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To: EDGES Group

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Subject: Ionospheric absorption from low band data.

The effects of the ionosphere are significant in the low band. If we assume that the foreground averaged over the EDGES beam is well represented by a spectral index without the need for any curvature in the spectral index (gamma = 0 in Oliveria-Costa et al. 2008) the opacity of the ionosphere can be estimated from a 3-parameter fit. The fitted parameters are scale (temperature at 75 MHz), spectral index and ionospheric opacity. When fitting the observed temperature rather than the log of temperature the fitted function is

$$T(f) = (f/75)^{-2.5}\left(b_0 + b_1 \log(f/75) + b_2 (f/75)^{-2}\right)$$

where $T_{75} = b_0$

Spectral index = $(b_1/b_0) - 2.5$

Opacity at 75 MHz = $-(b_2/b_0)/75$

$T(f)$ = calibrated temperature

= frequency in MHz.

alternately with log fitting

$$\log(T(f)) = b_0 + b_1 \log(f/75) + b_2 (f/75)^{-2}$$

Where $T_{75} = e^{b_0}$

Spectral index = b_1

Opacity at 75 = $-b_2$

In general fitting the temperature rather than the log temperature gives slightly better results and is easier to extend to more parameters. For example, adding an ionospheric emission term requires a Taylor expansion of the log instead of adding a term. Given the correlation with spectral index it is not possible to get good estimates of spectral index, ionospheric absorption and ionospheric emission which requires 4 terms. However, simulations show that this should be possible with a combination of high and low band to increase the frequency coverage from 50 to 200 MHz.

Three parameter fitting tests on the data from 2016_250 to 2017_009 show that there is little difference in rms residuals between using the ionospheric absorption and the curvature in spectral index (the “gamma” term). This shows that within the current accuracy of EDGES the foreground does not require a curvature term and any decline in the magnitude of the spectral index with frequency can be just as well represented with an absorption term. This absorption term cannot distinguish between ionospheric or interstellar medium (ISM) absorption. The results from the high and low band and the latest analysis of low frequency sky maps are consistent with little, change of spectral index between 45 at 200 MHz.

Figure 1. shows the daily for each hour from 2016_250 to 2017_009 absorption optical depth. There are some missing days due to power loss or computer problems at the MRO and some missing hours due to solar burst or strong RFI. While there is fairly good repeatability from one day to the next there are changes over a period of about 10 days. Some of this change is real and some is due to a correlation between the sidereal periodicity and sources of error in EDGES calibration, loss correction and beam chromaticity corrections. Some of these error sources can be separated and corrected when enough data has been collected to obtain the ionosphere opacity from the T_{75} temperature for a given LST taken at ionosphere minimum, which occurs between local midnight and 2 hours before sunrise minus the current T75 at the same LST as is done in the standard single frequency riometer. This will be when about 1 year of data is acquired. Figure 2 shows the sky temperature and Figure 3 shows the spectral index for each hour of local time of each day.

The combination of high and low band data on the same day has the potential to allow the measurement of ionospheric opacity and electron temperature from a 4-term fit of the spectrum from 50 to 200 MHz. At present, there is one only day of recent data with both the high and low band and that occurred on 2016_247. The combined spectrum with 2-term fit is shown in Figure 4 for one hour from 20 to 21 hours UT. The best fit is a spectral index of -2.56 and T_{150}=264.1 K. There is a 3 K difference at 100 MHz which is probably mainly due to the difference in beam correction which is 20 K at 100 MHz because on day 247 the low band was still on the small 10×10 m ground plane.

The determination of the spectral index using a 3-term fit is very sensitive to systematics as shown in Table 1. which lists the 2 most significant sources of systematic error. These are errors in beam correction and errors in the estimate of losses. Figure 5 and 6 shows the spectral index determined from 2-term fits to the low and high band data using only the available nighttime data. The low band result agrees quite well with the high band result away from the transit of the Galactic center but has a deeper and wider dip during transit. The spectral index determined for the low band data using a 3-term fit to account for the effect of the ionosphere during daytime is shown in Figure 7.

