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To: EDGES Group

From: Alan E.E. Rogers
Subject: Excision of weak broadband RFI signals

The removal of RFI is discussed in memo 137. In summary thresholds are set for the removal of all the frequency channels for a single 3 position switch cycle while individual frequency channels are marked for excision in an integration period of many cycles. This excision reduces the number of valid samples in a particular frequency bin for a given integration of many 3 position switch cycles. Currently frequencies are marked with zero weight based on an examination of the spectrum obtained for several hours integration for frequency channels that exceed the rms noise by a threshold usually taken as 2.5 sigma. This operation is done in an iterative fashion where rms noise for a sliding window is recalculated after channels that exceed the threshold are removed from those used to calculate the rms noise.

There are 2 problems:

1] If the RFI is weak and broadband it cannot easily be distinguished from the noise.
2] The RFI may be so weak that it will require many days of integration to detect.

The first problem may be solved in some cases by examining the spectra on intermediate times scales. For example Figures 1 and 2 show spectra obtained for 15 minute integration. Both of these show relatively wideband signals which are most likely from a satellite. The signals shown in Figure 1 are hard to understand but a most likely from a satellite whose transmitter has a malfunction. The center frequency of the signal around 160 MHz is exactly are 159.6 MHz which is seen at other times and on other days as a narrowband carrier.

When spectra are averaged the bias which results from an uneven distribution of unweighted frequency channels in the presence of changes is minimized by averaging residuals as follows

$$S_{av} = \left(1/N\right)\sum S_m + \left(1/M\right)\sum W\left(S - S_m\right)$$

Where S = spectra point
$S_{av}$ = average
N = number of spectra
$S_m$ = model fit
M = number of residuals within threshold
W = 1 for residuals within thresholds
= 0 otherwise

The model fit can be a Fourier series or a "sliding" polynomial. Since most RFI is not very wide an efficient model fit is to use a sliding fit over 3.125 MHz and apply this every 10 or 20 3-position cycles. The iterative method uses a weighted fit which starts with all frequency bins weighted and then downweights bins which exceed the threshold until all weighted bins are below the threshold. The rms for the determination of the threshold for the next iteration is calculated using the weights.

Weight of zero and one are used. For a 3 MHz width a 2-parameter fit using an offset and slope is sufficient and efficient enough to run on every 3 position switch cycle. Performing spectral RFI excision on every switch cycle offers no advantage unless the RFI is only present in a single cycle. Most RFI is present for several cycles and can be more easily detected in the average of several cycles.

Figure 3 shows the spectrum with 6 kHz resolution averaged during the time when the sun is 10 degrees below the horizon. Instead of removing spectral bins with RFI they are limited to 5 degrees K to illustrate the range of frequencies affected by RFI. Figure 4 shows the average of 30 days of RFI filtered data. The top lot is 4 hours each day centered at 9 GHA with RFI filtering each day. The middle plot shows that deliberate excision of a 1 MHz wide region centered at 150 MHz reduces the peak at 150 MHz. The bottom plot shows that the RFI at 150 MHz and some other regions is not excluded by filtering each day and additional filtering is needed on longer time scales. The presence of weak RFI at 150 MHz might be explained if it's from a geostationary satellite. Spectra from several days can be averaged by concatenating all the days into a large file and running the first stage processing all days to obtain a RFI filtered average with weights assigned to each channel. An alternate method is to obtain separate RFI filtered spectra for each day, calibrate these spectra and then average the calibrated spectra. In this second method the weight assigned to each frequency channel in the average calibrated spectrum can be assigned a weight equal to the sum of the weights for the individual days or a threshold can be set for which an individual channel is only assigned unit weight if all, or some fraction, of the days have unit weight. In practice it may be best to apply the former to minimize the effects of RFI. As the 10 mK level is approached in the average spectra there are significant challenges in removing the effect of low level RFI.

