Technical note

REMOVING THE INSTRUMENTAL BACKGROUND FROM C1XS DATA

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1. INTRODUCTION

Every spectrum ever obtained by the C1XS (Chandrayaan-1 X-ray Spectrometer) SCD (Swept Charge Device) detectors will contain an instrumental background. This is caused by the Galactic cosmic ray (GCR) background protons passing through the silicon in the detectors and depositing a certain amount of energy within the detectors which then gets interpreted as an X-ray signal. This background is very stable in the sense that it is always there at some minimal (quiescent) level. However, energetic electrons and protons in the lunar environment can also add to this minimum background level. And these additional energetic particles will then increase and modify the instrumental background spectrum. These interactions can be very vigorous and very dynamic.

2. BACKGROUND SPECTRA

In order to model the C1XS instrumental background, we have provided a number of integrated spectra from throughout the Chandrayaan-1 mission. Specifically, we have generated two different quiescent spectra and nine different "active" spectra. As the degree of activity increases the exposure time of the active spectra decreases reflecting the increasing rareness of the increased activity level. Table 1 describes these 11 spectra. They are shown graphically in Figure 1.

The parameter that distinguishes the different levels of activity is the "background gradient". This parameter needs a little explanation to understand exactly what it is measuring.

3. BACKGROUND GRADIENT

The background spectra shown in Figure 1 are from the entire Chandrayaan-1 mission of ~9 months. When the C1XS data was being processed for the Planetary Data System (PDS), each orbit of data would be divided into between 5 and maybe 15 spectra, depending on the level of activity (or quietness) of the data. The more activity present in an orbit, the more spectra would be extracted in order to track the activity. Each of these extracted spectra would then be compared with the mean quiescent spectrum – that is, the sum/average of Q1 and Q2, composed of around 9.8 million seconds of accumulated exposure time (obviously, the data had to be analysed at least twice in order to obtain the background reference spectrum in the first place). In particular, the sample spectrum and the quiet background spectrum would be compared in 4 broad energy bands:- 1.0 – 3.5 keV, 3.5 – 5.5 keV, 5.5 – 10 keV and 10 – 16.5 keV. To do the comparison, the quiet time reference spectrum can be rescaled to the same exposure time as the sample spectrum.

Table 1: Description of the Quiet and Active C1XS background spectra.

Name	Description	Exposure Time (seconds)	Background Gradient
Quiescent 1	The quiet time (minimum) background level from the first ~ 6 months of the Chandrayaan-1 mission.	4.622×10^6	N/A
Quiescent 2	The quiet time (minimum) background level from the last ~ 3 months of the Chandrayaan-1 mission.	5.238×10^6	N/A
Active 1	Lowest Level of activity.	310895	0.050 – 0.10
Active 2		199008	0.10 – 0.1675
Active 3		104028	0.1675 – 0.250
Active 4		163190	0.250 – 0.40
Active 5		174289	0.40 – 0.575
Active 6		150892	0.575 – 0.875
Active 7		36390	0.875 – 1.025
Active 8		20372	1.025 – 1.225
Active 9	Highest level of activity.	9633	➢ 1.225

