Mars Express ASPERA-3 ELS Background Data Examples

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This document attempts to answer the following questions:

1. What is background and how should I treat background? 1
2. Can you show me an example of a background data file? 4
3. Can you show me an example of how to visualize background corrected data? 6
4. I just want to get at the final data product, where do I find that? 13
5. How do I put together data from high and low energy sweeps? 19

1. What is background and how should I treat background?

If you are measuring an object and your measurement device is perfect, then you will recover the environmental signal. However, our measurement devices are not perfect, and as a result, what we measure is a mixture of the environmental signal modified by the device in some manner by mixing the environmental signal with some type of coherent or incoherent noise. In this archive we deal with a source of noise which is produced when we make electron measurements of the environmental energy spectrum on a macro scale. This noise is called instrument background. The type of instrumental background which will be dealt with is caused by any energy independent source of noise which adds to

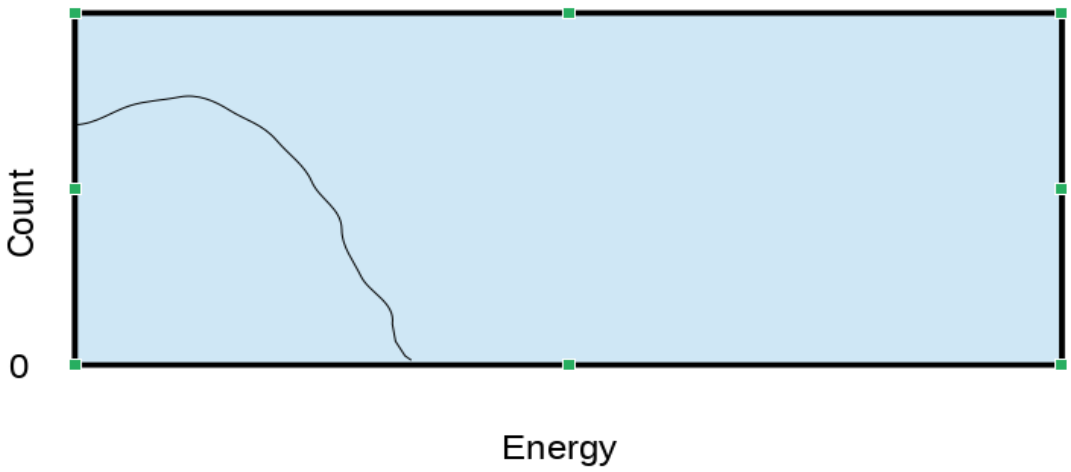

Figure 1. Measurement of an energy spectrum with a perfect device. For a perfect detector measuring the energy spectrum in the environment, the measurement corresponds to the signal obtained directly from the environment.

the signal from the environment.

For the perfectly measured energy spectrum, we will use as an example an environmental signal which looks like the energy spectrum shown in **Figure 1**. Since the detector is not perfect and adds a source of an energy independent noise to the signal, the measured spectrum will be modified as shown in **Figure 2**. Here we address one class of background noise, one which adds a noise signal to the environmental signal and this noise is energy independent. This means that the source of noise has an equal probability of adding to any energy measurement. These types of noise sources can be sensor related (e.g., the temperature may randomly produce extra counts within the detector), electronic related (e.g., electronics may produce leakage currents which get amplified and interpreted as counts), or

geophysical (e.g., penetrating radiation through the sides of the instrument can cause a signal within the detector), as these are examples of noise sources which are energy independent.

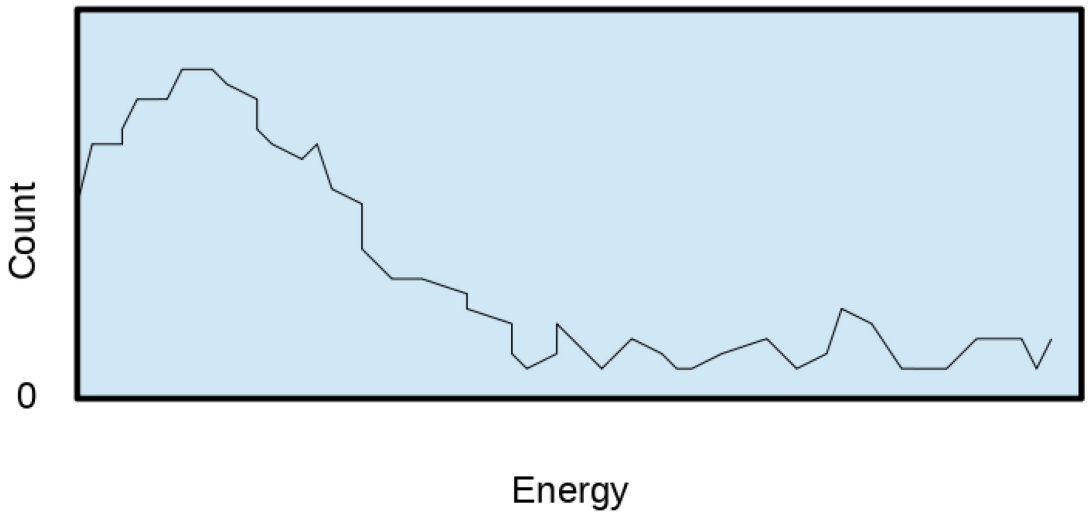

Figure 2. Environmental signal modified by an energy independent source of noise. For a non-perfect detector measuring the energy spectrum in the environment, the measurement corresponds to a combination of the signal obtained directly from the environment and the background noise created by the detector.

Once the environmental signal has been modified by the noise signal, statistical methods must be used in order to recover the environmental portion of the signal from the measured signal (Figure 2). We must realize that it is not possible to recover the exact environmental signal because we do not know the exact energy distribution of the noise included within each measurement. However, if we can determine a portion of the energy spectrum where there is no environmental signal, then this portion is all noise signal, and we can use statistical methods to remove the noise signal from the measured signal to recover an approximation to the environmental signal.

To determine the noise background, a portion of the energy spectrum (in which we are sure there is no environmental signal) is used to characterize the noise portion of the spectrum. Since the noise

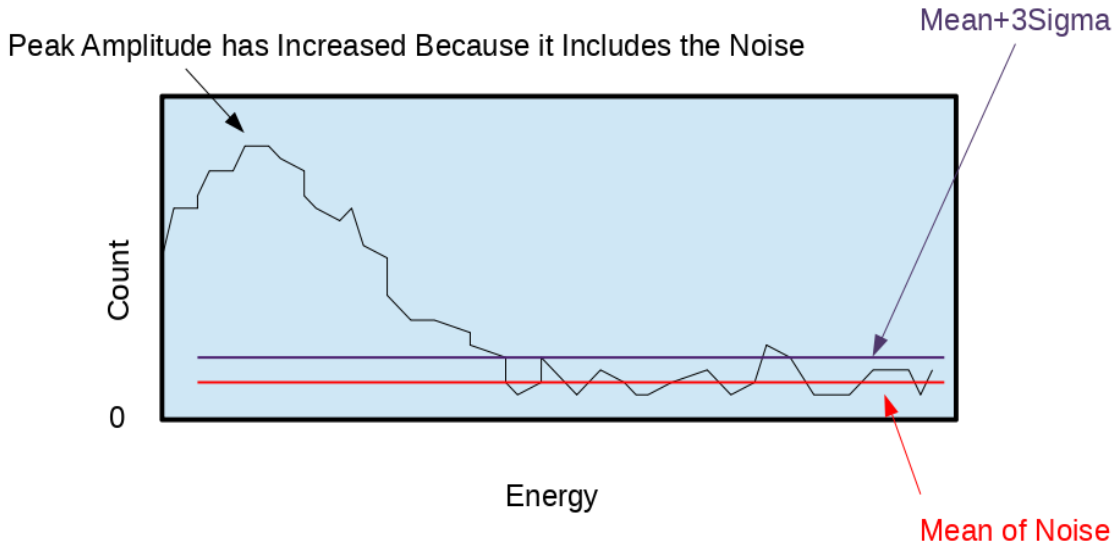

Figure 3. Measured spectrum where the environmental signal is increased due to adding noise to all energies. The background noise mean and mean+3*sigma levels are shown.

portion is energy independent, it should not matter where in energy we select, only that the energy measurements that we select are free of the environmental portion of the measured signal.