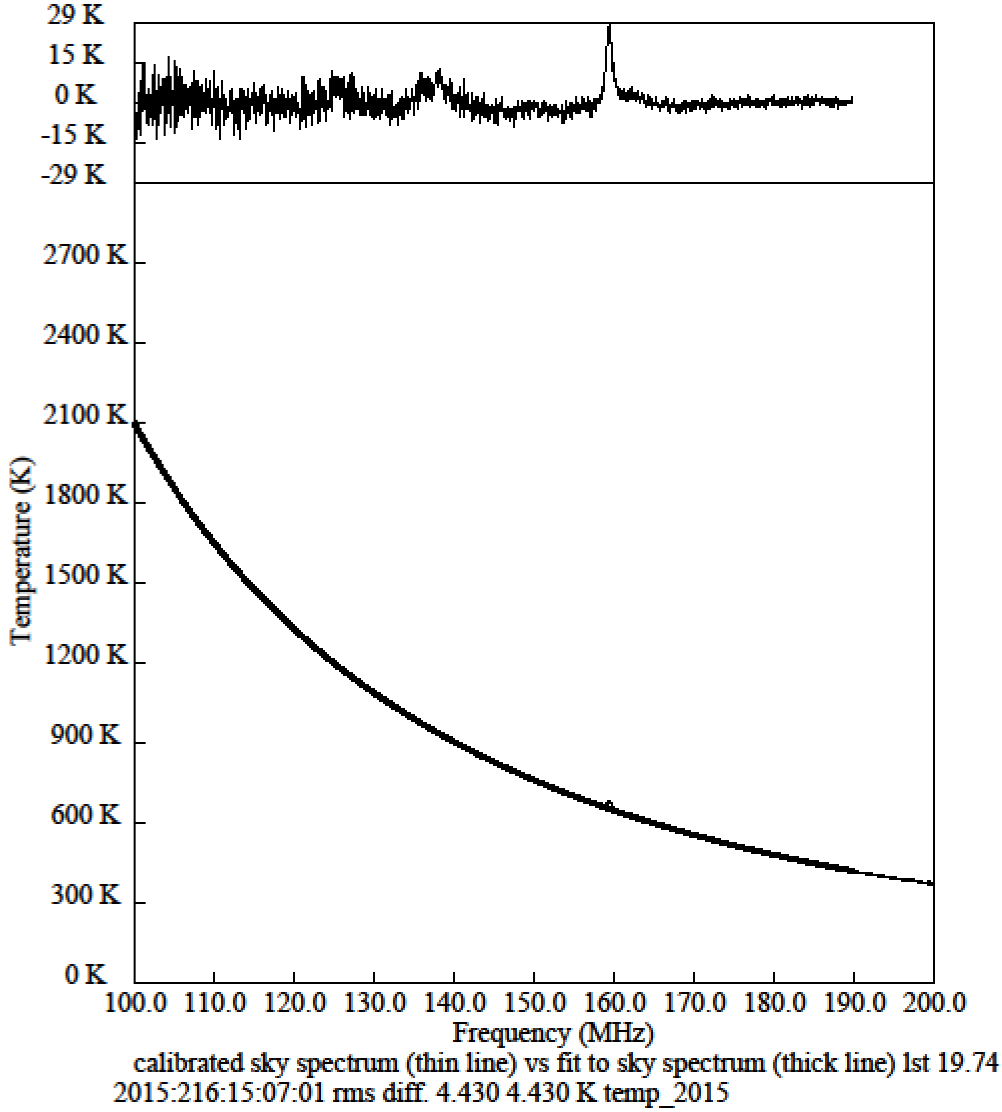


Figure 1. Wideband signals from malfunctioning transmitter.

