Mars Express ASPERA-3 ELS Background Data

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Introduction

Data found in this archive is the instrument background corrected electron data from the Electron Spectrometer (ELS) which was flown on the Mars Express (MEx) spacecraft as part of the Analyzer of Space Plasmas and Energetic Atoms (ASPERA-3) experiment. The original ELS flight data is archived at the ESA Planetary System Archive (PSA) found at:

https://www.cosmos.esa.int/web/psa/mars-express

The data found in this archive are meant to increase the usability of the ELS data and not to replace or duplicate the ELS data found in the PSA archive.

This document contains information about the archive, data, and data use, organized as a series of questions which should help make this archive usable. It is organized to give general information first, followed by more in-depth information. It is recognized that there will be users of these data which will want to generate background corrected spectra quickly while others will question subtleties that are seen in the data. These data are corrected for the combined background; however, it is realized that the user may feel that the flux obtained from subtraction of the combined background value may not be adequate and constant time resolution background subtraction is more appropriate. For this reason, this archive contains the background at different time resolutions which comprise the combined background product: 4 sec, 1 min average, 5 min average, and 25 min average. Thus, information is contained to allow the user to generate their own background and obtain their own flux values.

These data are not corrected for the spacecraft potential since there is no known source of spacecraft potential measurement on the MEx spacecraft. Thus, spacecraft potential correction is left up to the user of these data. In order to correct for spacecraft potential, the measured energy and the number flux both need to be corrected. For the measured energy, subtract the amount of spacecraft potential (ϕ) expressed in units of volts from the measured energy (E) expressed in units of eV for a positive spacecraft potential, or for a negative spacecraft potential, add the spacecraft potential to the measured energy in order to get the corrected energy value (E'). Any resulting energy value which is less than zero should be set to zero along with its corresponding flux value ($E' = E - \phi$ where $E' > 0$ or set $E' = 0$ if the value of E' is negative). The measured number flux (J) is corrected (J') by multiplying by the ratio of the corrected energy divided by the measured energy (E'/E), so

$$J'(E') = \frac{J(E) * E'}{E} \quad (1)$$

Any spacecraft potential correction should be made ***after*** correction for instrument background. Instrument backgrounds are not corrected for spacecraft potential.

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1. What is in this archive?

This archive contains the background data and corrected flux values from the Electron Spectrometer (ELS) which was flown on the Mars Express (MEx) spacecraft as part of the Analyzer of Space Plasmas and Energetic Atoms (ASPERA-3) experiment. This document describes how to use the background data, what to do if flux reveals that the background subtraction is not adequate, and how to judge if the background corrected flux is statistically significant.

In this archive, data is stored in three different formats: ASCII tables, Comma Separated Values (CSV), and Common Data Format (CDF). The background data are stored in ASCII tables (files with .TAB extension) which contain the background rates and their uncertainty for each ELS sector. Except for the combined background, the total anode background for the MCP is given. The background files are fixed time orientated: ELSBKGD, ELS01BK, ELS05BK, and ELS25BK. Background values from these files are combined by a pre-selection process based on the science data and stored in the

combined background files called ELSMCBK. The science data and energy levels are stored in CSV files (files with the .CSV extension). The science data files contain the raw data and background corrected flux spectra. The raw data files begin with the characters ELSHRCNTS or ELSLRCNTS, and the background corrected flux spectra science data files begin with the characters ELSHRBCNF or ELSLRBCNF. The data files that contain the energy levels for the spectra are found in files beginning with the characters ELSHRSTPS or ELSLRSTPS. The CDF files contain the science data products that are found in the CSV files, which includes (1) counts, (2) differential number flux uncorrected for background, (3) differential number flux corrected for background, (4) differential energy flux corrected for background, (5) distribution function corrected for background, and (6) a data quality flag. The CDF files begin with the names ELSLRCDF or ELSHRCDF and have the .cdf extension.

The CSV format files are meant to contain the detail so that they can be used to modify the background and background removal procedure in a different manner than what is described. The CDF format files are meant to contain the minimal amount of information that a scientist can use directly. This document describes the data stored in the ASCII tables and CSV files, and how they can be used to generate background corrected science values.