Expressed in terms of counts, the mean of the noise distribution, figured over the energy range where the measured signal does not include the environmental signal, is shown in **Figure 3.** The mean of the noise distribution is given by

$$Mean = \frac{1}{N}\sum_{i=Energy}^{N} Count\,(i) \tag{1}$$

where there are N samples of the noise signal located at Energy values (i). We recognize that the noise does contain a distribution of values, so that the standard deviation of the noise (σ) is the square root of the distribution variance (σ^2).

$$Variance = \frac{1}{N}\sum_{i=Energy}^{N}(Count(i) - Mean)^2 \tag{2}$$

The standard deviation describes how much variability there is in the mean

$$StandardDeviation = \sqrt{Variance} \tag{3}$$

The corrected spectra removes the mean count rate background noise value from the measured distribution.

Researchers often take three times the mean to be the sensitivity level below which the signal is not useful. An example of this level is also shown in **Figure 3**. However, one must be cautious when using this method. If after using a cut level and setting spectral values less then this level to zero, the spectra are then averaged, unwanted noise values can be seen to exist because values above the cut level remain in the final average. **Figure 3** shows there is some part of the noise signal at high energy above the three times the mean cut level which would remain in the corrected spectra.

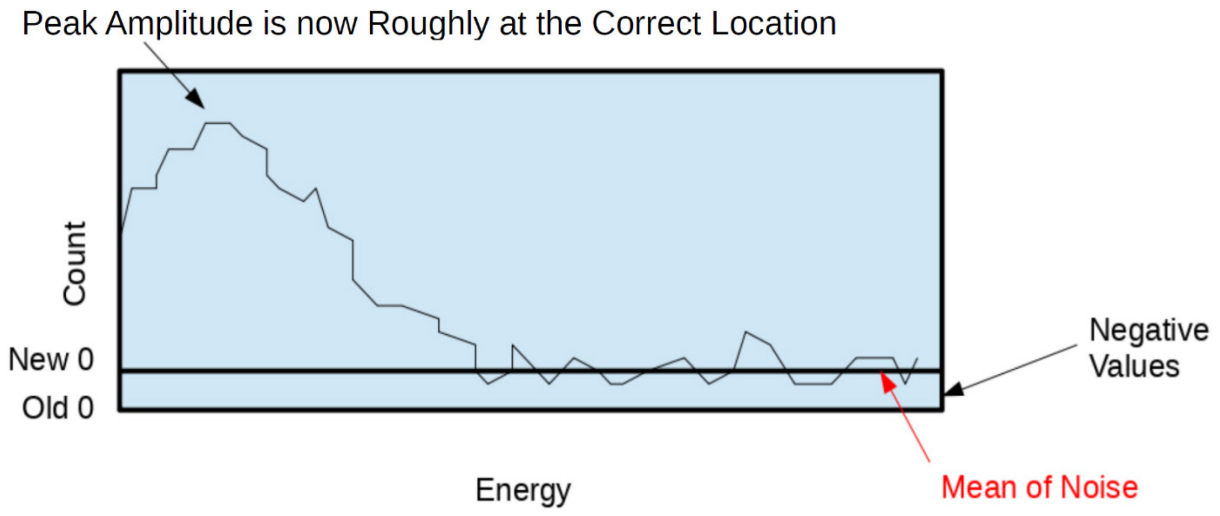

Figure 4. Negative values are obtained from measured values which are less than the mean. These values are statistically generated and result from numbers less than the mean. They are unphysical but need to be kept for use in further statistical analysis.

In the example shown in **Figure 3**, there is some part of the noise signal above the cut line. If one accumulates and averages these types of corrected spectra, then the small number of counts accumulate,

and you end up with additional level of noise which is not (and can never be) removed. If, however, you retain the negative values resulting from subtraction of the measured spectrum minus the mean of the noise background, then when you average over a large number of spectra, the noise values reduce. **Figure 4** shows that negative values arise from counts which are less than the mean. Averaging a large number of correct spectra where negative values are preserved causes the noise to approach the mean, which in the further corrected spectra, have values closer to zero. Thus, if you are going to average corrected spectra, then keep track of negative values and use them when determining the final average spectra. This will give you the lowest possible amount of background noise within your corrected spectra. Since the negative values are purely statistical, be sure to remove any remaining negative values when you achieve a final product as the negative values are unphysical.

2. Can you show me an example of a background data file?

In this archive there are background data files which represent the energy independent noise averaged over 25-minute intervals, 5-minute intervals. 1-minute intervals, at the 4 sec instrument resolution, and at a selected mixture (combination) of these values. These files are called: ELS25BK, ELS05BK, ELS01BK, ELSBKGD, and ELSMCBK respectively. The file format of each different type of background is the same for all except the combination background file differs slightly because two fields are missing. All background files are in ASCII table (TAB) format with at least one ASCII blank character separating the columns. In the background files, each record contains the start time of the measurement, the stop time of the measurement, the average count rate for the anode (this column is missing for the combination background file), then the count rate for each of the 16 ELS sectors, the standard deviation of the average count rate for the anode (this column is also missing for the combination background file), and finally, the standard deviation of the count rate for each of the 16 ELS sectors.

The background resolution to use is best determined by the science data. When background levels are high, shorter time resolution backgrounds are best to use, but when background levels are low, a longer time resolution background is best to use. The combination background file is a mixture of background types pre-selected from the different time resolution background files based on the science data and is in general, the best file of background to use. The procedure for judging and creating the best type of background (ELSMCBK) is described in the Mars Express ASPERA-3 ELS Description Document (MEX_ASPERA-3_ELS_Description.pdf) for this data set; however, it is generated by applying **Table 1** to the individual background resolutions for each sector.

Table 1. Optimal Background. For each background level, the background transition count and frequency range where the switch occurs from one level to the next finer resolution level is given.

Background Type	Transition Count				Frequency Range	
	4 second	1 minute	5 minute	25 minute	Maximum	Minimum
4 second	6	–	–	–	117 kHz	21.4 Hz
1 minute	90	20	–	–	21.4 Hz	5.42 Hz
5 minute	450	100	20	–	5.42 Hz	1.08 Hz
25 minute	2250	500	100	1	1.08 Hz	0.0108 Hz

The background files are in table format (TAB). There are 36 columns in the table and 34 columns in the Combination table. The first column in all background files represents the beginning

time the background data is valid. The second column represents the ending time when the background data is valid. Time is given in YYYY-DDDTHH:MM:SS.mmm format where YYYY is the 4-digit year, DDD is the 3-digit day of year (January 1 is day of year 1), HH is the 2-digit hour of the day, MM is the 2-digit minute of the hour, SS is the 2-digit second of the minute, and mmm is the 3-digit millisecond of the second. Accumulation times (the difference between the start and stop times) are not exact for the averaged background values (1, 5, and 25 min) due to data gaps and sampling rates. Always check the beginning and ending times for the exact time interval over which the background count rates apply.

For the Combined background file, columns 3 through 18 represent the background count rate in counts/second for each of the 16 sectors from the Electron Spectrometer (ELS) on the Mars Express (MEx) Analyzer of Space Plasmas and Energetic Atoms (ASPERA-3) experiment (Note: ELS sectors are numbered 00-15). For the remainder of the background files, columns 3 through 19 represent the background count rate in counts/second for the total MCP anode and then each of the ELS 16 sectors. The background values are kept separately because some ELS sectors contribute more to background count rates than other sectors. At the individual background time resolutions, the total background rate for the MCP is also given at specific resolutions so that it can be easily seen how much total noise is generated by the MCP. An example of the variability in the background count rate for each sector is shown in **Figure 5**.

