EDGES MEMO #099

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To: EDGES Group

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Subject: Preliminary estimates of EDGES-2 error sources.

The major error sources of EDGES-2 are estimated using a simulation of the calibration and processing described in memo 96. Actual measured values of the S11 of the antenna and LNA are used. The spectrum was derived from using the 408 MHz Haslam et al. sky map for a latitude of -26 degrees, converted to frequencies from 100 to 190 MHz using a spectral index of -2.5, and then convolved with the beam patterns from FEKO for the antenna described in memo 89. Values of the LNA noise wave were taken from measured open cable calibration. The calibrated spectra are derived after changing the parameters used for the generation of the spectra by the assumed errors for each error source by the values in the Table 1.

The Table gives the rms residuals which arise from a constant assumed error of the magnitude given in the second column. Columns labeled A, B, C and D give the rms residual to least squares fit using the parameters listed in Table 1B in the absence of an EoR signature. Column E gives the level of "false" EoR signature consisting of a Gaussian centered at 145 MHz with full width at half-power of 50 MHz.

Table 2 lists the parameters used to solve for the EoR signature in the simulations used to make estimates of the effects of the major errors. Columns 2 and 3 list the square root of the covariance for the EoR signature for 2 cases. The first case is for the current EDGES-2 prototype antenna and the second case is for the same antenna with an additional 10 feet of 50Ω transmission line to reduce the correlation required by the introduction of parameters to allow for errors in phase. A value of 15.1 for the square root of the covariance results in a 230 fold increase in the integration time needed to detect the EoR. For a 30 mK signature a 10 sigma detection would take about 100 days of 6 hour observing sessions. Column "F" gives the level of false EoR for the case of added transmission line.

The need to solve for the ionosphere results in a substantial increase in covariance. However the f^{-2} and $f^{-4.5}$ terms aid in the absorption of the effects of other error sources like the variation of antenna beam pattern with frequency. The "E" column of Table 1 shows that the level of systematics would make it difficult to detect an EoR signature at the level of 30 mK. An EoR with 25 MHz width should be detectable as indicated by the level of systematics shown in column "G".

		Residual mK				EoR mK			Note
Error source	Assumed error	A	B	C	D	E	F	G	
Antenna S11	0.01 dB, 0.1°	26	23	16	0	0	0	0	5
LNA S11	0.01 dB, 0.1°	20	18	18	0	0	0	0	6
Antenna loss	0.1%	130	0	0	0	0	0	0	2,4,10
Antenna beam	Fourpoint	500	300	0	0	5	5	2	7
Ionosphere	0.015 dB @ 150 MHz	1500	22	0	0	8	9	2	1
Sky spectral index	0.05	2800	200	1	1	6	12	4	
Spectral index steepening “gamma”	0.12	9000	2500	1	1	40	60	20	8
Slope in antenna loss	0.1% per 50 MHz	80	74	2	1	30	30	10	3
Slope in antenna S11	0.01 dB per 50 MHz	12	11	10	5	300	25	3	
Slope in LNA S11	0.01 dB per 50 MHz	11	10	6	4	300	25	9	
Temperature	1° K	700	10	10	0	30	10	2	9

Table 1A

A	Rms residual following removal of scale
B	Rms residual following removal of scale and offset
C	Rms residual plus removal of f^{-2} and $f^{-4.5}$
D	Rms residual plus functions for additional errors listed in table 2
E	Bias in EoR for 10 parameter solution
F	Bias with 10′ added cable
G	Bias with EoR width reduced by factor of 2

Table 1B

Notes:

1] The residuals from the ionosphere are about 1 mK and 5 mK at 150 and 75 MHz as a result of estimates of the departure of the optical depth from f^{-2} dependence. These estimates come from the difference between f^{-2} and $\left(f - f_{plasma}\right)^{-2}$ where f_{plasma} varies from about 0.5-1 MHz at night. Owing to the high correlation between the ionosphere and the sky spectral index variation we will need an accurate sky model only if we want to obtain accurate values of the ionosphere opacity and electron temperature.

2] Error is the uncertainty in the total loss of about 0.01 dB.

3] Antenna loss varies from 0.1% at 100 MHz to 0.2% at 190 MHz from FEKO assuming $\sigma = 3.5\times10^{7}\ S/m$ for aluminum. See memo 98

4] Ground plane/screen loss see memo 88.

5] The phase terms in Table 2 are needed to remove the error in VNA phases.

6] It is assumed that the temperature dependence of the LNA S11 measured in the laboratory will be used to make the best Apriori corrections based on the temperature monitor in the module containing the LNA.

7] The estimate of the effect of the frequency dependence of the antenna beam pattern assumes the sky spectral index is constant. It also assumes averaging over ± 5 hr centered at 2 hr LST at a latitude of -26°. The best result with lowest rms is obtained with the dipole arms approximately east-west which minimizes the east-west responses and minimizes the average antenna temperature over the LST range.