2. What is the global view of how the spectrum is adjusted for the background?

It is assumed that the average energy independent background count rate (*B*) for the averaging time (*T*) for each sector (*j*) applies across the entire spectrum and to all spectra for the time range *T*. This average background value can then be subtracted from the raw count value (*C*) for each energy step (*i*) and each sector (*j*) to generate the background corrected count (*Cb*):

$$Cb(i,j) = C(i,j) - B(j) * alpha \quad (2)$$

where ***alpha = 0.028125 sec***, the instrument accumulation period for each energy step. The background corrected count is then multiplied by the 1-count threshold value (*T1*) to give the background corrected differential number flux.

The subtraction process generates times when the corrected count *Cb(i,j)* has a negative value. These negative values should be maintained. When averaging spectra together, negative values of noise from some spectra will offset positive values of noise from other spectra giving a reduced value of noise. If we could average an infinite number of spectra, then the noise level should average to zero and the uncontaminated spectrum uncovered. However, for practical reasons, one cannot or may not desire to average an infinite number of spectra together. Thus, most of the time, there will be negative numbers in the background corrected spectra. These negative values are totally statistical. Negative values can be set to zero (0) once the final value is obtained.

When displaying or analyzing the spectra, first determine the desired time resolution. This could be anywhere from the finest instrument resolution to some predefined averaged time value. In either case, average together the background corrected values of flux to give the averaged ELS spectrum (i.e., perform background correction on each spectrum first, then average).

Now to decide how much of the spectrum is significant. If the background subtraction were perfect, then no noise should remain in the spectrum. However, things are not perfect, and a judgment needs to be made. For this, compare the background corrected count spectrum (*Cb*) to the standard

deviation (*SD*). The total standard deviation is the average summation of the deviation at each energy step. For example, if there are *S* spectra included within the time average *T*, then the average deviation (*D*) for each energy step, *i*, and each sector, *j*, is

$$D(i,j) = \frac{1}{S}\sum_{k=1}^{k=S} SD(i,j,k) \quad (3)$$

where *SD(i,j,k)* is the standard deviation for each energy step *i*, each sector *j*, and each spectra *k*. The value of *D(i,j)* is used as a cut level when examining the spectrum. *D(i,j)* is the statistical quantity which relates significance. Often times when the spectrum is very full of noise, researchers tend to be conservative and choose a larger value than the deviation to assess significance. The term 3**SD* is often used and means that researchers used the value 3**D(i,j)* as the significance cutoff, which is 99.7% of a normal distribution. This is normally done when it is not known how many spectra should be averaged together in order to be representative of the actual value. It is left up to the user to decide how much of a level beyond the average deviation (*D*) is appropriate. In this archive, the time average standard deviation values are included. If it is preferred to make this determination in units of flux, then multiply the average deviation (*D*) by the 1-count threshold value (*T1*) for each energy step and sector.

3. How do I use this archive to retrieve the background corrected flux spectra?

The science data files (ELSHRBCNF and ELSLRBCNF) contain the background corrected differential number flux spectra. To get the spectra, read the flux value for the desired ELS sector at each energy step, and get the energy level for the desired ELS sector from the corresponding energy step in the ELSHRSTPS or ELSLRSTPS file. The energy is stored in units of electron volts (*eV*), and the differential number flux is stored in units of

$$\frac{counts}{cm^2 \cdot sr \cdot s \cdot eV} \quad (4)$$

An example of data read from this archive is shown in **Figure 1** for August 2, 2015 (day 214) at 10:49:10 – 10:49:14 UT.

4. How do I use this archive to retrieve the background count rates?

For background count rates, decide on the time resolution of the background data, the choices are: ELSBKGD at the instrument rate (4 sec), ELS01BK for a 1-minute average, ELS05BK for a 5-minute average, ELS25BK for a 25-minute average, and ELSMCBK for the variable pre-selected value. For the desired ELS sector, read the spectral background count rate (*counts/sec*) and background count rate uncertainty (standard deviation in units of *counts/sec*). Successive reads can give the background values for additional times. An example of data read from this archive is shown in **Figure *2*** for May 3, 2004 (day 124) at 17:00:00 – 18:00:00 UT.

The Standard Deviation supplied in the background files describes the spread in the background distribution. This is essentially a measure of how well the background distribution is determined. If the standard deviation in the background is large when compared to the background value, it means that the distribution of background counts was large, or saying it another way, there was a large spread in the counts which make up the value chosen for the background. When the standard deviation is small compared to the background, then all of the background counts were close to the same value.