	3-term	2-term	
Test	Spectral index	Spectral index	GHA
Reference	-2.550	-2.550	0
No beam correction	-2.888	-2.654	0
No loss correction	-2.477	-2.504	0
No beam correction	-2.473	-2.497	12
No loss correction	-2.475	-2.502	12
No beam correction	-2.211	-2.414	6
No loss correction	-2.476	-2.503	6

Table 1. Sensitivity of spectral index determination to systematics for 2 and 3 term fit.

While some of the differences are most likely due to errors in beam correction the deeper dip at Galactic center transit may be real and probably due to a flattening of the spectrum of the Galaxy by the warm ionized medium (WIM) of the ISM which has an electron temperature $\approx$ 7000 K (see Peterson and Webber Ap.J. 575:217 224, 2002). While a 4-term fit is required to incorporate an emission term the third term can be augmented to incorporate emission with fixed electron temperature

by

$$T(f) = (f/75)^{-2.5}\left(b_0 + b_1 \log(f/75) + b_2 (f/75)^{-2}\right) - b_2 (T_e/T_{75})(f/75)^{-2}$$

Where T_e = electron temperature

T_{75} = sky temperature is a function of LST

$\approx 1475 + 3276\, e^{-GHA^2/23}$

A tentative model which fits the high and low band an extragalactic component with a spectral index of about -2.7 independent of frequency which dominates away from GHA=0 plus a Galactic component with spectral index of -2.50 at 150 MHz and -2.45 at 75 MHz which dominates at GHA = 0.