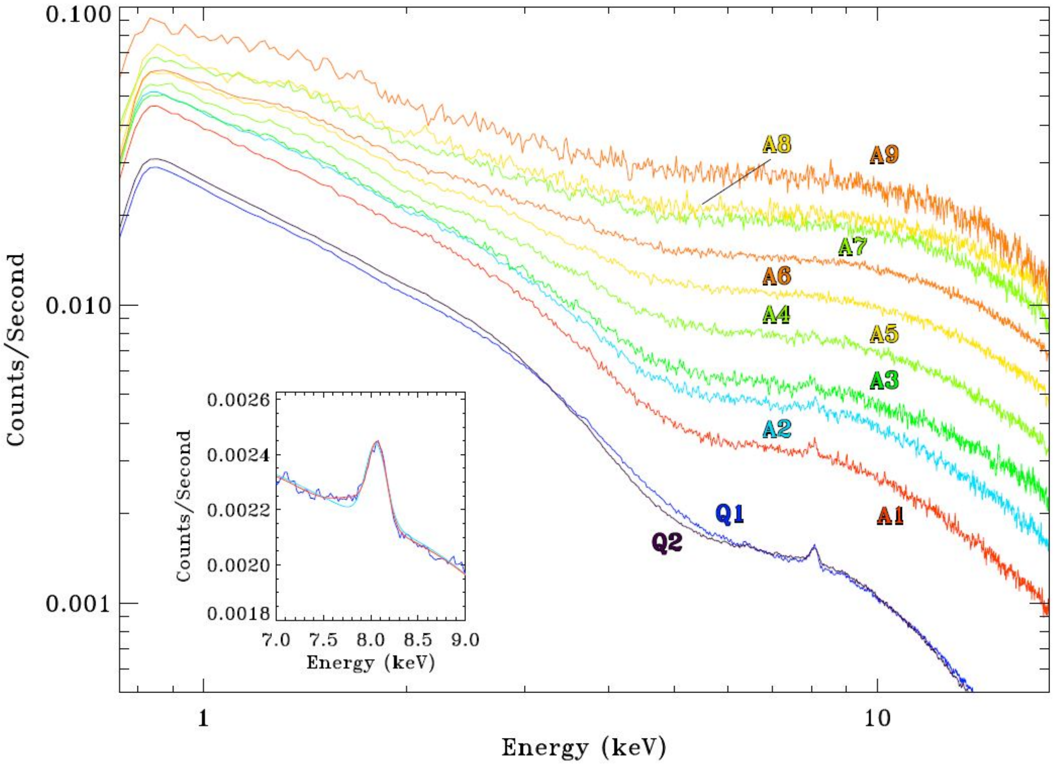

Figure 1: The two quiet time and 9 active time C1XS background spectra. The inset shows a close up of the copper Kα line at 8.04 keV from the detector collimators.

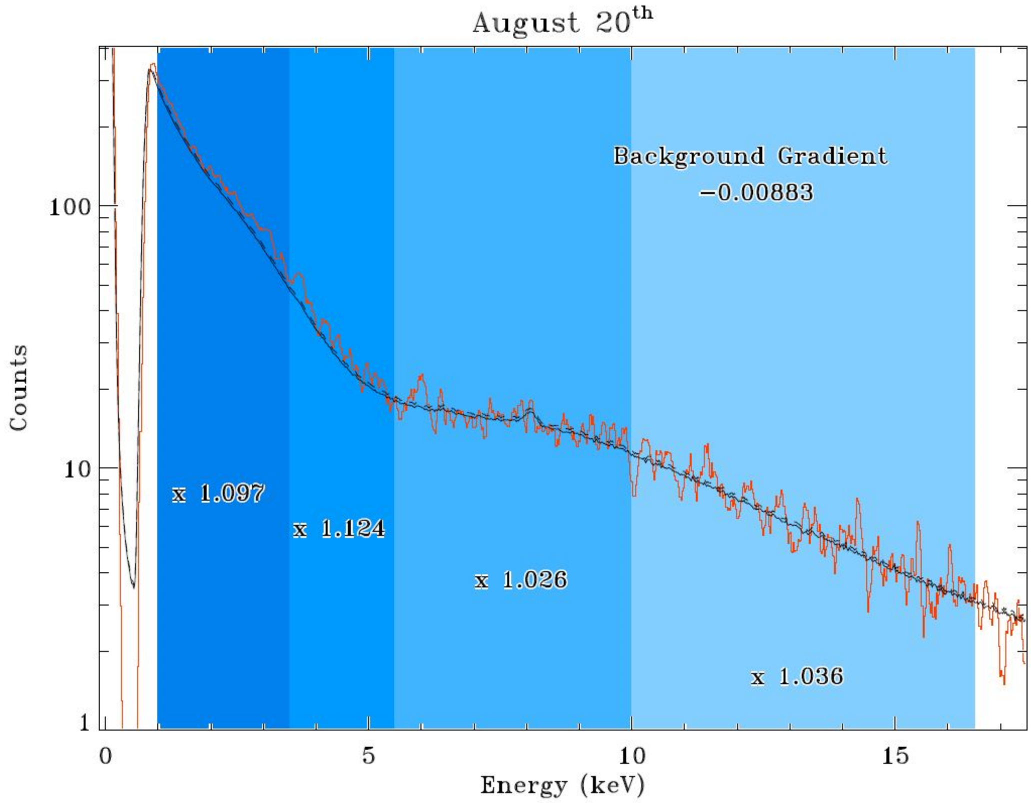

Figure 2: Example of the method used to calculate the “background gradient” of a sample spectrum. The sample spectrum was taken from August 20th, 2009, starting at 23:41 to 23:48 with an exposure time of around 5400s. [NB: the sample spectrum has had a slight boxcar smoothing for presentation purposes].