Parameter	Covariance ½	Covariance ½	Parameters
1	1	1	EoR signature
2	1.5	1.5	+ scale
3	2.2	2.2	+ constant
4	4.2	4.2	$+ f^{-2}$
5	13.8	13.8	$+ f^{-4.5}$
6	13.9	13.9	+|S11ant| error
7	14.2	14.4	+|S11lna| error
8	47.2	14.7	+S11 phase error
9	52.9	14.9	+S11 delay error
10	60.1	15.1	+ temperature scale

Table 2.

The effect of adding a longer cable between the antenna and the 3 position switch is to rotate the phases of the noise waves and signal waves reflected back from the antenna. While the optimum cable length is still under study a preliminary result of a simulation is shown in Figure 1. While longer cables provide a higher degree of de-correlation of instrumental errors the added loss needs to be minimized. When adding significant loss the temperature coefficient of loss which is expected to increase by $0.2\%/1°\mathrm{C}$ needs to be taken into account.

8] The largest influence of the sky background is the result of the uncertainty in the steepening of the spectral index. This steepening results in the spectral index, β, becoming frequency dependent

$$\beta = \gamma \ln\left(f/f_0\right)$$

With the parameter, γ, as defined by Oliveira-Costa et al 2008.

9] When the EDGES is calibrated an error in the temperature of the hot load or equivalently an error in the ambient temperature results in a scale error. While an overall scale error on all temperatures is not important a scale difference between temperatures above and below ambient results in significant error. This source of error can be reduced, without significant increase in the covariance, by adding a parameter with the signature of the error. With the addition of this parameter a temperature error in the ambient temperature of EDGES or of the hot load of 1 K can be tolerated.

10] If the effect loss in the balun and added cable is included the dependence of cable loss on the antenna mismatch (see memo 98) results in a bias in the EoR solution at the same level as a slope in the antenna loss for a 0.1% error.

11] Scatter of TV/FM etc. from the moon is significant so EDGES EoR observation need to have the moon below the horizon. In addition, EoR observations need to be made between about midnight and sunrise to minimize the ionosphere and solar emission.

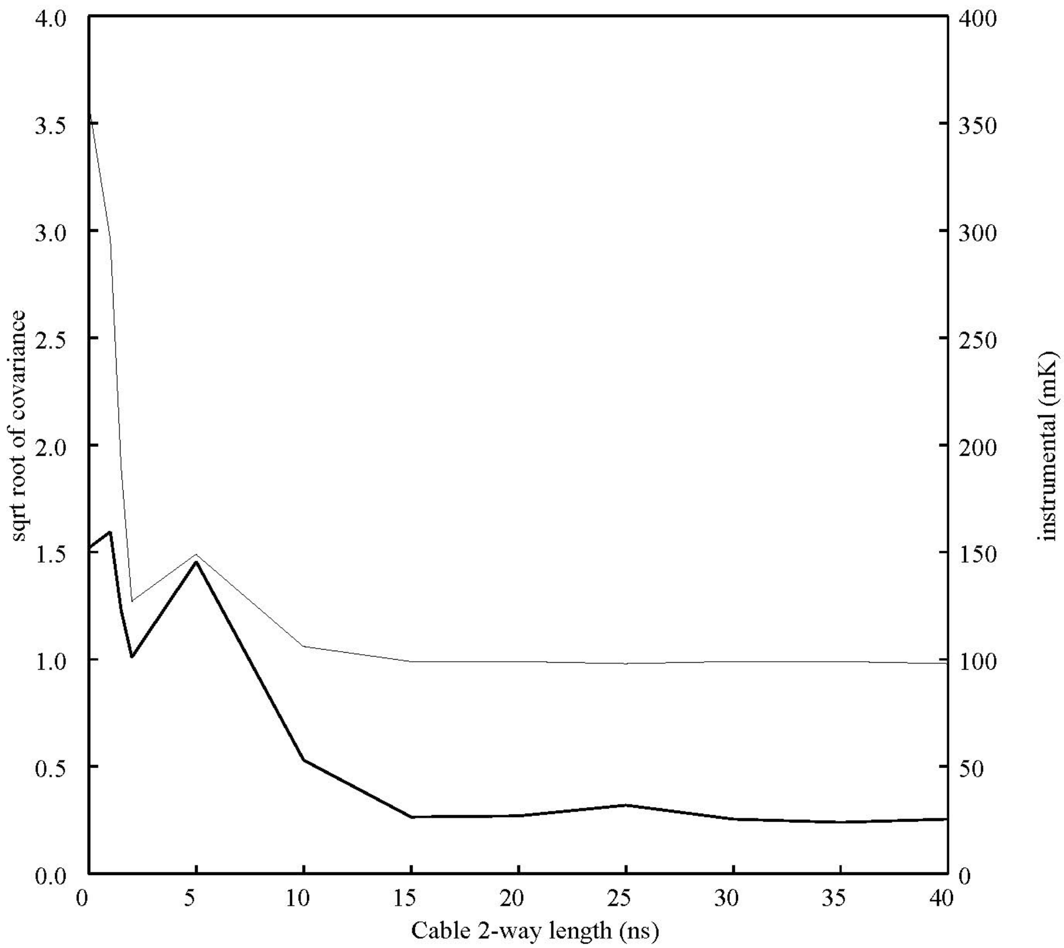

Figure 1. Systematic instrumental error (thick line) and covariance ½ as a function of cable length.