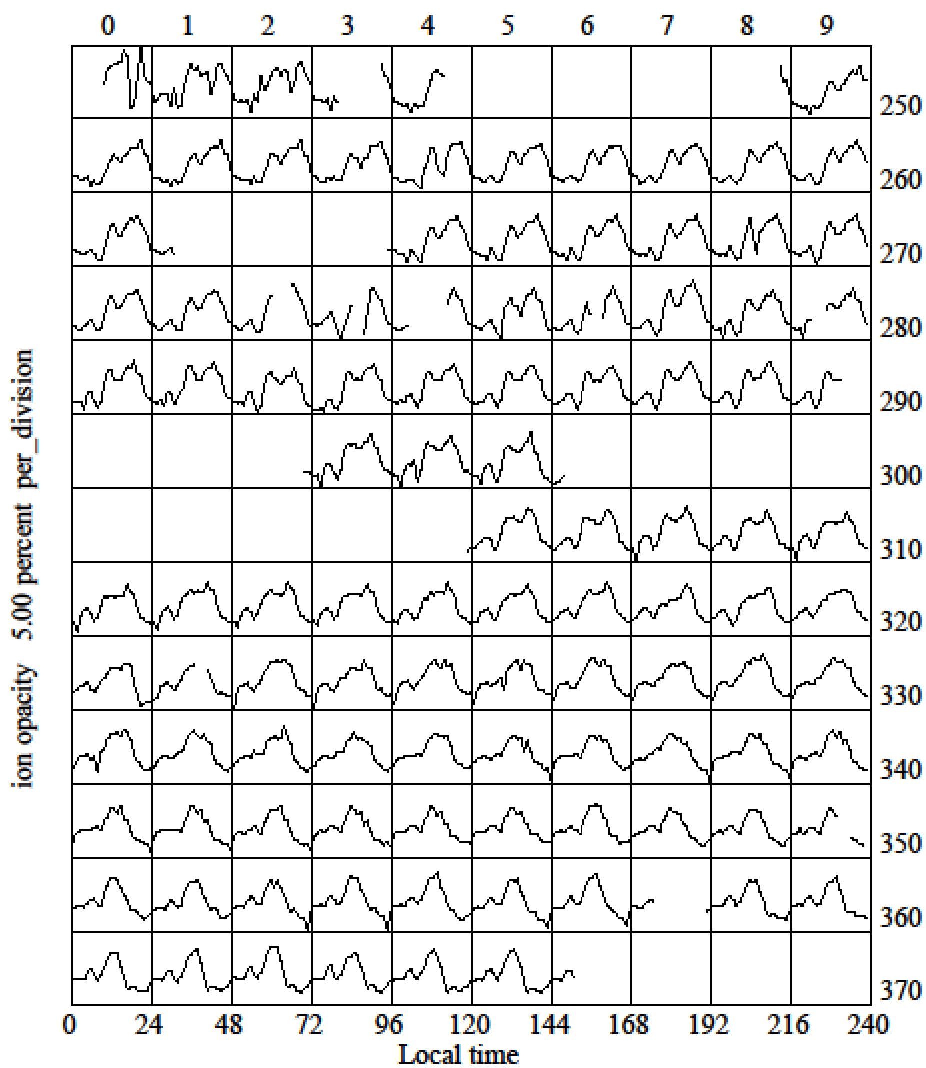

Figure 1. Opacity of ionosphere at 75 MHz estimated from a 3-parameter fit each hour.

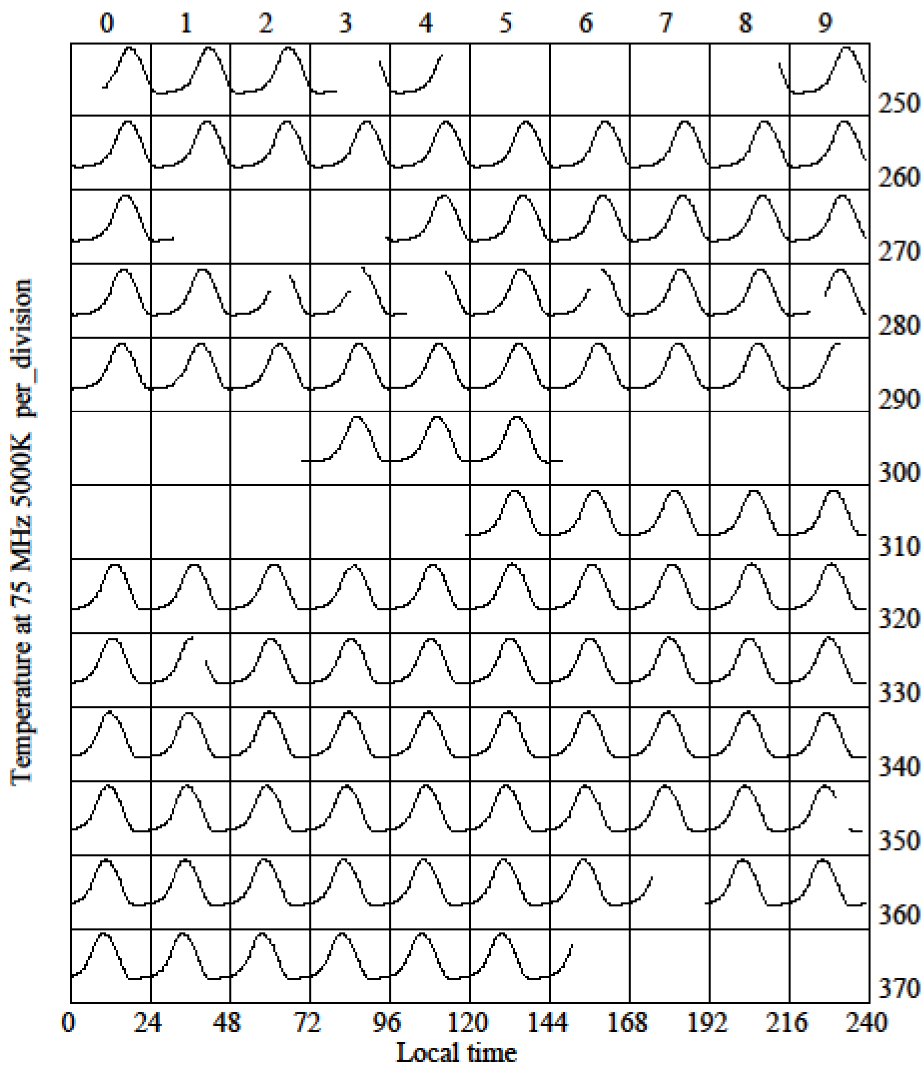

Figure 2. Sky temperature at 75 MHz from 3-parameter fit.