In Figure 2 we have actually used the Q2 reference spectrum appropriate for the end of the mission, rather than the average of Q1 and Q2. The difference is actually very small. The counts in the sample spectrum and quiet time reference spectrum are then summed in each of the four bands and the ratio of these sums is calculated. Then, using the central energy of each of the 4 bands and the sample-to-reference background ratio, a linear fit is made to the ratios and the gradient of this fit is the “background gradient”. This is shown for a sample background spectrum from very close to the end of the Chandrayaan-1 mission in Figure 2.

It can be seen from Figure 2 that the RATIO of the sample spectrum to the reference spectrum is approximately constant across the 4 bands resulting in a background gradient of very close to 0.0. This means in simple terms that the sample spectrum shown here is essentially the SAME shape as the reference spectrum … i.e. this is a quiet time spectrum. This is actually the case for the vast majority of the spectra obtained by C1XS. This can be seen from Figure 3 which shows the distribution of background gradients among the ~6,400 C1XS spectra from throughout the Chandrayaan-1 mission that were used to assemble the quiet and active spectra shown in Figure 1. In fact, 85.67% of the spectra are in the peak at ~

0 gradient … more than 5 out of every 6 spectra analysed! [NB: If we use the exposure times from Table 1 we find that, in fact, for the data analysed so far, C1XS was in an "active" state for 1.17×10^6 s, or 10.6% of the total time.]

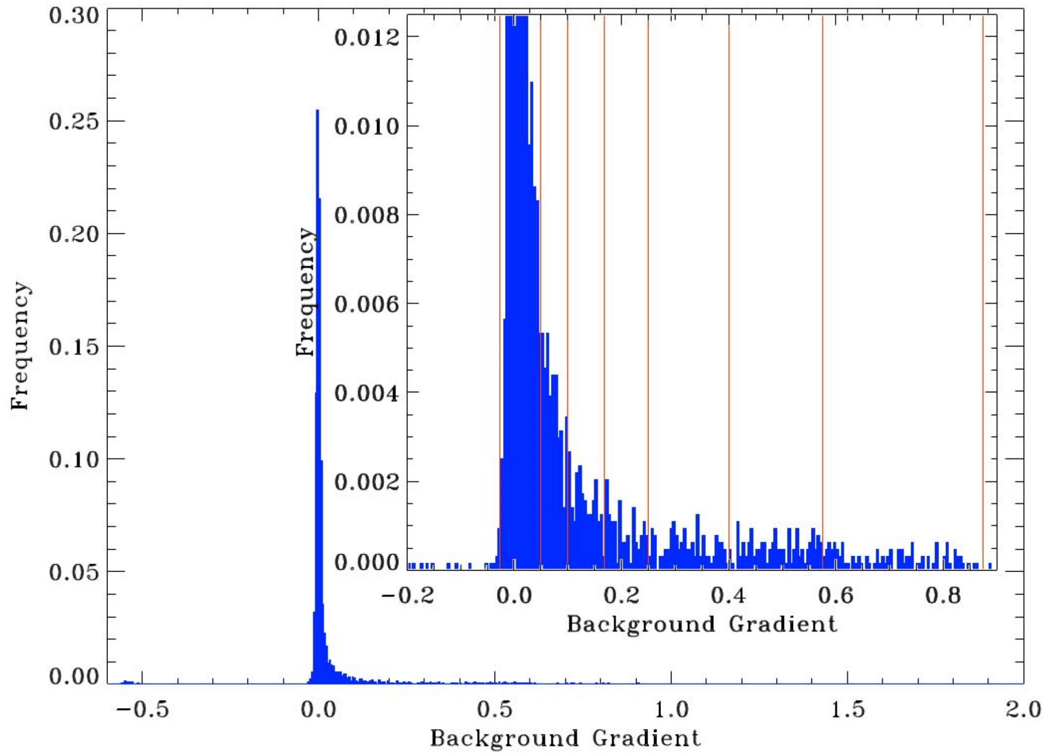

Figure 3: The distribution of background gradients from over 6000 C1XS spectra from throughout the C1XS mission. The inset shows a zoom into the data and the red lines shows where the data cuts for the different levels of activity where made.