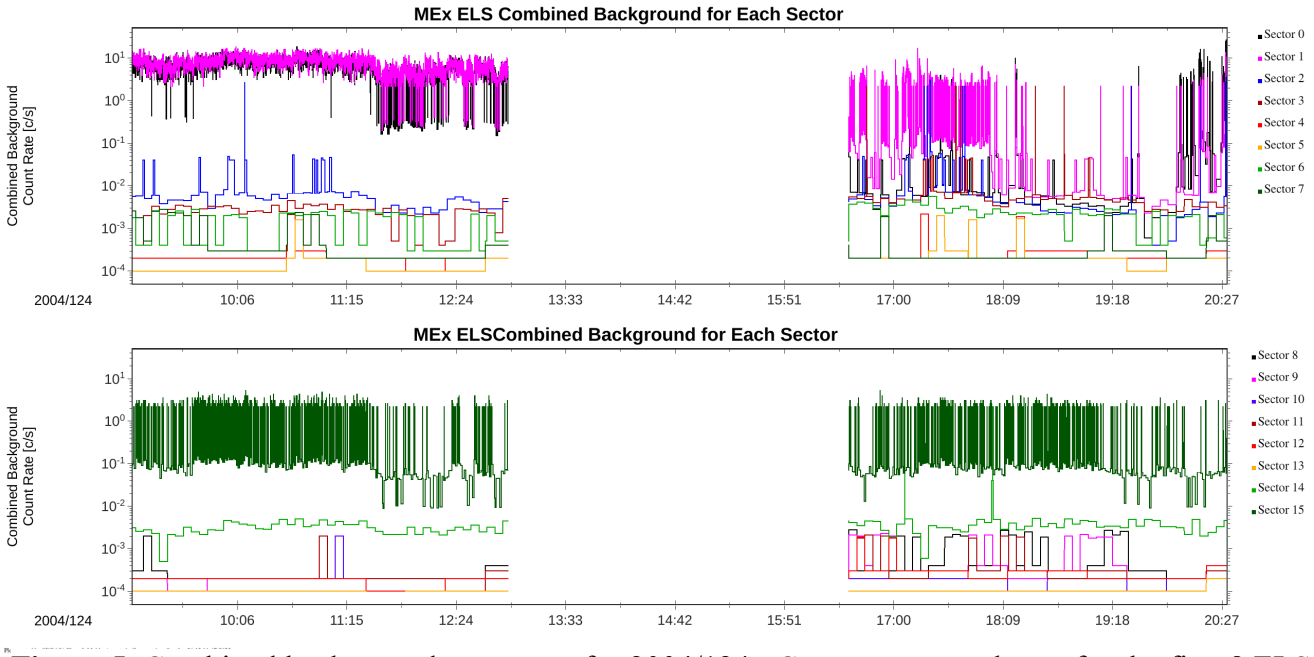

Figure 5. Combined background count rate for 2004/124. Count rates are shown for the first 8 ELS sectors in the top panel and the second 8 in the bottom panel. Count rate scales differ between the two panels so that all data is included. Some sectors shown in the upper panel have much higher count rates then other sectors requiring faster accumulated background subtraction while other ELS Sectors show larger background accumulation times indicating quieter sectors.

For the Combined background file, columns 19 through 34 represent the standard deviation of the background count rate in counts/second for each of the 16 sectors of ELS. For the remainder of the background files, columns 20 through 36 represent the standard deviation of the background count rate for the total MCP anode and then each of the ELS sectors (Note: ELS sectors are numbered 00-15). The standard deviation of the count rate describes the width of the count rate distribution. Standard

deviations are larger if there is a large spread in the count rate distribution and smaller for a narrower distribution. An example of the standard deviation of the count rate distribution is shown in **Figure 6**.

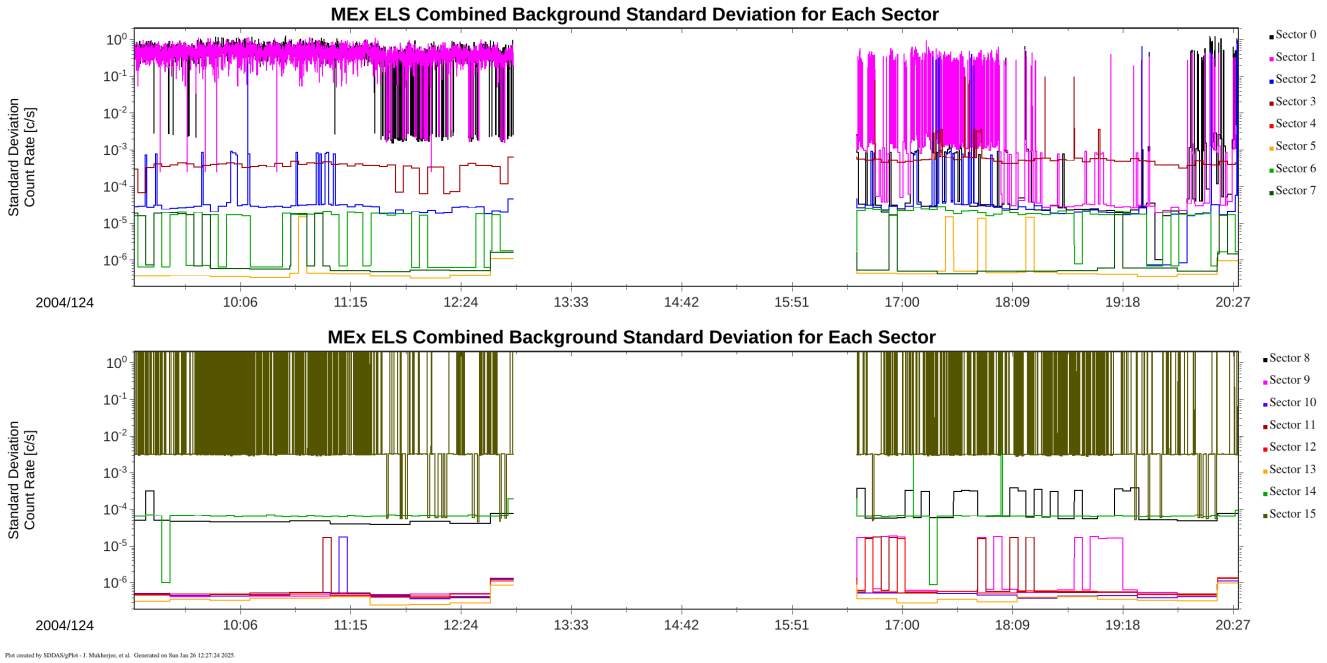

Figure 6. The standard deviation of the background count rate distributions from day 2004/124. Although the format is the same as **Figure 5**, the standard deviations show a difference in the distribution shapes of the background count rates for each sector.

This particular day (2004/124) was chosen to show an example where the background count rates can change over the course of a day and not all sectors show the same level of background. The combined background chooses the shortest time resolution when the background is high and changing fast for sectors and at the same time, selecting to use a lower time resolution background for other sectors. Here, sector 01 is showing the largest count rate which reduces over time, but sector 15 is showing the most variability in its distribution. Thus, the determination of background to adjust the science data adapts to the changing spectrum.

3. Can you show me an example of how to visualize background corrected data?

The Mars Express ASPERA-3 ELS background corrected data is organized into comma separated variable (CSV) files, where fill values are not supplied but are implied by adjacent commas without a value between. In the case of the end of a line, the fill value is implied when the last comma is followed by the end-of-line character (carriage return/line feed). The CSV file is a NASA Planetary System Standard and is meant to be read by a spreadsheet program. A CSV file is an ASCII text file which can be viewed or read by a program written by the user; however, the fill values must be handled properly. When processing the data read from CSV data files, locations where a fill value occurs should be ignored as if no measurement was made at that location. Any value of fill can be used which would not normally be contained in the data. For these examples, the value of -1.0e+31 was used for the fill value as it could easily be identified and would not conflict with any negative statistical (geophysical) values contained within the data files.

There are 8 types of CSV files in this archive which fall into two groups. The two groups are referred to as high range data and the low range data. The high range data is prefaced by the letters "ELSHR" and the low range data by "ELSLR". For this instrument, the range refers to the power supply used internally within ELS to generate the stepped sweep (energy levels). There are 4096 possible values for high range power steps and 4096 possible values for low range power steps; however, only a small subset of values was used. The ELS stepping sweep decays from its highest value of energy to its lowest value of energy. Within a stepping sweep, there are 127 values with each step acquiring data for 28.125 msec and a latency between steps of 3.125 msec (power supply transition), for a maximum stepping rate of 32 steps per sec. There is one flyback step at the end of the sweep where no valid science data is collected, and it is excluded from the PDS-4 data files. This gives a sweep having 127 steps (numbered 0 to 126). The 127 sweep steps may be made up of a combination of high and low range values in various proportions. For each high and low range data, the steps are translated into the energy of the diagnosed electron and stored in the CSV files which include the label "STPS" within their file name.

The file formats for the CSV files are similar. The first column contains the beginning time of the data presented on the rest of that same line. The second column represents the ending time of the data shown on the rest of the same line. Time is given in YYYY-DDDTHH:MM:SS.mmm format where YYYY is the year, DDD is the day of year (January 1 is day 1), HH is the hour of the day, MM is the minute of the hour, SS is the second of the minute, and mmm is the millisecond of the second. The third column is either the word "SCAN" or the word "SENSOR". "SCAN" refers to the step sweep data which are the energy levels (in eV) for each step of the energy. The word "SENSOR" refers to the data measurement shown in the file name. Besides the "STPS" keyword, the labels "CNTS", "THR", and "BCNF" are also available: "CNTS" refers to the counts which were measured, "THR" refers to the 1-count threshold differential number flux [cnts/(cm^2 s sr eV)], and "BCNF" refers to the background corrected differential number flux [cnts/(cm^2 s sr eV)]. The fourth column is the spacecraft-sensor-sector-power range for the data (spacecraft is MEx, sensor is ELS, sector is 00 through 15, power range is either HR or LR). The fifth column is the units of the data. From the sixth column on, the data values are given. The length of the line is dependent on the operational mode of the instrument at the time the data was acquired and may not be a fixed value from file-to-file in each energy range; however, the total number of steps in the combination of high range and low range is always 127 values.