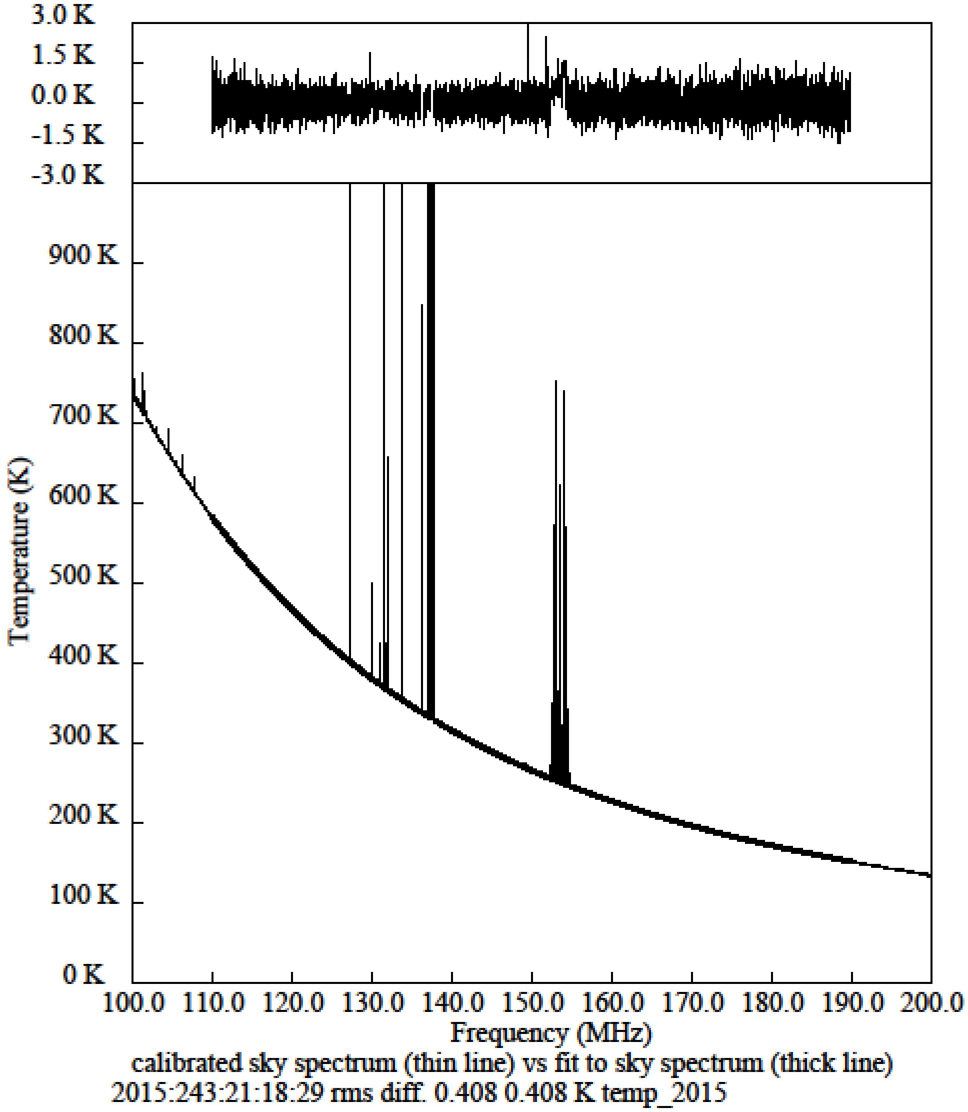


Figure 2. Wideband signal from 152 to 155 MHz.