So, a simple method of obtaining an estimate of the background spectrum for the sample period shown in Figure 2 would be to scale the reference spectrum by a factor of 1.0295. This is shown by the dashed line in Figure 2. Here the scaling was calculated for the 5.5 – 16.5 keV energy range (i.e. over bands 3 and 4 in Figure 2). This energy range is usually chosen to avoid any "excess" counts that might be present at lower energies. Such excesses can be related to solar flares and the resulting increase in low energy counts from the fluorescence X-rays generated by the Moon. We will see some examples of active and flare spectra in the next Section, and develop a simple method for obtaining a good background comparison spectrum.

4. CALCULATING A "PERFECT" BACKGROUND SPECTRUM

Calculating a "perfect" background for the sample spectrum shown in Figure 2 is rather pointless – since there is no significant excess to analyse. We would just be fitting a background spectrum to a background spectrum. However, there are, fortunately, times when we DO want to estimate the background because we DO have a significant excess in the 1-3.5 keV band. In other words… when we have a solar flare or other form of "activity" present in the spectrum. Approximately 1 out of every 6 spectra, in fact, can be classed as an active spectrum.

Figure 4 shows data from February 10th, 2009. Three orbits are shown from that day (they are not consecutive). The top two show a phenomena called PIXE … Particle Induced X-ray Emission. In this case it is very likely to be low energy electrons as well as more energetic electrons that are the particles. It is the more energetic (i.e. 100s of keV) electrons that generated the "active" spectra shown in Figure 1. However, in Figure 4, we also see very strong evidence for the presence of low energy electrons. The PIXE we see is caused by these low energy electrons striking the opaque filter that is fitted to C1XS immediately in front of the detectors. The filter is present to block optical light from the Moon from striking the detectors. It uses two very thin layers of aluminium to block the light. Unfortunately, if aluminium is struck by sufficient low energy (i.e. 1-2 keV energy) electrons, the aluminium can be made to fluoresce. The third (bottom) panel of Figure 4 shows an actual solar flare and the response of the Moon producing three low energy lines. However, all three panels show cyan and green counts extending up above 2 keV. The data here should be the darker blue and magenta colours seen at the beginning of the second and third panels. We even get yellow and orange colours between 15:12 and 15:30 (15.2–15.5 UT) during the most intense PIXE in the middle panel. These are the more active electrons that will distort the sample spectra that we would like to analyse. Therefore, for data like that shown in Figure 4, we do need a method that will automatically adjust the quiet reference background to provide a good estimate of the 1–5 keV background. This adjustment requires adding a "suitable" amount of one of the active spectra from Figure 1 to the quiet reference spectra.

Figure 5 shows two C1XS spectra from the middle panel in Figure 4. A "quiet" spectrum from around 14:55-15:03 (at the beginning of the orbit), and an "active/PIXE" spectrum from the peak of the event around 15:26-15:32. The active spectrum clearly shows a greatly modified gradient compared to Figure 2. Even the "quiet" spectrum shows some indications of being mildly active … its background gradient is not shown on Figure 5, but it is 0.0364 … putting it on the upper side of the "quiet" distribution.

So, while the Q1 spectrum is quite a good match to the quiet time spectrum from Feb 10th, it is DEFINITELY *NOT* a good match to the active time spectrum. So, what can we do to improve the match?