To use the data, the "STPS" files determine the energy level of the spectrum and the "BCNF" files determine the background corrected differential number flux. To reconstruct the energy sweep, high range data comes before low range data. Energy steps are given in sequential order and data values correspond 1-to-1 with the energy step values. The background corrected spectral data is shown in **Figure 7**. Also shown on **Figure 7** is the uncorrected differential number flux to show an example of how much influence the background has on the uncorrected spectral data. In order to obtain the uncorrected differential number flux, multiply the value obtained from the "CNTS" file with those obtained from the "THR" file (e.g., uncorrected differential number flux = counts per accumulation * 1 count threshold). The values in the "CNTS" file represent the number of counts in an accumulation period (28.125 sec) and could be a fractional value if the instrument was in a telemetry compression mode. The values in the "THR" file represent the differential number flux obtained if there was 1 count obtained during the accumulation period. If generating average data as in **Figure 7**, be sure to generate the value to be averaged (in this case, the uncorrected flux) at each time step before accumulation, and then average the result. Be sure to exclude any times represented by filled values and include any negative flux values (as in the corrected differential number flux). The numbers obtained and shown in **Figure 7** are presented in **Table 2**.

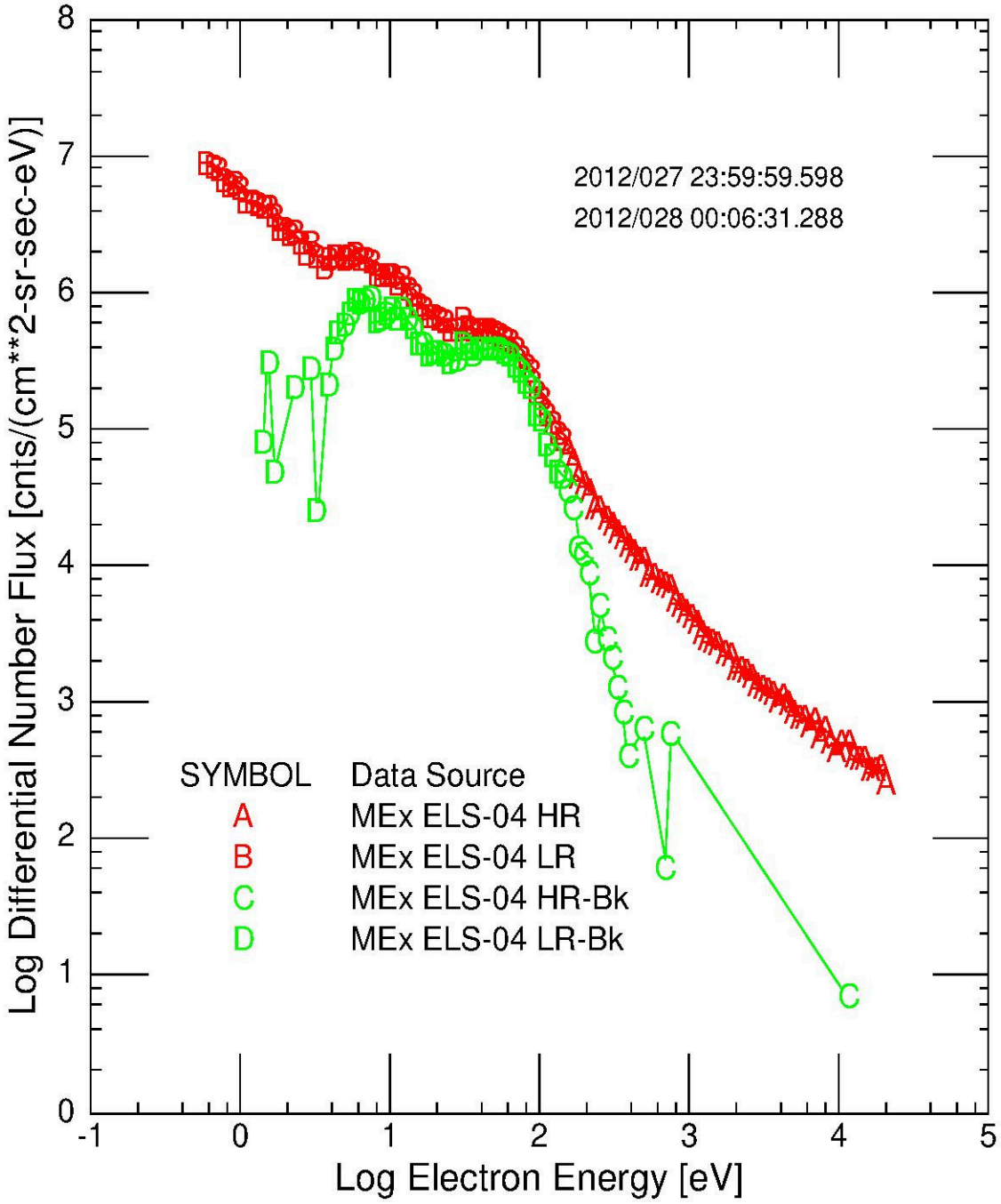

Figure 7. Influence of background correction. The uncorrected spectrum is shown in red for ELS sector 04 while the background corrected spectral data is shown in green. In order to display these data, negative values were ignored. These data are the result of a straight average from the time range 2012-027 at 23:59:59.598 UT to 2012-028 at 00:06:31.288 UT.

The corrected differential number flux is also obtained by subtracting the accumulation time adjusted background value from the same time frame as the count per accumulation, and then multiplying by the 1 count threshold (e.g., corrected differential number flux = [count per accumulation – background * accumulation period] * 1 count threshold); however, the corrected differential number flux has been provided in the "BCNF" file (recall that the accumulation period is 0.028125 sec and the background is given in counts/sec). The counts and threshold values are given in case (1) there is a need to determine

the uncorrected differential number flux (as shown in **Figure 7**) or (2) the user determines a need to use their own computation of the background. Determination of background is given elsewhere in the documentation which is associated with this archive. Reasons for the user wanting to generate a different time cadence may involve either not enough background has been removed (e.g., the background determined by the combined average is too small/large for the event, and a larger or smaller time base needs to be used to give a better estimate of the background) or too much background has been removed (e.g., the background determined by the combined average is too small/large for the event, and a larger or smaller time base needs to be used to give a better estimate of the background). These are not the only conditions under which the user may require the use of a different background value; the choice has to be determined by the user.

Table 2. Corrected and uncorrected average results shown in **Figure 7**. These data are the result of a straight average from the time range 2012-027 at 23:59:59.598 UT to 2012-028 at 00:06:31.288 UT. The last column performs a check on the differential number flux average shown in column 3 by using the formula: corrected differential number flux = [count per accumulation – background * accumulation period] * 1 count threshold. This computation was performed before averaging. Fill values have been excluded.

Step	-1.2390e+02Energy [eV]	Differential Number Flux [cnts/(cm^2 s sr eV)]	Uncorrected Number Flux [cnts/(cm^2 s sr eV)]	Corrected Number Flux (Check)
0	20126	-3.6132e+01	2.4919e+02	-6.7943e+01
1	18529	2.3768e+01	3.2939e+02	-1.0190e+01
2	17064	-1.5007e+01	3.1045e+02	-5.1169e+01
3	15713	-1.8040e+01	3.2685e+02	-5.6360e+01
4	14469	1.7190e+01	3.8449e+02	-2.3622e+01
5	13324	-1.3255e+01	3.7980e+02	-5.6928e+01
6	12268	-1.1589e+01	4.0938e+02	-5.8363e+01
7	11299	5.4483e+01	5.0428e+02	4.5058e+00
8	10405	1.9475e+01	4.9910e+02	-3.3816e+01
9	9579.1	-7.7372e+01	4.3364e+02	-1.3415e+02
10	8822.2	-2.8484e+01	5.1609e+02	-8.8993e+01
11	8124.3	6.6810e+01	6.4810e+02	2.2225e+00
12	7480.4	-7.1025e+01	5.5066e+02	-1.4010e+02
13	6890.6	4.7644e+01	7.1328e+02	-2.6316e+01
14	6345.1	-4.1741e+01	6.7179e+02	-1.2102e+02
15	5838.9	-6.8484e+00	7.5859e+02	-9.1897e+01
16	5376.9	-3.2746e+01	7.8760e+02	-1.2390e+02
17	4954.2	-4.5939e+01	8.3234e+02	-1.4353e+02
18	4561.0	1.4886e+01	9.5527e+02	-8.9602e+01