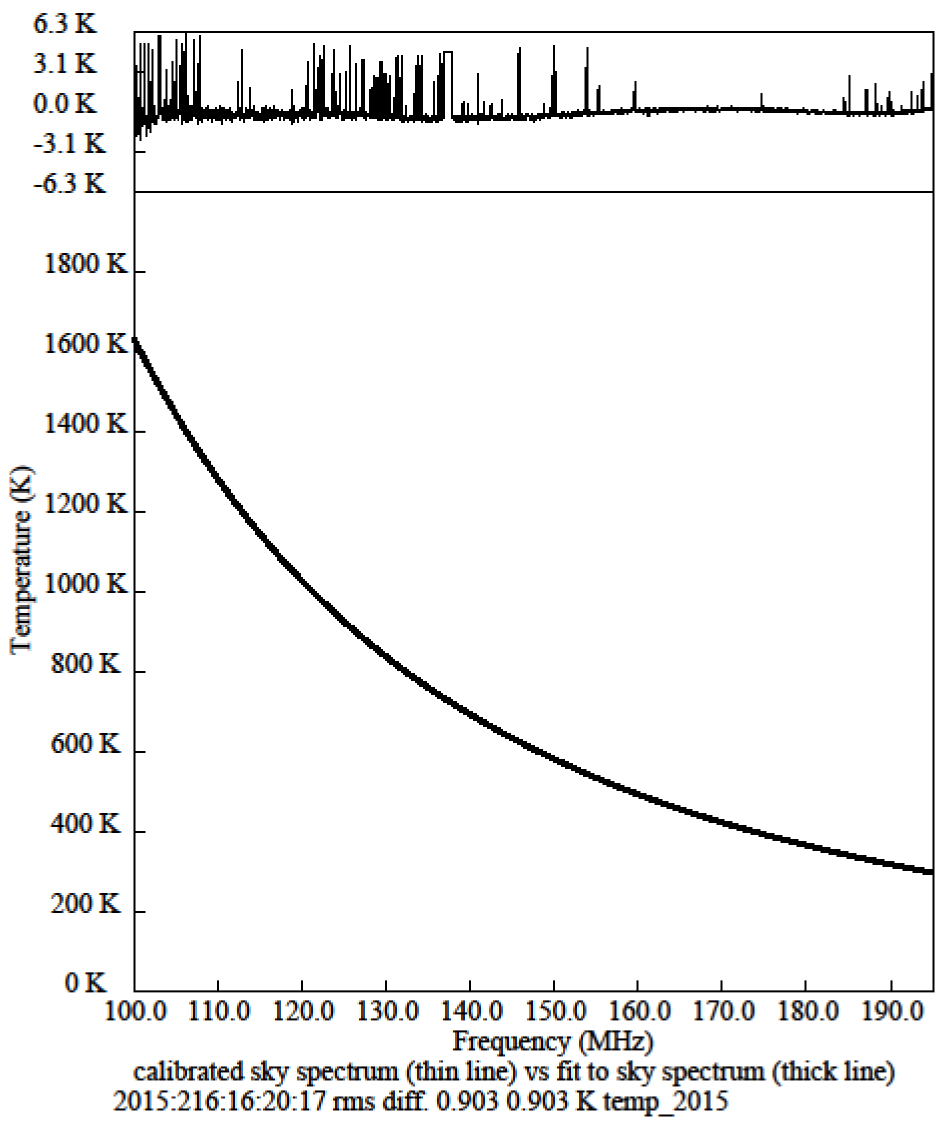


Figure 3. Sky noise spectrum without RFI excision for nighttime on day 216.

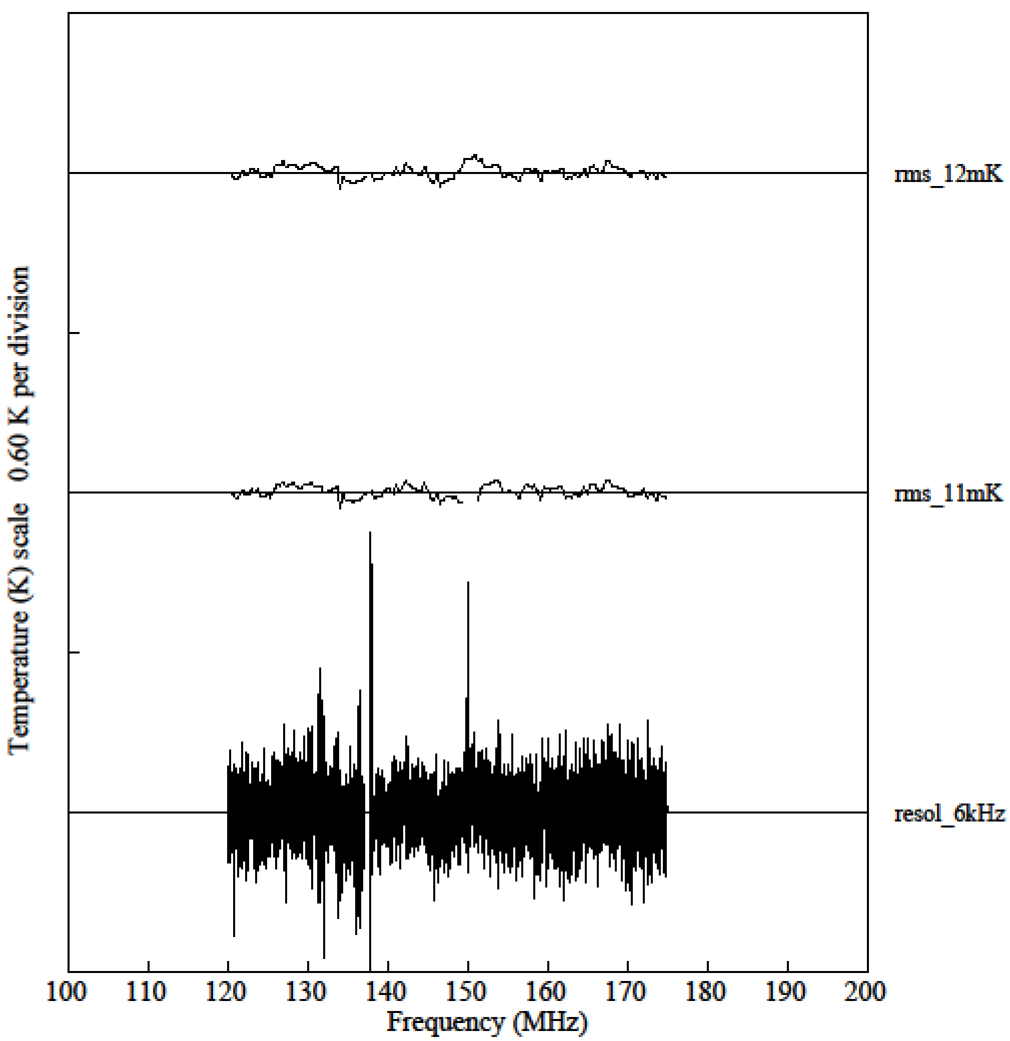


Figure 4. Top plot shows weak RFI at 150 MHz. Middle plot shows spectrum after excluding a 1 MHz wide window at 150 MHz. Bottom plot shows 6 kHz resolution spectrum.