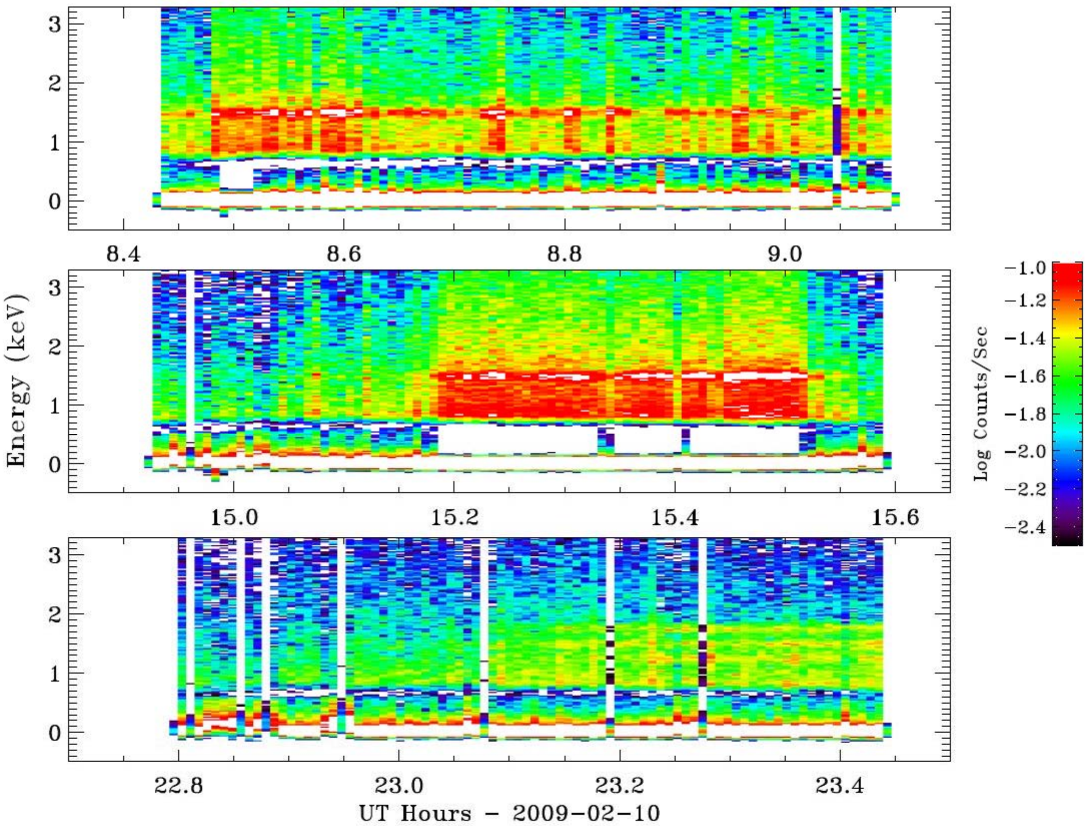

Figure 4: Three C1XS orbits from Feb. 10th, 2009. The top two panels show PIXE (Particle Induced X-ray Emission) – the intense feature at around 1.5 keV is the aluminium filter “glowing” in X-rays. The bottom panel shows a solar flare that started around 23:05 UT. The three weaker features at around 1.25, 1.5 and 1.75 keV are now the fluorescent lines of magnesium, aluminium and silicon generated on the Moon by the solar flare X-rays.

5. METHOD

The method described here is designed to provide a reasonably good fit to the low energy portion of the spectrum for MOST of the data. In fact, the “active” spectrum shown in Figure 5 is one of the more extreme examples – it qualifies the spectrum to be in Active Band 8, the next to top level of activity! By low energy we mean the 1 – 5 keV energy range.

The method is very straight forward. Simply follow the 6 step procedure outlined below and you should be able to get similar results to those shown in Figure 6.