Step	-1.2390e+02Energy [eV]	Differential Number Flux [cnts/(cm^2 s sr eV)]	Uncorrected Number Flux [cnts/(cm^2 s sr eV)]	Corrected Number Flux (Check)
19	4197.3	9.7015e+01	1.1039e+03	-1.4860e+01
20	3868.0	-6.9668e+01	1.0072e+03	-1.8932e+02
21	3558.4	2.5416e+01	1.1795e+03	-1.0281e+02
22	3278.2	-3.4042e+00	1.2332e+03	-1.4080e+02
23	3017.7	-6.9458e+01	1.2585e+03	-2.1700e+02
24	2781.8	-1.2767e+02	1.2993e+03	-2.8623e+02
25	2560.6	-3.2830e+01	1.5059e+03	-2.0380e+02
26	2359.1	-2.5162e+01	1.6367e+03	-2.0981e+02
27	2172.4	-1.6104e+01	1.7838e+03	-2.1610e+02
28	2000.4	-1.5063e+02	1.8035e+03	-3.6775e+02
29	1838.2	2.0529e+01	2.1512e+03	-2.1621e+02
30	1695.6	-6.3827e+01	2.2547e+03	-3.2144e+02
31	1558.0	8.7330e+01	2.6251e+03	-1.9465e+02
32	1435.1	4.3918e+01	2.8184e+03	-2.6436e+02
33	1322.1	-1.2120e+02	2.9151e+03	-4.5858e+02
34	1218.9	-7.0898e+01	3.2521e+03	-4.4012e+02
35	1120.6	1.9345e+02	3.8440e+03	-2.1216e+02
36	1032.1	1.1297e+02	4.1166e+03	-3.3188e+02
37	948.57	1.2423e+02	4.5269e+03	-3.6495e+02
38	874.85	1.9583e+02	5.0185e+03	-3.4002e+02
39	806.04	1.4922e+02	5.4375e+03	-4.3836e+02
40	742.15	1.2778e+03	7.0799e+03	6.3314e+02
41	683.17	6.5279e+02	7.0185e+03	-5.4520e+01
42	629.10	5.8599e+02	7.5650e+03	-1.8946e+02
43	579.95	4.9947e+02	8.1387e+03	-3.4934e+02
44	530.81	1.3337e+02	8.5588e+03	-8.0279e+02
45	491.49	1.7357e+03	1.0906e+04	7.1672e+02
46	452.17	9.6821e+02	1.1017e+04	-1.4831e+02
47	412.85	1.1380e+03	1.2235e+04	-9.5048e+01
48	383.36	1.6804e+03	1.3708e+04	3.4400e+02
49	353.87	2.4012e+03	1.5517e+04	9.4383e+02

Step	-1.2390e+02Energy [eV]	Differential Number Flux [cnts/(cm^2 s sr eV)]	Uncorrected Number Flux [cnts/(cm^2 s sr eV)]	Corrected Number Flux (Check)
50	324.38	2.6372e+03	1.7043e+04	1.0366e+03
51	299.81	3.9381e+03	1.9615e+04	2.1962e+03
52	275.23	4.9537e+03	2.2132e+04	3.0450e+03
53	250.66	7.3534e+03	2.6331e+04	5.2447e+03
54	231.00	5.0708e+03	2.5767e+04	2.7712e+03
55	211.34	1.1486e+04	3.4225e+04	8.9600e+03
56	196.59	1.5285e+04	3.9825e+04	1.2558e+04
57	181.85	1.6756e+04	4.3393e+04	1.3796e+04
58	167.11	2.8587e+04	5.7694e+04	2.5353e+04
59	152.36	3.7642e+04	6.9702e+04	3.4080e+04
60	142.99	4.8282e+04	8.2537e+04	4.4463e+04
61	131.68	5.2607e+04	8.9930e+04	4.8460e+04
62	121.25	6.7891e+04	1.0855e+05	6.3373e+04
63	111.67	7.9970e+04	1.2425e+05	7.5049e+04
64	102.83	1.1935e+05	1.6758e+05	2.5390e+04
65	94.689	1.3191e+05	1.8442e+05	1.2607e+05
66	87.173	1.9995e+05	2.5713e+05	1.9360e+05
67	80.283	2.1993e+05	2.8216e+05	2.1301e+05
68	73.946	2.6110e+05	3.2881e+05	2.5358e+05
69	68.088	3.0012e+05	3.7381e+05	2.9193e+05
70	62.708	3.5429e+05	4.3445e+05	3.4538e+05
71	57.735	3.6659e+05	4.5381e+05	3.5690e+05
72	53.166	3.8230e+05	4.7717e+05	3.7175e+05
73	48.966	3.9656e+05	4.9973e+05	3.8510e+05
74	45.060	4.0026e+05	5.1254e+05	3.8779e+05
75	41.523	3.8960e+05	5.1160e+05	3.7604e+05
76	38.207	3.8612e+05	5.1887e+05	3.7137e+05
77	35.186	3.6880e+05	5.1313e+05	3.5277e+05
78	32.423	3.9581e+05	5.5260e+05	3.7839e+05
79	29.844	4.4629e+05	6.1681e+05	4.2735e+05
80	27.486	3.3696e+05	5.2228e+05	3.1637e+05

Step	-1.2390e+02Energy [eV]	Differential Number Flux [cnts/(cm^2 s sr eV)]	Uncorrected Number Flux [cnts/(cm^2 s sr eV)]	Corrected Number Flux (Check)
81	25.312	3.3004e+05	5.3144e+05	3.0766e+05
82	23.285	3.7262e+05	5.9173e+05	3.4828e+05
83	21.443	3.8871e+05	6.2682e+05	3.6226e+05
84	19.748	3.8871e+05	6.4744e+05	3.5996e+05
85	18.201	3.8549e+05	6.6639e+05	3.5428e+05
86	16.764	4.4335e+05	7.4851e+05	4.0945e+05
87	15.438	4.6323e+05	7.9479e+05	4.2639e+05
88	14.185	5.9832e+05	9.5935e+05	5.5821e+05
89	13.080	6.6617e+05	1.0579e+06	6.2264e+05
90	12.048	7.7886e+05	1.2043e+06	7.3159e+05
91	11.090	6.7178e+05	1.1342e+06	6.2040e+05
92	10.206	7.9875e+05	1.3014e+06	7.4290e+05
93	9.3952	7.6985e+05	1.3160e+06	7.0916e+05
94	8.6583	6.8507e+05	1.2779e+06	6.1920e+05
95	7.9583	6.9760e+05	1.3428e+06	6.2591e+05
96	7.3320	9.6567e+05	1.6662e+06	8.8783e+05
97	6.7424	9.5597e+05	1.7179e+06	8.7131e+05
98	6.2266	9.1272e+05	1.7380e+06	8.2102e+05
99	5.7108	9.6193e+05	1.8619e+06	8.6193e+05
100	5.2687	8.0111e+05	1.7768e+06	6.9270e+05
101	4.8634	6.8467e+05	1.7419e+06	5.6720e+05
102	4.4581	6.5416e+05	1.8077e+06	5.2599e+05
103	4.1265	5.0610e+05	1.7525e+06	3.6761e+05
104	3.7949	3.8248e+05	1.7380e+06	2.3187e+05
105	3.5002	-2.2255e+04	1.4476e+06	-1.8557e+05
106	3.2054	1.9443e+05	1.7996e+06	1.6080e+04
107	2.9475	4.7100e+05	2.2168e+06	2.7702e+05
108	2.7265	-1.6888e+04	1.8707e+06	-2.2662e+05
109	2.5054	1.9794e+05	2.2523e+06	-3.0319e+04
110	2.2843	4.4043e+05	2.6938e+06	1.9006e+05
111	2.1001	8.4350e+04	2.5356e+06	-1.8801e+05

