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To: EDGES group

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Subject: Simulation of 21-cm feature subtraction tests

A "subtraction test" is a useful test for the confirmation of a result from the "preliminary data analysis of the EDGES-3 data using the c-coded processing pipeline while awaiting processing using the new Bayesian analysis pipeline.

Subtraction tests on EDGES-3 data are reported in memos 419, 444, 466, 475 and 477. Table 1 shows change in the rms from the value of rms1 with N in the subtract column for before and Y for after subtract respectively. The value of tau in a row with Y is the value of tau for a feature centered at 78 MHz with depth of 0.5 K and width of 19 MHz. For example first two entries in table 1 show that subtracting the 2018 result drops the rms from 204 to 185 mK made on the relatively low SNR and restricted frequency range data obtained from Devon Island described in memo 419. The last column in the table also shows the change of the rms residuals with the subtraction.

memo	Frequency	SNR	amp K	width	# terms	s tau	subtract	rms1	rms2	range	subtraction
	MHz			MHz				mК	mК	MHz	change mK
419 Devon	77.4	14	0.59	20.9	5	7	Ν	204	46	64 - 98	
419 Devon	84.0	6	0.28	17.0	5	7	Y	185	48	64 - 98	204 - 185
444 WA	79.7	26	0.52	19.2	5	7	Ν	72	27	58 - 102	
444 WA	83.2	17	0.30	20.0	5	7	Y	40	21	58 - 102	72 - 40
466 WA	77.3	36	0.59	21.5	4	4	Ν	71	20	58 - 102	
466 WA	67.6	5	0.08	10.0	4	4	Y	33	30	58 - 102	71 - 33
475 WA	79.3	33	0.54	19.4	4	4	Ν	83	26	57 - 106	
475 WA	78.9	27	0.52	20.6	4	4	Ν	74	27	57 - 104	
475 WA	84.4	7	0.14	19.5	4	4	Y	39	32	57 - 104	74 - 39
477 Adak	78.9	18	0.73	17.6	6	4	Ν	53	24	60 - 98	
477 Adak	78.9	17	0.46	24	6	7	Ν	54	24	60 - 98	
477 Adak	82.8	6	0.38	23.1	6	7	Y	39	26	60 - 98	54 - 39
477 Adak	79.3	6	0.29	16.9	6	4	Y	43	26	60 - 98	53 - 43
Table 1 list of results of subtraction test on EDGES-3 data											

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A subtraction test was made on EDGES-3 data from 2023 day 54 to 2024 day 86

GHA range hours	rms mK before	rms mK after subtraction
00 - 04	175.8	163.0
04 - 08	56.5	53.2
08 - 12	68.3	58.7
12 - 14	98.1	80.0
16 - 20	156.1	137.6
20 - 24	165.3	147.3

Table 2. list of results for range of GHA tau =7 58 – 102 MHz 5-terms removed

In order to get an understanding of the expected change in rms residual with subtraction it is useful to run simulations as follows:

Vertical ant	.Frequency	SNR	amp K	width	# terms	s tau	subtract	rms1	rms2	range	subtraction
s11 bias dB	MHz			MHz				mК	mК	MHz	change mK
0	77.0	4.7	0.72	15.9	7	7	Ν	239.0	233.1	55 - 85	
0	77.1	2.5	0.38	15.6	7	7	Y	235.1	233.1	55 - 85	239.0 - 235.1
0.1	77.1	2.7	0.41	15.7	7	7	Ν	234.7	233.3	55 - 85	
0.1	76.0	1.1	0.16	10.9	7	7	Y	235.3	233.2	55 - 85	234.7 - 235.3
-0.1	77.0	6.6	1.02	16.0	7	7	Ν	253.6	233.2	55 - 85	
-0.1	77.0	4.3	0.67	15.9	7	7	Y	245.5	233.2	55 - 85	253.6 - 233.2
Table 3 Test of subtraction test using simulated data for vertically polarized entering on a lake											

Table 3. Test of subtraction test using simulated data for vertically polarized antenna on a lake

This simulation shows that when there is a high noise level so that a detection of a 21-cm feature of only 0.5 K depth would have a low SNR owing to the high noise level as in the first two entries of table 3 the subtraction reduces the rms from 239.0 to 235.1 mK but when a systematic is introduced by applying a 0.1 dB offset to the antenna s11 the subtraction actually increases the rms from 234.7 to 235.3 mK because the bias introduced by the 0.1 dB is anti-correlated with the 2018 21-cm result. The last 2 entries of the table show that when the sign of the bias is changed it becomes correlated and the subtraction decreases the rms from 253.6 to 233.2 mK. The noise level and other parameters of this simulated subtraction were made to produce spectra similar to those in Fig. 2 of Singh et al. Nature Astronomy 6, no. 5 (2022): 607-617. The beam was modeled by FEKO using an inverted cone of height and radius of 58 cm 3 mm gap, for the antenna input, above a circular plate with 62 cm radius floating on a lake with some 5 m high trees on the shore 75 m away. The simulated data change of about 1 mK out of about 230 mK with subtraction in the presence of 0.1 dB is similar to the change of about 1 mK out of about 210 mK in Fig. 2 of Singh et al.

In summary a subtraction test is a good test for a EDGES results when analysis code is used provide simulations of the potential systematics and how they effect 21-cm absorption profile and the expected change in rms residual when an absorption profile is subtracted from the sky noise. The tests down on EDGES-3 data in table 1 all have a detection consistent with the EDGES 2018 result with significant SNR and large drop in rms with subtraction. The results in table 2 also have a significant drop in rms with subtraction and show the significant drop in rms over the full range of GHA.

Table 3 which simulates the data shown in Fig. 2 of Singh et al. has a very marginal sensitivity due to the high noise level and the use of 7 terms so that it has insufficient sensitivity and low enough systematics to provide a significant confirmation or rejection of the EDGES 2018 result.