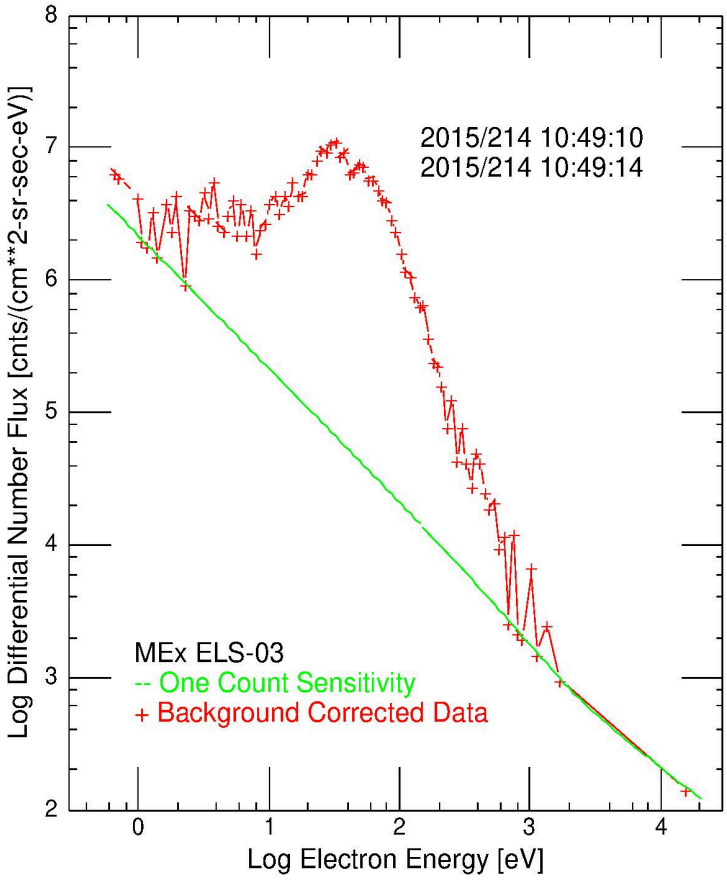


Figure 1. *Corrected ELS number flux spectra for sector 03 from August 2, 2015 (day 214) between 10:49:10 and 10:49:14 UT. Data corrected for background is drawn in red with a plus symbol. This is compared to the 1 count sensitivity line shown in green. At this time, the Mars Express spacecraft is traveling through Magnetosheath toward the bow shock of Mars, and the background correction is low as shown by the location of points near (but below) the sensitivity line.*

5. What values do I read from the science data files?

The following text is just an overview. Please refer to the MEX_ASPERA-3_ELS_Spec.pdf document for details of how the data products are organized and the specific formats of the data files.

The science data are organized into three types of files: (1) background corrected number flux (ELSHRBCNF and ELSLRBCNF), (2) 1-count threshold (ELSHRTHR and ELSLRTHR), and (3) energy levels or steps (ELSHRSTPS and ELSLRSTPS). All of these files are in CSV (Comma Separated Values) format, which gives the time period the data was accumulated (at the start of the accumulation period and stop of the accumulation period); a SENSOR or SCAN descriptor (SENSOR for science data, SCAN for energy levels); description indicating the ELS sector of the data; and the data values which are dependent on the file type: (1) the background corrected differential number flux (ELSHRBCNF and ELSLRBCNF), (2) the 1-count threshold (ELSHRTHR and ELSLRTHR), or (3) the energy steps (ELSHRSTPS and ELSLRSTPS). The beginning and ending time for accumulation is given in universal time (UT) as the year, day of year, hour of the day, minute of the hour, second of the minute, and millisecond of the second (format: YYYY-DDDTHH:MM:SS.mmm). The ELS sector

indicated in the description is a zero padded integer from 00 through 15. The differential number flux is the background corrected flux value, and the 1-count threshold is the amount of differential number flux obtained for one electron in the accumulator of the sector and energy channel. Both the 1-count threshold and the differential number flux are given in units of $\frac{counts}{cm^2 \cdot sr \cdot s \cdot eV}$ and the energy levels are given in units of *eV*.