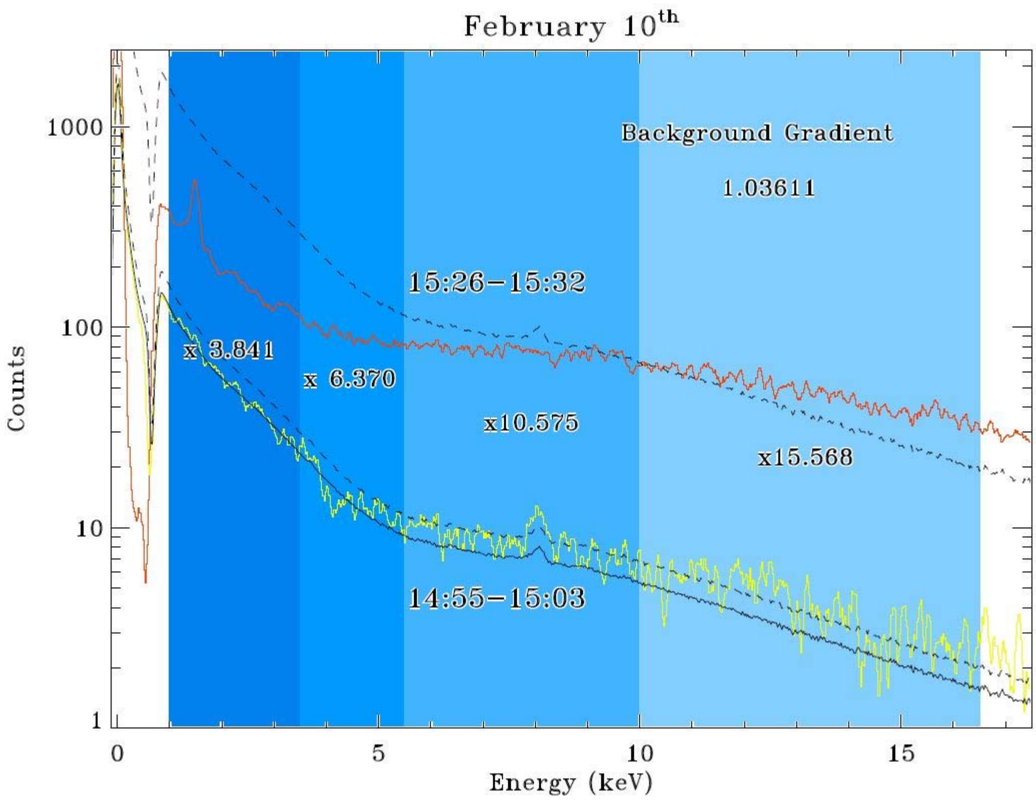

Figure 5: Quiet and active spectra from the middle panel of Figure 3. (The active spectrum was very slightly scaled to have the SAME exposure time as the quiet spectrum for comparison purposes).

1. Boxcar smooth the sample spectrum (5 or 7 channel wide boxcar).

2. Take the appropriate quiet time reference spectrum (Q1 is good for before June 1st, Q2 after that, or take some average of the two). However, divide the counts in the spectrum by some large factor, say 100,000. (This is to make the exposure time more comparable to the active spectra, which have much shorter exposure times).

3. Now, for each of the nine levels of activity shown in Table 1 you need to create a composite spectrum by adding a scaled amount of the active spectrum to the reduced exposure quiet spectrum from (2). The scaling factors should vary from around 0.0001 to 100,000 or even a million. Take maybe 1000 scaling factors that are evenly spaced logarithmically. (That is, take the log of the start and end values and form a series that is uniformly spaced between these two limits and then take the anti-log).

4. Scale the “test background” spectrum to the smoothed sample spectrum in the 5.5 – 16.5 keV range as already advised above.

5. Using “suitable” energy channels, calculate a χ^2 value for the goodness-of-fit.
That is, calculate the sum of the squares of the differences of the (sample – test) background. It is important to only form this summation over channels that are truly representative of the background. So, for example, from ~3.9 keV up to 16.5 keV. But, it is also important to include low energy points in this χ^2 summation. However, care needs to be taken to avoid “channels of

interest" that MIGHT contain a real signal above the background. So, DO NOT include the channels from around 1.15 to 1.95 keV – this is where the three commonest flare-related Moon lines reside (Mg, Al and Si Kα lines). Also avoid the Ca Kα line around 3.7 keV and the region around 2.1 keV where (very rarely) the gold L lines can be seen. It is especially important to include points from around 1 keV (0.9 – 1.03 keV).

6. Calculate the χ^2 for every scaling factor in your desired range and then for every one of the nine levels of activity. The minimum χ^2 is then the best fit, so keep account of the activity band and scaling factor which had the LOWEST χ^2.

This procedure should be very quick and should produce a reasonable good match to the low energy channels of the sample spectrum. Figure 6 shows the results I achieved with this method for the two spectra from Figure 5. According to my fitting, the "quiet" spectrum was best fitted with a very small amount of A2 added to the Q1 quiet reference spectrum … 0.00072 was the scaling factor used here. However, to get the fit shown for the "active/PIXE" spectrum I needed to use 0.0071 of the A7 spectrum.