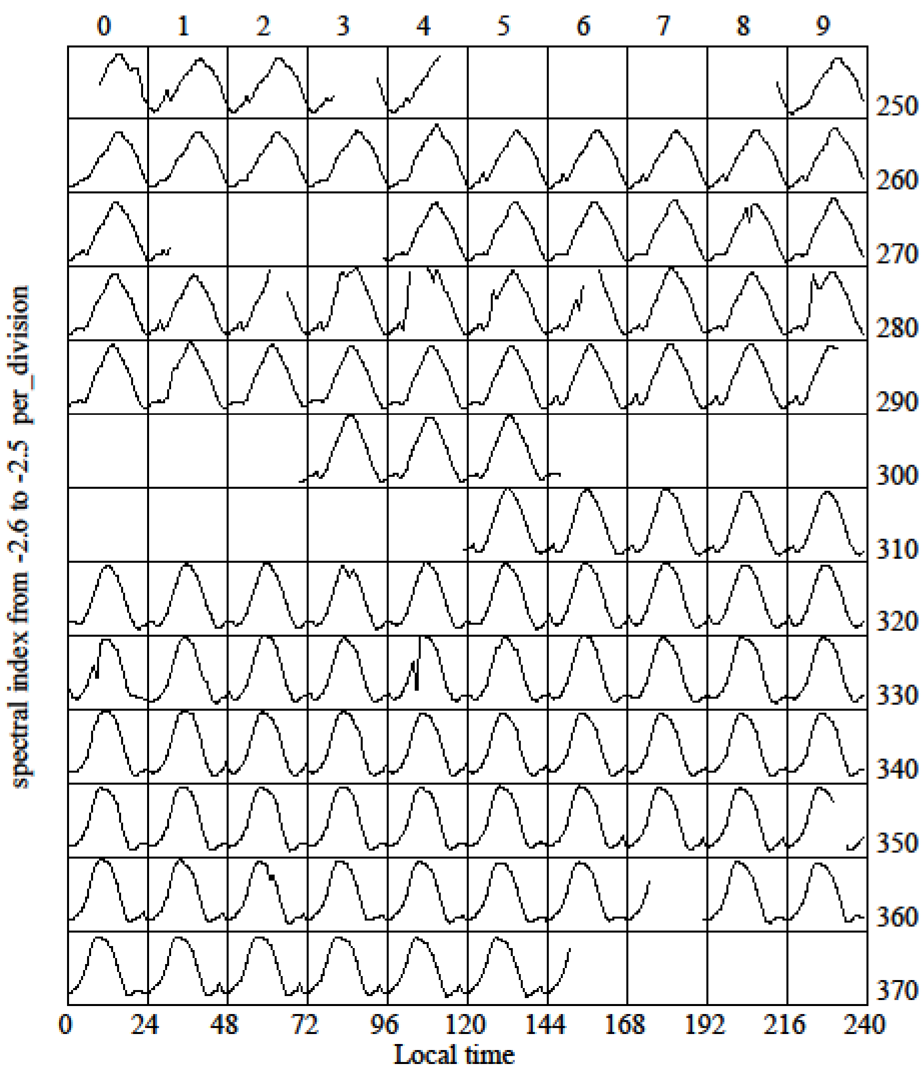

Figure 3. Spectral index from 3-parameter fit.