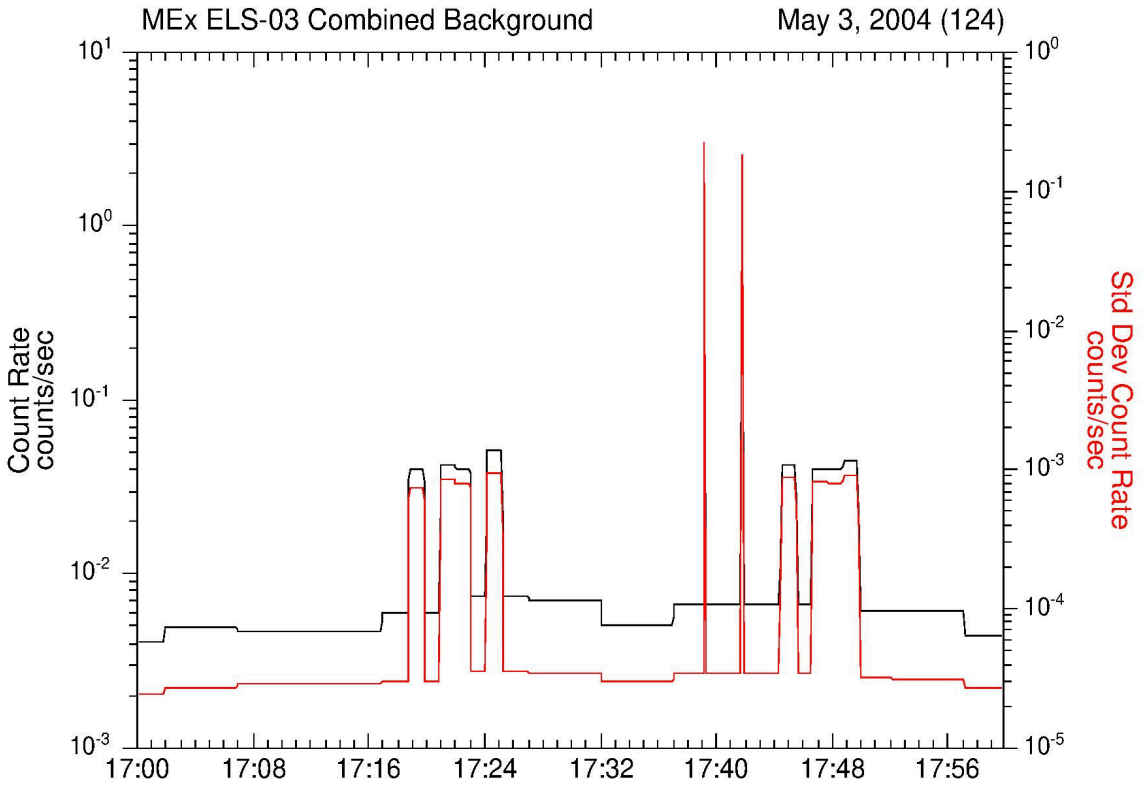


Figure 2. *ELS sector 03 background count rate data (left in black) and the standard deviation of the background count rate data (right in red) are shown for May 3, 2004 (day 124). The time at the bottom is in UT as hours:minutes (HH:MM). The pre-selected combination background can be seen changing time resolution between the instrument rate, the 1 min average, and the 5 min average. Deviation is the background noise is seen to be values less than 10% of the background count rate. At this time, some sectors of ELS have larger background counts than other sectors at the same time.*

6. What values do I read from the background data file?

The background data is an ASCII table which gives the time period the data was accumulated (at the start of the accumulation period and stop of the accumulation period), the background count rate for the entire anode (if the file is not ELSMCBK), 16 values of the background count rate – one for each ELS sector (00-15 left to right), the uncertainty in the background count rate for the entire anode (if the file is not ELSMCBK), and 16 values of the uncertainty in the background count rate – one for each ELS sector (00-15 left to right). The beginning and ending time for accumulation is given in universal time (UT) as the year, day of year, hour of the day, minute of the hour, second of the minute, and millisecond of the second (format: YYYY-DDDTHH:MM:SS.mmm). The background and uncertainty count rates are given in *counts/sec* and each energy step accumulation is 0.028125 seconds.

Thus, in order to determine the average number of background counts in a sample, just multiply the background count rate from this file by the instrument accumulation time for each energy step. In this archive, background values are determined from either the average counts accumulated in an approximate 1-, 5-, or 25-minute time period or as a combination of these background values pre-selected for the most appropriate value (the ELSMCBK file).

7. What do I do if I feel the amount of background subtraction is inadequate?

The background values used to correct the flux values in this archive are stored in the file ELSMCBK. The ELSMCBK background values were removed from the science data. In this case, the only way to change the amount of background which has been subtracted from the flux data is to recompute the background. Choose the time period over which the background value will be generated. Access the raw data counts found in this archive (ELSHRCNTS and ELSLRCNTS) and also found in the PSA archive, representing the number of ELS counts per sample. Determine the newly desired background count rate. For each count rate, subtract the quantity 0.028125 s (the instrument accumulation period for each energy step) times the background. After this value is achieved, multiply the result by the 1-count threshold value.