The fit to the quiet sample spectrum is pretty good for the full energy range of the spectrum. You can see that even though only a very tiny amount of the active spectrum was added to the quiet reference spectrum, it has significantly changed the gradient of the spectrum. This is a very important point. It is only ever possible to FLATTEN the quiet time reference spectra, STEEPER spectra cannot be generated by this method. However, steeper spectra are very unlikely to be found in the C1XS data archive.

The fit to the active/PIXE sample spectrum in Figure 6 might appear to be less good. As mentioned above, this is a pretty extreme example of an active spectrum. Certainly, the simple method described above does struggle to find a good match to the ENTIRE spectrum. The fit does deviate from the sample spectrum above 10 keV. However, it is very unlikely that you will ever be interested in this energy range – there are no obvious lines of interest in this energy range. (If you do want to investigate this energy range then only calculating the χ^2 for these higher energy channels would probably allow a better match to be made. Alternative, you could try a 2-D method where two different active spectra were used to find a best fit.). On the plus side, the fitting method has done a fairly good job of matching the data in the 1 – 5 or 1 – 10 keV energy range which is the energy range that contains all the lines of interest that you are likely to want to analyse. And the method is very quick. If you use the method on less extreme spectra, you should find it does a much better job of fitting the entire spectrum.

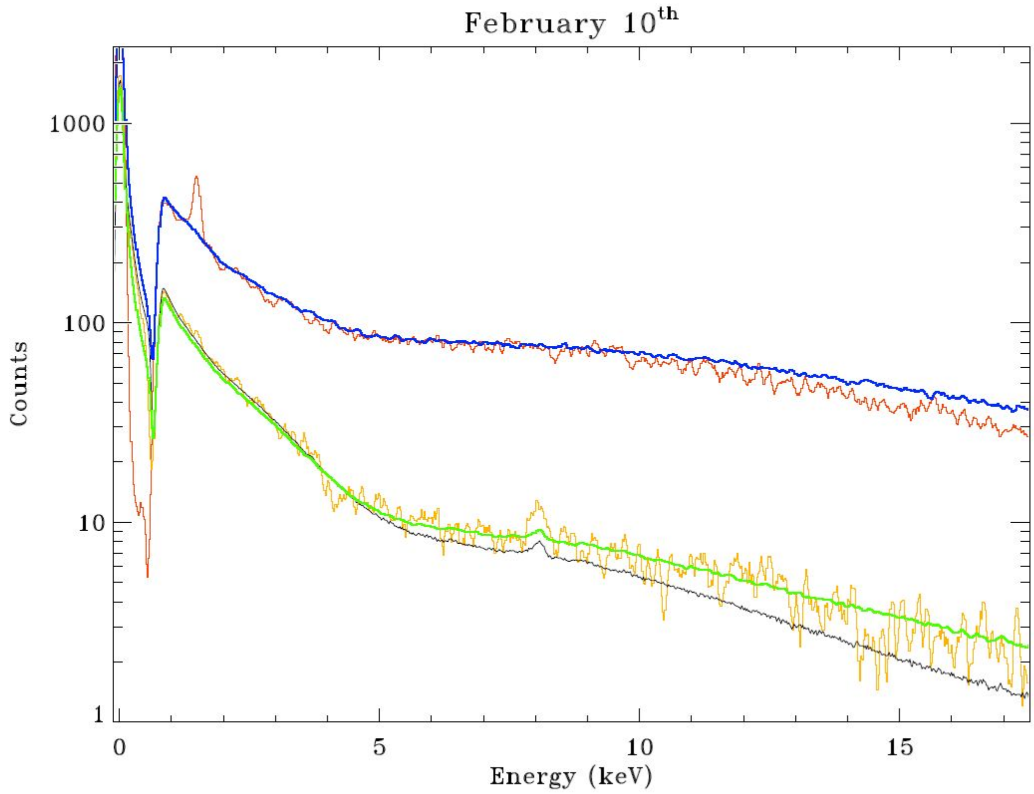

Figure 6: The best fit background for the quiet and active sample spectra from Figure 4. See the text for details.