Step	-1.2390e+02Energy [eV]	Differential Number Flux [cnts/(cm^2 s sr eV)]	Uncorrected Number Flux [cnts/(cm^2 s sr eV)]	Corrected Number Flux (Check)
112	1.9527	2.5402e+05	2.8904e+06	-3.8909e+04
113	1.8054	2.7477e+04	2.8792e+06	-2.8938e+05
114	1.6580	4.3387e+05	3.5393e+06	8.8815e+04
115	1.5106	7.0847e+05	4.1171e+06	3.2973e+05
116	1.4001	5.3663e+05	4.2146e+06	1.2797e+05
117	1.2895	1.8689e+05	4.1803e+06	-2.5682e+05
118	1.1790	9.6197e+04	4.4642e+06	-3.8913e+05
119	1.0685	-1.9240e+05	4.6276e+06	-7.2797e+05
120	0.99479	4.9884e+05	5.6761e+06	-7.6410e+04
121	0.92110	5.7340e+05	6.1650e+06	-4.7890e+04
122	0.84741	-2.0497e+05	5.8731e+06	-8.8031e+05
123	0.77372	-5.9562e+04	6.5976e+06	-7.9924e+05
124	0.70004	4.8109e+05	7.8392e+06	-3.3648e+05
125	0.66319	5.0782e+05	8.2749e+06	-3.5518e+05
126	0.58950	-2.4056e+04	8.7142e+06	-9.9497e+05

4. I just want to get at the final data product, where do I find that?

The final data values are stored in multiple CSV files as previously discussed; however, science data may also be found in Common Data Format (CDF) files. The CDF files contain the counts, uncorrected differential number flux, the corrected differential number flux, the corrected differential energy flux, the corrected distribution function, and a data quality flag. It is meant to be used directly with the default (combined) background removal applied. The counts unit allows Poisson statistics to be applied to the flux values. The uncorrected differential number flux shows the calibrated data without removal of the background. The corrected differential number flux has the background removal applied. Comparison between the uncorrected and corrected differential number flux indicates the amount of energy independent contamination removed, or in the case of a solar energetic particle (SEP) event, comparison shows the amount of contamination generated by the event. This also assists in identifying at what time the SEP event occurs, its time profile, and when the event ends.

One should note that times where the ELS is in calibration is included within the archived data. These times should be used with caution. Some of the values within the calibration period are accurate and some are not. Scans of the ELS MCP voltage are conducted during calibration. Some values may include more noise than expected during the beginning of the calibration cycle while not enough gain is observed later in the calibration sequence. It is included in the data set so that a trend can be followed across the calibration period. Most calibrations were conducted in the solar wind, but a few toward the start of the mission were not. Calibration time periods should only be used for qualitative purposes and the user should be cautious about claiming an event occurrence during a calibration cycle. **Table 3** shows the calibration times.

Table 3. ELS Calibration Times. Listed are the times of Mars Express ELS successful MCP in-flight calibrations. No science data is reported for unsuccessful ELS calibrations.

Begin Date	Begin Time	End Date	End Time
2004 May 11 (132)	08:27:25.000	2004 May 11 (132)	08:45:05.000
2004 May 27 (148)	14:35:05.000	2004 May 27 (148)	14:46:55.000
2004 June 10 (162)	21:29:10.000	2004 June 10 (162)	21:41:00.000
2004 June 16 (168)	05:13:53.000	2004 June 16 (168)	05:25:36.000
2004 July 8 (190)	15:04:53.000	2004 July 8 (190)	15:16:36.000
2005 March 12 (071)	15:15:08.000	2005 March 12 (071)	15:26:56.000
2005 June 1 (152)	00:40:17.000	2005 June 1 (152)	00:52:13.000
2005 July 7 (188)	00:17:32.000	2005 July 7 (188)	00:29:18.000
2005 November 17 (321)	22:24:46.000	2005 November 17 (321)	22:46:34.000
2005 December 14 (348)	00:11:08.000	2005 December 14 (348)	00:22:56.000
2006 January 16 (016)	20:02:14.000	2006 January 16 (016)	00:14:40.000
2006 February 15 (046)	05:38:34.000	2006 February 15 (046)	05:50:20.000
2006 March 13 (072)	20:23:20.000	2006 March 13 (072)	20:35:40.000
2006 March 22 (081)	12:51:06.000	2006 March 22 (081)	13:03:00.000
2006 April 6 (096)	09:14:18.000	2006 April 6 (096)	09:26:10.000
2006 April 18 (108)	17:04:32.000	2006 April 18 (108)	17:16:20.000
2006 May 19 (139)	15:36:06.000	2006 May 19 (139)	15:48:26.000
2006 June 20 (171)	05:17:30.000	2006 June 20 (171)	05:29:18.000
2006 November 6 (310)	10:29:18.000	2006 November 6 (310)	10:41:06.000
2006 December 5 (339)	03:45:34.000	2006 December 5 (339)	03:57:20.000
2006 December 18 (352)	20:52:02.000	2006 December 18 (352)	21:04:30.000
2007 January 8 (008)	07:35:42.000	2007 January 8 (008)	07:47:30.000
2007 January 15 (015)	21:09:48.000	2007 January 15 (015)	21:21:40.000
2007 January 30 (030)	08:05:40.000	2007 January 30 (030)	08:17:24.000
2007 February 5 (036)	18:38:00.000	2007 February 5 (036)	18:49:42.000
2007 February 19 (050)	11:55:00.000	2007 February 19 (050)	12:06:40.000
2007 March 6 (065)	11:02:06.000	2007 March 6 (065)	11:14:00.000
2007 March 12 (071)	14:58:20.000	2007 March 12 (071)	12:10:10.000
2007 August 7 (219)	03:23:20.000	2007 August 7 (219)	03:35:10.000
2007 August 15 (227)	12:44:30.000	2007 August 15 (227)	12:56:20.000
2007 August 27 (239)	13:42:48.000	2007 August 27 (239)	13:54:40.000

Begin Date	Begin Time	End Date	End Time
2007 September 11 (254)	03:11:54.000	2007 September 11 (254)	03:23:50.000
2007 September 17 (260)	20:30:20.000	2007 September 17 (260)	20:42:10.000
2007 September 24 (267)	20:30:54.000	2007 September 24 (267)	20:43:20.000
2007 October 29 (302)	07:18:20.000	2007 October 29 (302)	07:30:10.000
2007 November 6 (310)	03:33:28.000	2007 November 6 (310)	03:45:20.000
2007 November 26 (330)	11:28:40.000	2007 November 26 (330)	11:40:44.000
2008 June 2 (154)	13:03:48.000	2008 June 2 (154)	13:15:36.000
2008 June 24 (176)	15:43:34.000	2008 June 24 (176)	15:55:20.000
2008 June 30 (182)	22:34:34.000	2008 June 30 (182)	22:45:32.000
2008 September 8 (252)	19:43:22.000	2008 September 8 (252)	19:55:10.000
2008 September 22 (266)	12:25:54.000	2008 September 22 (266)	12:37:40.000
2008 September 29 (273)	15:32:30.000	2008 September 29 (273)	15:43:44.000
2008 October 15 (289)	01:09:14.000	2008 October 15 (289)	01:21:00.000
2008 October 27 (301)	21:13:44.000	2008 October 27 (301)	21:25:32.000
2008 November 10 (315)	20:42:56.000	2008 November 10 (315)	20:55:16.000
2009 January 26 (026)	23:33:20.000	2009 January 26 (026)	23:45:10.000
2009 February 2 (033)	21:01:04.000	2009 February 2 (033)	21:21:50.000
2009 February 16 (047)	15:27:00.000	2009 February 2 (033)	15:38:50.000
2009 February 24 (055)	09:30:40.000	2009 February 24 (055)	09:48:00.000
2009 March 23 (082)	16:34:44.000	2009 March 23 (082)	16:46:30.000
2009 March 30 (089)	00:15:00.000	2009 March 30 (089)	00:27:20.000
2009 April 6 (096)	11:31:12.000	2009 April 6 (096)	11:43:00.000
2009 April 19 (109)	23:34:30.000	2009 April 19 (109)	23:46:20.000
2009 April 28 (118)	00:37:40.000	2009 April 29 (119)	00:49:30.000
2009 May 11 (131)	19:39:42.000	2009 May 11 (131)	19:51:30.000
2009 June 1 (152)	18:59:14.000	2009 June 1 (152)	19:11:00.000
2009 June 28 (179)	19:11:16.000	2009 June 28 (179)	19:23:10.000
2009 July 12 (193)	21:07:14.000	2009 July 12 (193)	21:19:00.000
2009 July 26 (207)	16:08:48.000	2009 July 26 (207)	16:20:40.000
2010 January 20 (020)	19:03:34.000	2010 January 20 (020)	19:15:24.000
2010 January 25 (025)	23:12:00.000	2010 January 25 (025)	23:23:20.000
2010 February 8 (039)	04:25:04.000	2010 February 8 (039)	04:36:50.000
2010 March 8 (067)	05:27:50.000	2010 March 8 (067)	05:39:40.000
2010 April 5 (095)	09:55:28.000	2010 April 5 (095)	10:07:20.000