8. How is the Background for Mars Express ASPERA-3 ELS Determined?

The purpose of background removal in ASPERA-3 ELS is to remove energy independent, random signals from the data and uncover the environmental signal of electrons. Energy independent signals occur at any time during the energy sweep. These signals add to that from the electron environment and distort the environmental spectrum. Because of the shape of the electron spectrum at Mars and the characteristics of the ELS, electrons from the Mars environment rarely are present in the ELS energy channels above 10 keV.

The threshold energy (*ET*) is the minimum electron energy above which instrument counts (*C*) are accumulated when determining the background, *ET = 10 keV*. The ELS energy sweep is a series of 127 decay steps from its highest energy value to its lowest energy value (there is one additional energy step used for power supply flyback and is not included). When the ELS instrument is in its survey mode, it measures electrons with energies above 10 keV. Each energy step of the ASPERA-3 ELS has a fixed 0.028125 seconds of electron accumulation time (*alpha*) where the number of electrons is counted, followed by 0.003125 seconds of latency (*beta*), where the instrument readout occurs and instrument potentials are adjusted for the next energy step.

The minimum amount of time that is practical to use is 1 energy sweep. This is about 4 seconds in the survey mode. For the remainder of the ELS modes on ASPERA-3, the electron energy never reaches 10 keV *ET*, so the ELS background is not determined for these modes and is left to the user to determine a background value. For most times, the background count rate is too low to form an accurate determination of the background level in just one energy sweep. Several sweeps are needed in order to accumulate enough counts for adequate statistics. Four different accumulation times (t) for background have been used: the 4 sec instrument accumulation period ($t = 4$), a 1 min average ($t = 60$), a 5 min average ($t = 300$), and a 25 min average ($t = 1500$). The number of complete energy spectra in the accumulation time t for determination of the background is S. The number of spectra within the background accumulation time will vary due to ASPERA-3 clock drifts and the cadence of the

instrument (every 8th spectrum is missing due to operation of the data handling in the ASPERA-3 main unit). The best way to determine *S* is to count the number of complete spectra within the time period *t*. This number does not have to be the same for each time segment *t*.

Background count rates are determined for each sector of ELS. The ELS sectors are independent, and some sectors are noisier than other sectors. In addition, some of the ELS sectors exhibit time-dependent noise which can be independent of other ELS sectors. Creating an anode dependent background (e.g. from the entire MCP) would cause an over correction in some sectors and an under correction in others; however, it is provided for completeness. Thus, the background values are generated per ELS sector (*j*). There are 16 ELS sectors, normally referred linearly from 0 to 15.

For each ELS sector (*j*), the background count rate (*B*) is generated by (1) accumulating all of the counts (*Bc*) above the energy threshold (*ET*), (2) accumulating the total instrument accumulation time above the energy threshold (*Bt*), and then (3) dividing the total background counts by the total accumulated time of the instrument.

$$(1)\quad Bc(j) = \sum_{k=1}^{k=S} \sum_{i=0}^{i=laststepaboveET} C(j,i,k) \tag{5}$$

$$(2)\quad Bt(j) = \sum_{k=1}^{k=S} \sum_{i=0}^{i=laststepaboveET} alpha \tag{6}$$

$$(3)\quad B(j) = \frac{Bc(j)}{Bt(j)} \tag{7}$$

where the subscript *i* refers to the energy step (which runs from 0 to 126), *j* is the ELS sector, and *C(j,i,k)* is the count for sector *j* at energy step *i* for *k* spectra. As an example: suppose there are *S* = 8 spectra within *t*. The first 10 energy steps in the energy sweep are above *ET*=10 keV for sector 3 (*j*=3). The counts generated from the instrument are shown in **Table 1**.

Table 1. An example of background counts generated from Sector 3.

