worrisome source of VNA error is an error of only 100 ps which introduces enough fine scale structure into the antenna and LNA S11 to find a result outside the confidence limits of the Nature result. However, a 100 ps which corresponds to only about 3 degrees of phase at 75 MHz is much larger than the expected error in VNA based on the tests reported in memo 351. Measurements of VNA accuracy even with some I/Q crosstalk which is studied in memo 351 should have amplitude error under 0.05 dB and 0.5 degrees of phase and crosscheck has been made with an independent measurement of antenna S11 using a benchtop VNA in the pit under the antenna. The effect of the difference of the “INPIT” S11 and the remote S11 is checked in memo 254 using simulations. The rms difference between 2017_153_INPIT.txt.csv and 2017_153_INPIT.txt.csv over 50 to 200 MHz is 0.008 dB and 0.052 deg.

The changes in VNA offsets reported in memo 222 have lower values because they are made for a GHA averaged for 4 to 16 hours which results in a lower averaged sky temperature and consequently a lower sensitivity by a factor about a factor of two. The difficulties of getting an accurate measurement of the LNA S11 and the sensitivity to offsets is discussed in memo 237. The sensitivities to offsets in S11 using lowband1 data is given in memo 246 and the sensitivities for lowband2 are ranked in memo 249.

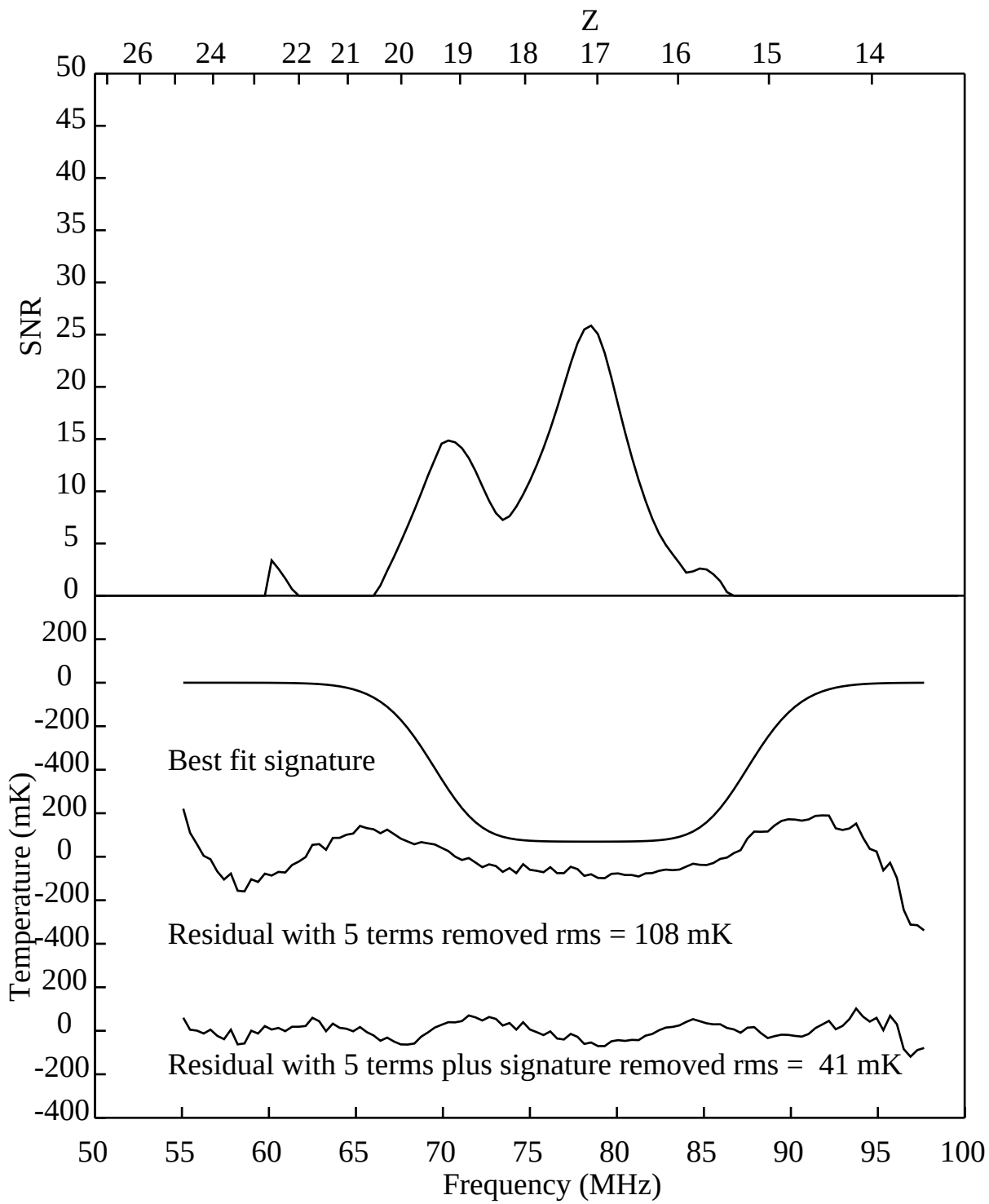
The goal of getting an absorption signature results for blocks of GHA is pursued in the Nature paper and in many of the memos is important in verifying that the Nature result is “global” coming equally from all directions but for short blocks is very sensitive the scattering effects which change on GHA scales on an hour or less. Some information towards confirming the global nature has been obtained on 6 and even 4 hour blocks in the Nature paper and memos 287 and 339. These time blocks are useful in placing limits on S11 and receiver calibration accuracy because the instrumental errors have effects that are proportional to the sky noise at night when the ionosphere doesn’t have a significant absorption as long as changes with temperature are small or can be corrected. Condensation of moisture (see memo 178) on the antenna is another factor which needs to be taken into account. The goal of obtaining the constancy of the 21cm absorption signature on shorter time blocks is currently limited by scattering but a larger more even ground is planned and it may be possible to improve the beam correction for the current data with modeling when a photogrammetric survey of the 30x30m low2 ground plane is completed.

Figure 1 shows is a plot of the reference case in table 1 and Table 2 shows the 2-D search for the absorption using 24 hour blocks over all GHA for each day using 5-terms as in Figure 1.



freq 78.5 snr 34.1 sig 0.57 wid 19.30 tau 7 rmsin 0.0735 rms 0.0216 55 - 98

Figure 1. Plot of the reference in Table 1.



freq 78.5 snr 25.9 sig 0.73 wid 18.40 tau 7 rmsin 0.1083 rms 0.0407 55 - 98

Figure 2. Plot of the feature search for a fixed tau = 7 using 24 hour blocks for each day to cover all GHA.