Begin Date	Begin Time	End Date	End Time
2010 May 3 (123)	09:20:30.000	2010 May 3 (123)	09:32:20.000
2010 May 31 (151)	08:45:38.000	2010 May 31 (151)	08:57:30.000
2010 June 27 (178)	18:11:38.000	2010 June 27 (178)	18:23:28.000
2010 July 25 (206)	17:37:08.000	2010 July 25 (206)	17:48:56.000
2010 August 24 (236)	04:01:30.000	2010 August 24 (236)	04:13:20.000
2010 September 19 (262)	23:19:36.000	2010 September 19 (262)	23:31:24.000
2010 October 18 (291)	05:46:00.000	2010 October 18 (291)	05:57:48.000
2010 November 14 (318)	15:13:08.000	2010 November 14 (318)	15:24:56.000
2010 December 20 (354)	18:42:32.000	2010 December 20 (354)	18:54:20.000
2011 February 22 (053)	00:24:36.000	2011 February 22 (053)	00:36:32.000
2011 March 7 (066)	17:10:26.000	2011 March 7 (066)	17:22:44.000
2011 April 4 (094)	16:38:18.000	2011 April 4 (094)	16:50:10.000
2011 May 2 (122)	16:02:52.000	2011 May 2 (122)	16:15:12.000
2011 May 30 (150)	15:22:56.000	2011 May 30 (150)	15:34:44.000
2011 June 27 (178)	14:43:00.000	2011 June 27 (178)	14:54:50.000
2011 July 25 (206)	14:08:44.000	2011 July 25 (206)	14:20:32.000
2011 August 22 (234)	13:36:32.000	2011 August 22 (234)	13:48:20.000
2011 September 19 (262)	13:06:30.000	2011 September 19 (262)	13:18:20.000
2012 June 20 (172)	22:46:16.000	2012 June 20 (172)	22:58:04.000
2012 September 24 (268)	03:33:30.000	2012 September 24 (268)	03:45:18.000
2012 November 12 (317)	01:57:34.000	2012 November 12 (317)	02:09:32.000
2013 January 6 (006)	23:51:08.000	2013 January 7 (007)	00:03:28.000
2013 February 3 (034)	22:47:58.000	2013 February 3 (034)	23:00:14.000
2013 March 3 (062)	21:29:38.000	2013 March 3 (062)	21:41:58.000
2013 May 12 (132)	18:36:26.000	2013 May 12 (132)	18:48:44.000
2013 June 24 (175)	14:04:34.000	2013 June 24 (175)	14:16:52.000
2013 August 19 (231)	11:36:34.000	2013 August 19 (231)	11:58:22.000
2013 September 16 (259)	10:47:02.000	2013 September 16 (259)	10:59:20.000
2013 October 14 (287)	09:38:20.000	2013 October 14 (287)	09:50:40.000
2013 November 11 (315)	08:19:56.000	2013 November 11 (315)	08:31:44.000
2013 December 11 (345)	07:55:20.000	2013 December 11 (345)	08:07:08.000
2014 January 6 (006)	12:45:38.000	2014 January 6 (006)	12:57:26.000
2014 February 3 (034)	18:38:44.000	2014 February 3 (034)	18:50:32.000
2014 March 3 (062)	10:25:40.000	2014 March 3 (062)	10:38:00.000

Begin Date	Begin Time	End Date	End Time
2014 April 28 (118)	01:10:44.000	2014 April 28 (118)	01:23:02.000
2014 May 26 (146)	06:57:52.000	2014 May 26 (146)	07:09:38.000
2014 June 23 (174)	12:55:30.000	2014 June 23 (174)	13:07:16.000
2014 July 28 (209)	04:45:18.000	2014 July 28 (209)	04:57:36.000
2014 August 18 (230)	04:24:48.000	2014 August 18 (230)	04:36:34.000
2014 September 15 (258)	03:30:44.000	2014 September 15 (258)	03:40:02.000
2014 October 13 (286)	09:31:54.000	2014 October 13 (286)	09:43:40.000
2014 November 10 (314)	15:32:48.000	2014 November 10 (314)	15:53:04.000
2014 December 8 (342)	21:41:02.000	2014 December 8 (342)	22:01:24.000
2015 January 5 (005)	06:51:22.000	2015 January 5 (005)	07:11:44.000
2015 February 2 (033)	13:15:50.000	2015 February 2 (033)	13:31:24.000
2015 March 2 (061)	05:36:58.000	2015 March 2 (061)	05:52:30.000
2015 March 30 (089)	04:48:48.000	2015 March 30 (089)	05:03:50.000
2015 April 27 (117)	04:28:32.000	2015 April 27 (117)	04:44:04.000
2015 September 14 (257)	20:56:24.000	2015 September 14 (257)	21:11:56.000
2015 October 12 (285)	13:10:32.000	2015 October 12 (285)	13:26:24.000
2015 November 9 (313)	05:36:08.000	2015 November 9 (313)	05:51:08.000
2016 January 4 (004)	04:21:38.000	2016 January 4 (004)	04:36:40.000
2016 January 31 (031)	20:32:54.000	2016 January 31 (031)	20:48:26.000
2016 February 29 (060)	03:30:54.000	2016 February 29 (060)	03:46:28.000
2016 March 27 (087)	20:29:32.000	2016 March 27 (087)	20:45:06.000
2016 April 25 (116)	03:37:44.000	2016 April 25 (116)	03:53:18.000
2016 May 23 (144)	03:06:04.000	2016 May 23 (144)	03:21:36.000
2016 September 12 (256)	14:01:00.000	2016 September 12 (256)	14:16:32.000
2016 October 10 (284)	13:44:38.000	2016 October 10 (284)	14:00:10.000
2016 November 6 (311)	16:29:38.000	2016 November 6 (311)	16:44:40.000
2016 December 4 (339)	23:13:14.000	2016 December 4 (339)	23:28:50.000
2017 January 1 (001)	09:28:12.000	2017 January 1 (001)	09:43:46.000
2017 January 29 (029)	23:00:56.000	2017 January 29 (029)	23:16:30.000
2017 May 22 (142)	23:58:28.000	2017 May 23 (143)	00:14:00.000
2017 September 11 (254)	01:25:06.000	2017 September 11 (254)	01:40:40.000
2017 October 9 (282)	08:13:24.000	2017 October 9 (282)	08:28:58.000
2017 November 6 (310)	08:06:56.000	2017 November 6 (310)	08:22:28.000
2017 December 4 (338)	08:19:48.000	2017 December 4 (338)	08:35:20.000

Begin Date	Begin Time	End Date	End Time
2018 January 1 (001)	21:33:16.000	2018 January 1 (001)	21:52:04.000
2018 January 27 (027)	19:51:52.000	2018 January 27 (027)	20:12:44.000
2018 February 24 (055)	18:15:48.000	2018 February 24 (055)	18:37:14.000
2018 March 24 (083)	16:38:28.000	2018 March 24 (083)	16:58:20.000
2018 May 19 (139)	19:10:36.000	2018 May 19 (139)	19:26:08.000
2018 July 13 (194)	12:30:04.000	2018 July 13 (194)	12:45:36.000
2019 March 23 (082)	01:14:48.000	2019 March 23 (082)	01:30:20.000
2019 April 19 (109)	16:43:52.000	2019 April 19 (109)	16:59:24.000
2019 May 17 (137)	22:51:22.000	2019 May 17 (137)	23:06:54.000
2019 June 15 (166)	03:54:32.000	2019 June 15 (166)	04:10:04.000
2019 July 12 (193)	19:48:24.000	2019 July 12 (193)	20:03:56.000
2019 December 28 (362)	19:50:22.000	2019 December 28 (362)	20:05:54.000
2020 January 25 (025)	11:11:40.000	2020 January 25 (025)	11:27:12.000
2020 February 21 (052)	19:34:34.000	2020 February 21 (052)	19:50:06.000
2020 March 21 (081)	22:01:48.000	2020 March 21 (081)	22:17:20.000
2020 April 18 (109)	06:45:44.000	2020 April 18 (109)	07:01:20.000
2020 May 16 (137)	19:25:56.000	2020 May 16 (137)	19:41:28.000
2020 June 13 (165)	04:30:20.000	2020 June 13 (165)	04:45:52.000
2020 December 26 (361)	06:55:38.000	2020 December 26 (361)	07:11:10.000
2021 January 24 (024)	02:14:12.000	2021 January 24 (024)	02:35:08.000
2021 February 21 (052)	15:42:32.000	2021 February 21 (052)	15:01:50.000
2021 March 20 (079)	19:02:36.000	2021 March 20 (079)	19:22:00.000
2021 April 19 (109)	02:25:34.000	2021 April 19 (109)	02:44:54.000
2021 September 4 (247)	04:59:00.000	2021 September 4 (247)	05:15:38.000
2021 November 1 (305)	02:04:52.000	2021 November 1 (305)	03:20:24.000
2021 November 28 (332)	04:29:24.000	2021 November 28 (332)	04:44:56.000
2021 December 24 (358)	23:05:34.000	2021 December 24 (358)	23:21:06.000
2022 January 21 (021)	21:48:40.000	2022 January 21 (021)	22:04:12.000
2022 February 20 (051)	00:06:52.000	2022 February 20 (051)	00:22:24.000
2022 July 10 (191)	13:13:04.000	2022 July 10 (191)	13:32:58.000
2022 September 4 (247)	10:07:26.000	2022 September 4 (247)	10:29:26.000
2022 October 2 (275)	08:39:26.000	2022 October 2 (275)	08:59:16.000
2022 October 30 (303)	07:09:14.000	2022 October 30 (303)	07:29:06.000
2022 November 26 (330)	08:41:28.000	2022 November 26 (330)	09:01:20.000