Energy Step	Spectrum Number							
	1	2	3	4	5	6	7	8
0	0	0	1	3	0	1	0	0
1	0	0	0	2	0	0	0	1
2	0	1	0	0	0	0	0	0
3	0	1	1	0	0	0	2	0
4	2	0	0	0	1	0	0	0
5	0	2	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	3	1	1	0	2	0	0
8	0	0	0	0	1	0	0	0
9	1	0	0	0	0	1	1	1
Sum	3	7	3	6	2	4	3	2

Gives a total summation of:

$$\text{Sum} = 3 + 7 + 3 + 6 + 2 + 4 + 3 + 2 = 30 \quad (8)$$

then

$$Bc(3) = \sum_{k=1}^{k=S=8} \sum_{i=0}^{i=9} C(3,i,k) \quad (9)$$

or

$$Bc(3) = 3 + 7 + 3 + 6 + 2 + 4 + 3 + 2 = 30 \quad (10)$$

and

$$Bt(8) = \sum_{k=1}^{k=S=8} \sum_{i=0}^{i=9} alpha \quad (11)$$

or

$$Bt(8) = 80 * 0.028125 sec = 2.25 sec \quad (12)$$

so

$$B(3) = \frac{30}{2.25} = 13.333\, cnts/sec \quad (13)$$

Thus, for the time period *t* the background value for sector 3 (*j*=3) is 13.333 *counts/sec*. Since each step is 0.028125 seconds in accumulation, that means that 13.333 *counts/sec* * 0.028125 *sec* = 0.375 counts in each energy step (on the average) are due to background noise and are not from the Mars environment. Since there were *S* = 8 spectra within *t*, this means that the background value was determined from 0.375 counts * *S* * Number of energy steps above 10 keV = 0.375 * 8 * 10 = 30. So, the background is based on 30 counts.

9. How do you determine the combined background?

A constant time resolution background does not handle all cases well as in some sectors, it may be removing too much of the science data and in others, it may be removing too little. The combined background (ELSMCBK) is meant to address this issue. The combined background examines the amount of background removal from the four different time resolutions of background (4 sec, 1 min, 5 min, and 25 min). These were constructed from the science data and is representative of the number of counts above the threshold energy of 10 keV. If you have a constant noise source, a shorter time base is determined from a smaller number of counts than a longer time base, but their frequency (number of counts per sec) will be the same. In this case, the uncertainty determined from the shorter time base is statistically larger than that determined from a longer time base because there is less uncertainty in the larger number of counts. However, if there are changes in the flux within the longer time base, these changes will be captured by the shorter time base and represent the flux change better than the long-time base.

Table *2* shows the crossover points for each time resolution of background used to generate the combined background. These points are highlighted in red, and the combined background is pre-determined for ease of use.

Table 2. 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

Table *2* is read vertically, so that when there are 20 counts in the 1-minute transition, there are 100 counts in the 5-minute background and 500 counts in the 25-minute background. The transition point represents the lowest count used for the transition to that background type. When the 25-minute background value is less than 1, no background is removed from the science data. When the 5-minute background accumulates to 20 counts or more, then the 5-minute background count is recorded in the combined background file unless the 1-minute background has accumulated 20 counts or more. The value of the 1-minute background type is then recorded in the combined background file. Finally, when the 4-second background accumulates to 6 or more, then it is used in the combined background.

There are about 10 energy steps above 10 keV used to determine the value of background. At 4 sec per spectrum, there are about 130 values accumulated to determine a 1-minute background and 655 for a 5-minute background (taking into account a 7/8 duty cycle). This means that if there are 20 counts in a 1-minute background, there are about 7.5 locations with no counts for every 1 count in the 1-minute spectra. Likewise, if there are 20 counts in the 5-minute background, there are about 33 locations with no counts for every 1 count in the spectrum.

ELSMCBK is generated at the instrument rate. At each time step, each background type is examined for the transition and the type which just exceeds its accumulated count minimum is selected for inclusion in the combined background. Judgements are made for each sector and each spectrum. Since there is no accurate analog to the total MCP anode value, this value is not included in ELSMCBK.

10. What if I find time periods when the combined background corrected flux seems too high?

At times, the background count rate can become so low that it is not well determined by the combined product and not enough background is subtracted from the raw flux. During these times, the number of counts used to determine the combined background can become too small. In this situation, lengthen the background accumulation time *t*. This will increase the number of spectra (*S*) that determine the background. We have found that at times the accumulation of background takes 25 minutes (1500 sec). For these times, the user can re-compute the background with the same method as described under ***"8. How is the Background for Mars Express ASPERA-3 ELS Determined?".*** The user will have to experiment to determine the appropriate background to use.