6. CALCULATING THE BACKGROUND SPECTRUM FOR A FLARE.

The bottom panel of Figure 4 does show a flare spectrum. Certainly, at the beginning of the flare, the background is somewhat raised while the end of the flare seems to be less badly affected. However, the technique for analysing a flare is slightly different to the above described method. This is because a flare usually extends over a longer time interval with a greater chance that the background will vary during the flare. The technique is to divide the spectrum up into a number of smaller time intervals. You will probably want to do this anyway with a flare. You then fit each interval separately following the previously described method but this time you will sum both the flare + background data and the background fit to the data in each interval. At the end of the fitting procedure you will then have a composite total flare and total background spectra. The result for the flare in Figure 4 is shown in Figure 7. This illustrates very well the above mentioned care that is needed in selecting the correct points to fit when judging the background. With a flare spectrum in particular, getting ANY points below about 1.1 keV can be tricky. However, the background fitting procedure has done a very good job of fitting the entire background as can be seen in the top inset spectrum and the flare

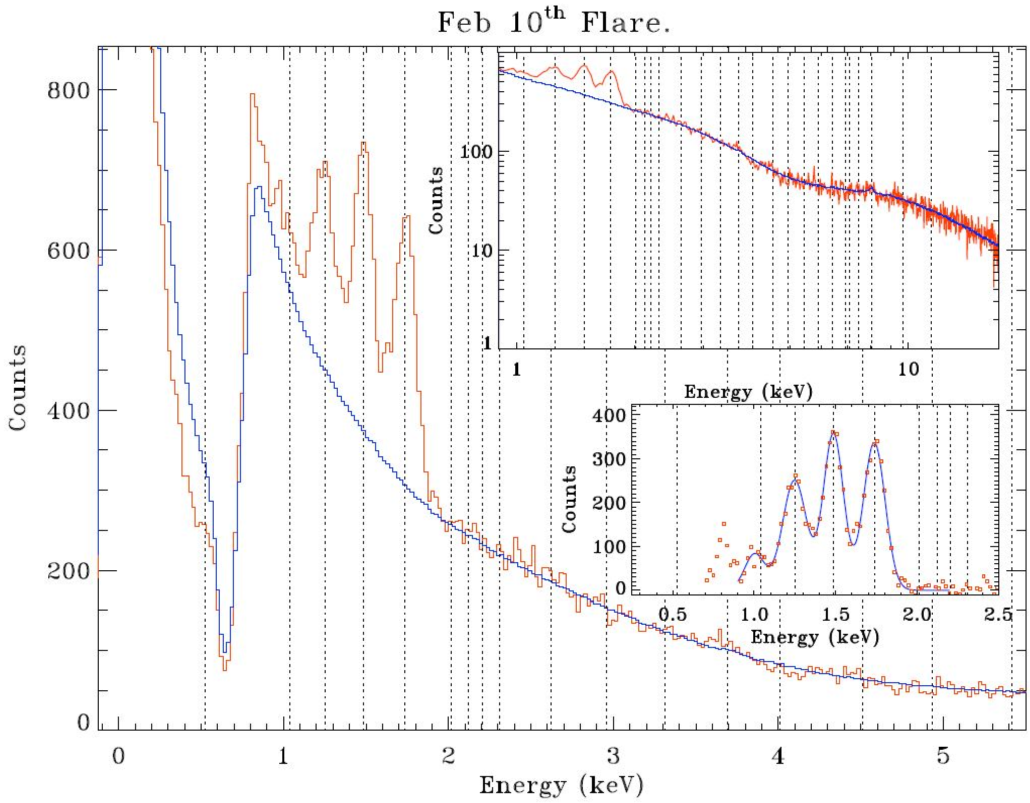

Figure 7: The complete background fit to the entire flare on Feb 10th (bottom panel of Figure 4). The top inset shows the complete energy range and the bottom inset is the background subtracted "flare only" spectrum with a 4-Gaussian line fit shown for illustration.

only spectrum does show a very good background subtraction with a good zero level in the 2 – 2.5 keV range. This is a very weak flare, a B1.3 on the GOES scale of X-ray flares! (According to GOES, the flare started at 23:00, reached a peak at 23:11 and ended at 23:43. It arose in Active Region 11012).

7. SUMMARY

By using the supplied set of quiet time and active time background C1XS spectra and the method described in this note it should be possible to achieve excellent background fits to around 97% of the data in the C1XS archive and adequate fits in the 1 – 5 keV energy band for the remaining very extreme times.