Begin Date	Begin Time	End Date	End Time
2022 December 25 (359)	11:07:48.000	2022 December 25 (359)	11:27:40.000
2023 January 22 (022)	10:37:16.000	2023 January 22 (022)	10:57:06.000
2023 March 18 (077)	23:30:54.000	2023 March 18 (077)	23:50:44.000
2023 April 15 (105)	21:59:04.000	2023 April 15 (105)	22:19:16.000
2023 May 13 (133)	19:52:20.000	2023 May 13 (133)	20:08:24.000
2023 June 10 (161)	06:00:32.000	2023 June 10 (161)	06:20:22.000
2023 July 9 (190)	21:27:34.000	2023 July 9 (190)	21:45:16.000
2023 September 2 (245)	14:29:30.000	2023 September 2 (245)	14:49:20.000
2023 October 1 (274)	16:55:36.000	2023 October 1 (274)	17:14:22.000
2023 October 29 (302)	15:22:54.000	2023 October 29 (302)	15:42:44.000
2024 January 21 (021)	17:48:16.000	2024 January 21 (021)	18:08:06.000
2024 March 17 (077)	07:50:08.000	2024 March 17 (077)	08:10:00.000
2024 May 13 (134)	08:49:54.000	2024 May 13 (134)	09:09:44.000
2024 June 9 (161)	03:26:38.000	2024 June 9 (161)	03:46:28.000
2024 July 7 (189)	01:59:20.000	2024 July 7 (189)	02:19:10.000
2024 August 31 (244)	23:03:06.000	2024 August 31 (244)	23:22:56.000
2024 September 28 (272)	21:34:48.000	2024 September 28 (272)	21:54:40.000
2024 November 24 (329)	22:35:02.000	2024 November 24 (329)	22:54:52.000
2024 December 31 (366)	00:43:44.000	2024 December 31 (366)	01:02:28.000
2025 January 18 (018)	23:45:30.000	2025 January 19 (019)	00:04:48.000
2025 March 16 (075)	16:52:28.000	2025 March 16 (075)	17:12:16.000
2025 June 9 (160)	05:39:35.000	2025 June 9 (160)	05:51:00.000
2025 July 6 (187)	00:39:10.000	2025 July 6 (187)	00:50:56.000
2025 September 7 (250)	14:45:24.000	2025 September 7 (250)	14:57:12.000
2025 October 26 (299)	05:00:12.000	2025 October 26 (299)	05:12:00.000
2025 December 7 (341)	02:40:56.000	2025 December 7 (341)	02:52:44.000
2026 February 2 (033)	03:34:18.000	2026 February 2 (033)	03:46:10.000
2026 February 14 (045)	15:54:00.000	2026 February 14 (045)	16:05:22.000

5. How do I put together data from high and low energy sweeps?

The data files in this archive are split into the high energy range and the low energy range. Both energy sweeps are formed from decay steps starting at the highest value of energy in the range to its lowest value. The instrument steps through the high range energy before stepping through the low range energy. Time tags are given at the begin and end times for each sweep in its energy range. If timing is desired at each step in the sweep, then the begin time starts the accumulation of data from the first energy

step, accumulates electrons for 28.125 msec, and is followed by 3.125 msec of dead time when the power supply changes energy levels. This sequence is followed for all of the other energy steps in the sweep. The high energy range does not overlap in time with the low energy range. There are ELS modes which do not produce high range data; however, there should always be low range data.

When placing together high and low range data, only select data which have the same units and the same sector number. Do not mix uncorrected data with corrected data and only use the same units for the data when analyzing both high and low range data together. Do not mix sector numbers since this will not generate a true energy spectrum from the same portion of the instrument. **Figure 8** shows an example of combining high and low range data from the CDF files in an energy-time spectrogram format of background subtracted (-Bk) differential energy flux (DEF).

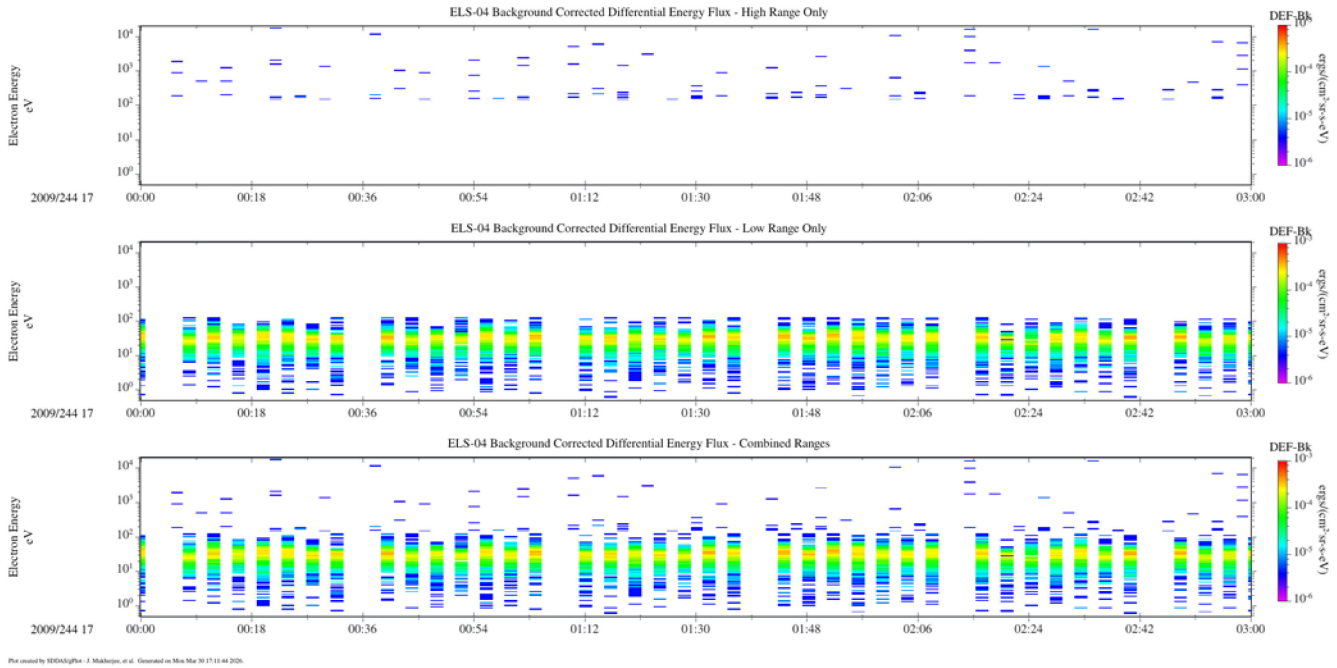

Figure 8. Example of combining ELS data from 2009 September 1 (244) for the background corrected differential energy flux in the Mars magnetosheath from sector 4. Top panel shows data from only the High Range, center panel shows data from only the Low Range, and data in the bottom panel shows the combined high and low ranges. Data is drawn from the files ELSHRCDF_20092441223_v01.cdf for the high range and ELSLRCDF_20092441223_v01.cdf for the low range in which the background corrected differential energy flux was the selected unit.

CDF files are intended to be used for the best selection as chosen by the experimenters. Since the amount of background subtraction is highly subjective, tab and CSV files are supplied so that the user can tailor the amount of background subtraction as desired. The tab and CSV files contain the pieces necessary to form background-subtracted data and changes to these files will produce the user adjusted background data. A significant learning curve should be expected in order to manipulate the CSV and tab data to produce a user defined product.