11. What if I find time periods when the combined background corrected flux seems too low?

At times, the background count rate can become so high that it is not well determined by the combined product. During these times, the number of counts used to determine the combined background can become too high; however, it could also be that the background is rapidly changing on time scales faster than determined from **Table *2***. For these times, shorten the background accumulation time *t*. This will decrease the number of spectra (*S*) that determine the background. We have found that at times the accumulation of background takes 1 min (60 sec), or when the spectra are widely varying, 1 spectrum (4 sec). Examples might be when penetrating radiation increases quickly and the combined background value over corrects data at the beginning of the period and under corrects data toward the end of the period. Another example might be when random electronic noise changes at a frequency faster than corrected for by the combined product, producing spectra both too much and too little corrected at the same time within a larger accumulation window. For these times, the user can recompute the background with the same method as described under ***"8. How is the Background for Mars Express ASPERA-3 ELS Determined?".*** The user will have to experiment to determine the appropriate background to use.

12. What if I find time periods when the combined background period is too long?

This symptom occurs when the sector is very noisy and this noise changes on a time scale less than the rate chosen for the combined background product. This results in not enough noise being removed from different times and too much noise being removed from other times within the selected background period used to determine the combined product. These are typically time periods when the number of spectra, S, times the number of energy steps selected for background accumulation exceeds the average number of counts in the accumulation. The solution is to reduce the time average value *t* to generate background values at smaller time scales. The user can recompute the background with the same method as described under ***"8. How is the Background for Mars Express ASPERA-3 ELS Determined?".*** The user will have to experiment to determine the appropriate background to use.

13. How do I generate new flux values using my own background values?

For a given background value at a specific time, find the corresponding values of the MEx ASPERA-3 ELS instrument counts found in this archive (ELSHRCNTS and ELSLRCNTS), and also in the ESA Planetary System Archive (PSA): https://www.cosmos.esa.int/web/psa/mars-express. The numbers stored are the counts per sample (*C*) separated by time (*t*), ELS sector (*j*), and energy step (*i*) which is stored from high energy at each ELS sector to low energy at each ELS sector. Multiply your count rate backgrounds (*B*) by the 0.028125 second accumulation period and subtract this from each of the counts at each energy step obtained from the ELSHRCNTS and ELSLRCNTS files, or the PSA files. Then multiply the result by the 1-count threshold value (*T1*) found for the same time, energy step, and ELS sector from the ELSHRTHR and ELSLRTHR files in this archive. This generates the new differential number flux values in $\frac{counts}{cm2 \cdot sr \cdot s \cdot eV}$. This is expressed mathematically at time *t* as:

$$Flux(i,j) = [C(i,j) - (B(j) * 0.028125sec)] * T1(i,j) \quad (14)$$

14. How do I judge if the background corrected flux is statistically significant?

There is always a trade-off between the statistical accuracy of the background value and the period of time over which the background is generated. How well the background is determined is a function of the number of counts collected. The background represents the average energy independent count obtained over a time period (t) and represents the average added to the environmental spectrum. For the best determination of the environmental plasma, only the environmental spectrum is desired to be retrieved, so the background is subtracted.

First in constructing the background, one must consider the energy region of the measured spectrum from which the background is determined. If this energy region contains environmental values, then the background will be incorrect, and it will not represent only the energy independent component of the spectrum. The user will want to choose an energy range where there is no environmental signal, and for this instrument, the experimenters have chosen energies above 10 keV as the energy region from which to generate the background. If the user feels this is too low or too high, other values of background can be generated and new flux values determined. The user can recompute the background using the same method described under **"8. *How is the Background for Mars Express ASPERA-3 ELS Determined?"*.**

Next, the sum of the counts determining the background is calculated. Counts which are larger, more frequent, and have a small variation aid in the determination of the average and reduce the uncertainty in the background, which increases the error in the corrected flux value. Background values generated from counts which are sparse and low in value can be better determined by averaging over a longer time period. In the case of this archive, we have chosen to generate a combined background product where we have determined the most representative of the background count rate by applying
Table 2.

Background value once applied can generate a negative flux value. This negative flux value represents a deviation from the average value and should be kept until the final product is calculated. Remember that the background subtraction values of flux are now statistical, so the statistics must remain until the final result is determined. For example, if the corrected spectra are additionally averaged over 1 minute, negative flux values contribute to this average and aid in determination of the final flux value. After the final averaging is complete, then any remaining negative flux values can be set to a value of zero since they represent no real flux. The remaining value should be the environmental flux.