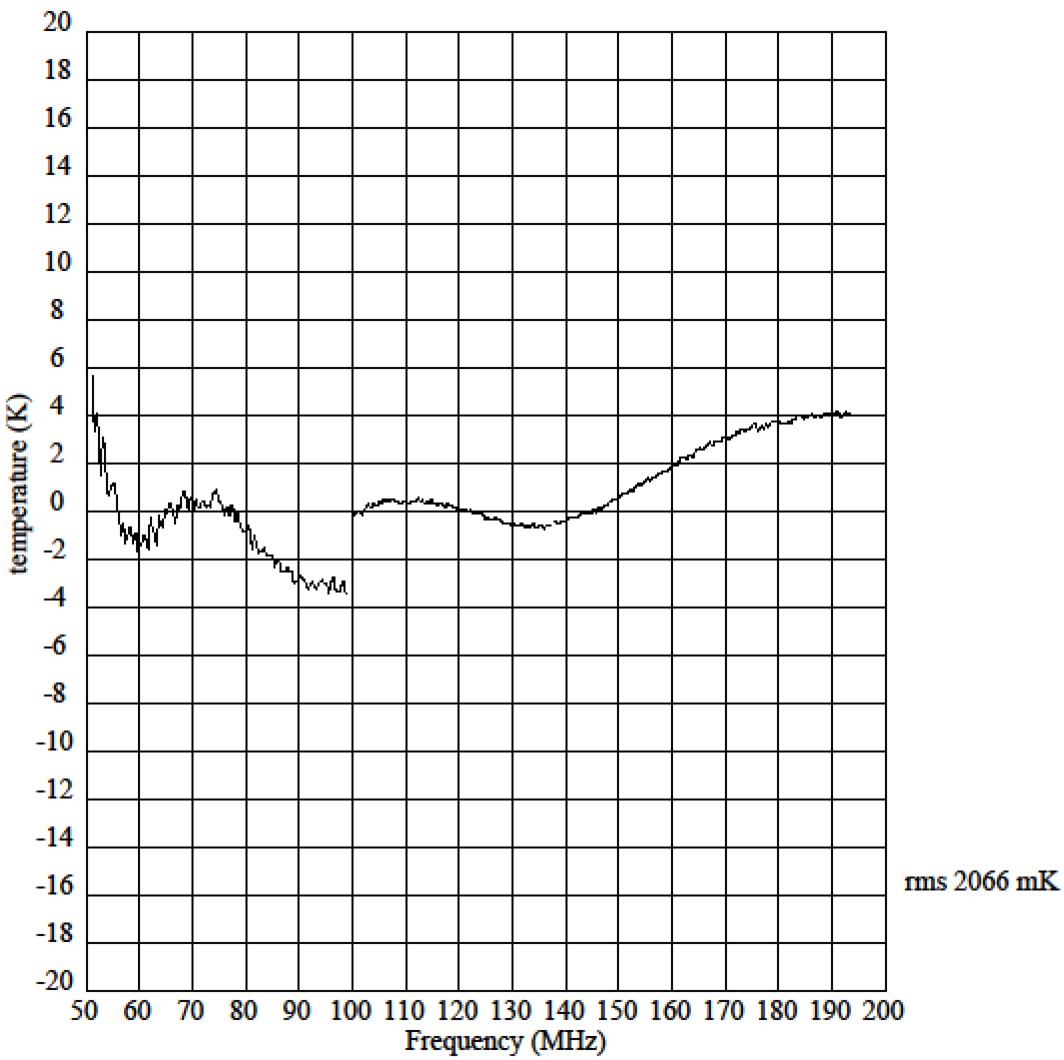

Figure 4. Low and high band data combined for 2017_247.

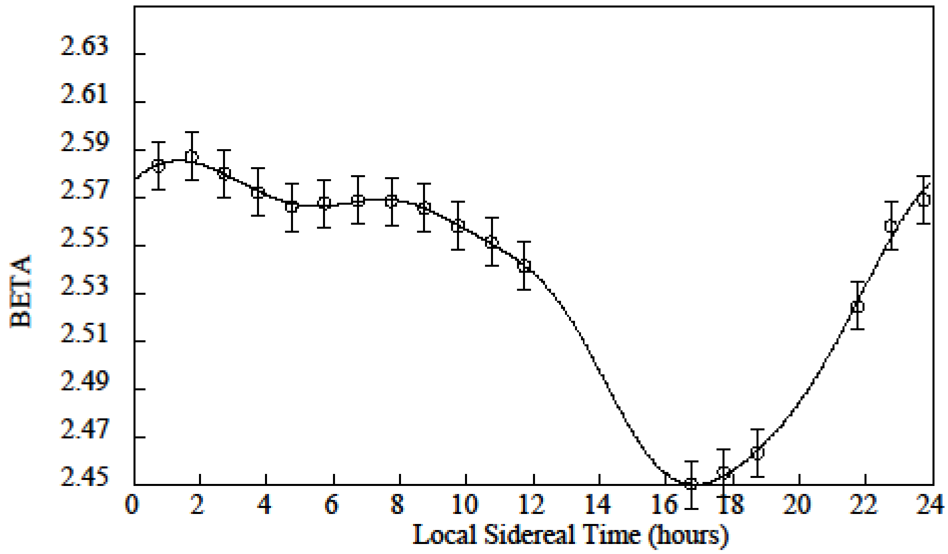

Figure 5. Spectral index for nighttime data from low bands using 2-term fit.

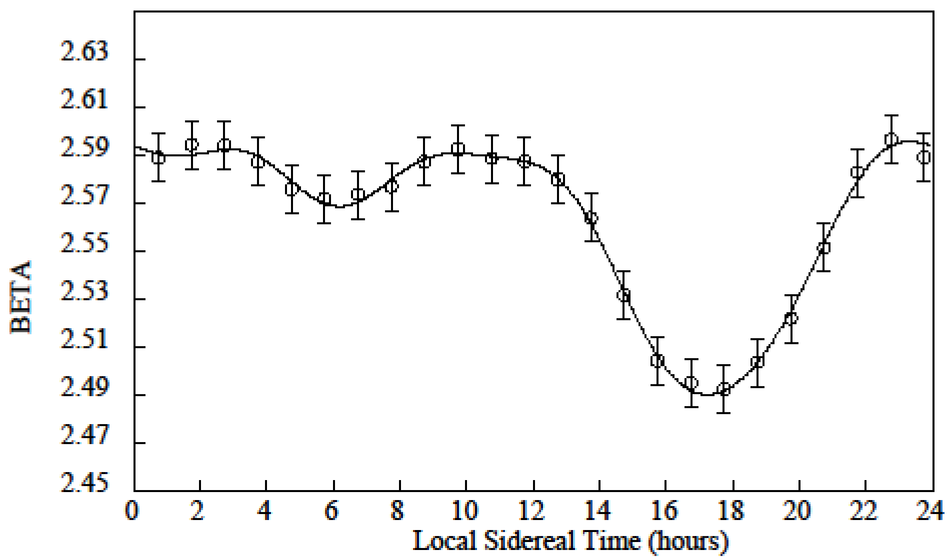

Figure 6. Spectral index for nighttime data from high band using 2-term fit.

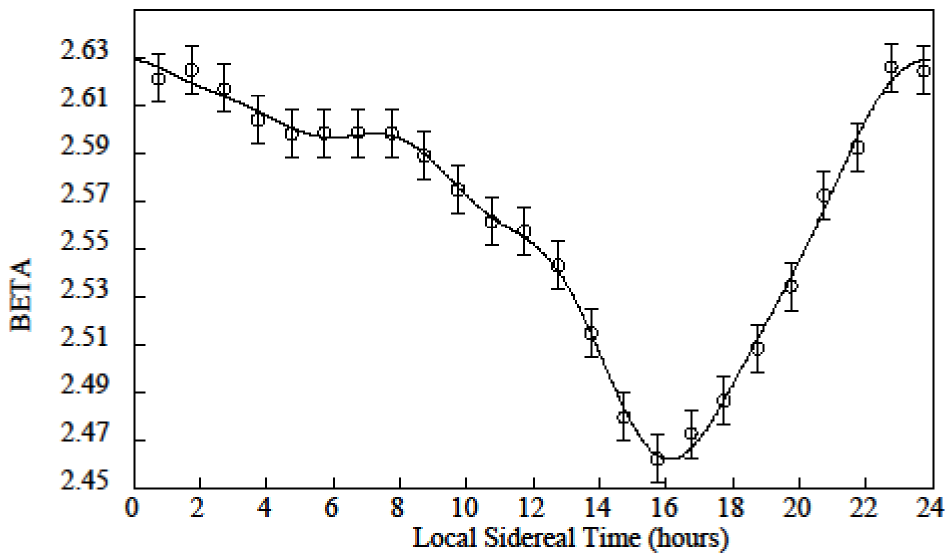

Figure 7. Spectral index from low band using 3-term fit.