The uncertainty in the background flux is the standard deviation in the background flux. When judging the significance of a feature seen in the environmental spectrum, that value is compared against the standard deviation (SD) to determine if it is significant. In statistics, the standard deviation of a normal distribution is the point at which 68% of the distribution (in this case, the background distribution) lies below the standard deviation. Many users use two (95%) or three (99.7%) times the standard deviation (MT) to use as a significance level. If the flux level is above the MT standard deviation level, it is considered significant, and if the flux level is below the MT standard deviation level, it is considered not significant. In order to determine the significance level of the flux measured, select the standard deviation of the background for the particular time and ELS sector (either from the

background file included within this archive or one that the user generates), and then multiply this factor by the adjustment to get the *MT* value. Add this number to the background value, subtract this number from the count, and then multiply by the 1-count threshold flux to achieve the significance level from which judgments can be made:

$$Flux(i,j) = \left[C(i,j) - \left(B(j) + MT(j)\right) * 0.028125sec\right] * T1(i,j) \quad (15)$$

where *MT(j)* = X * *SD(j)* and X is 1, 2, 3, or some other level the user desires, *j* is the ELS sector, and *i* is the energy step for each time step.

15. How is the uncertainty in the background computed?

For this section, the background (*B*) is the average count per energy step (*i*). The error in the background is determined from the statistics of the measured count (*C*) in each energy channel generated in accumulation of the average time (*T*). This is the total number of counts (*count*) used to generate the background. The average time (*T*) is currently set to the number of seconds which contains the number of complete spectra (*S*). The energy threshold (*ET*) is currently set at 10 keV (*ET* = 10 keV). The energy sweep for ELS is a decay sweep, starting at the maximum energy and stepping to the lowest measured energy. The background value (*B*) is the mean count per ELS sector (*j*) which is above an energy threshold (*mean*). This can be written as

$$count(j) = \sum_{k=1}^{k=S} \sum_{i=0}^{i=laststepaboveET} C(j,i,k) \quad (16)$$

and

$$N(j) = \sum_{k=1}^{k=S} \sum_{i=0}^{i=laststepaboveET} \{1\} \quad (17)$$

gives

$$B(j) = mean(j) = \frac{count(j)}{N(j)} \quad (18)$$

The number of spectra (*S*) within the background average time period (*T*) is taken as an integer number. For those cases when the average time period (*T*) does not include an integer number of spectra, the average time period (*T*) is adjusted (either up or down) to include an integer number of spectra (*S*).

The standard deviation (*SD*) for each sector (*j*) is the average square root (*SQRT*) of the average deviation from the mean. The variance (σ^2) is the average square of the deviation from the mean and is also the square of the standard deviation. This can be written as:

$$SD(j) = \sqrt{\sigma^2(j)} \quad (19)$$

where

$$\sigma^2(j) = \frac{1}{N(j)} \cdot \sum_{k=1}^{k=S} \sum_{i=0}^{i=laststepaboveET} [C(j,i,k) - mean(j)]^2 \quad (20)$$

OR

$$\sigma^2(j) = \left[\frac{1}{N(j)} \cdot \sum_{k=1}^{k=S} \sum_{i=0}^{i=laststepaboveET} C^2(j,i,k)\right] - \left[\frac{1}{N(j)} \cdot \sum_{k=1}^{k=S} \sum_{i=0}^{i=laststepaboveET} 2 * C(j,i,k) * mean(j)\right] + \left[\frac{1}{N(j)} \cdot \sum_{k=1}^{k=S} \sum_{i=0}^{i=laststepaboveET} mean^2(j)\right] \quad (21)$$

OR

$$\sigma^2(j) = \left[\frac{1}{N(j)} \cdot \sum_{k=1}^{k=S} \sum_{i=0}^{i=laststepaboveET} C^2(j,i,k)\right] - \left[\frac{2*mean(j)}{N(j)} \cdot \sum_{k=1}^{k=S} \sum_{i=0}^{i=laststepaboveET} C(j,i,k)\right] + \left[\frac{mean^2(j)}{N(j)} \cdot \sum_{k=1}^{k=S} \sum_{i=0}^{i=laststepaboveET} \{1\}\right] \quad (22)$$

OR

$$\sigma^2(j) = \left[\frac{1}{N(j)} \cdot \sum_{k=1}^{k=S} \sum_{i=0}^{i=laststepaboveET} C^2(j,i,k)\right] - \left[\frac{2*mean(j)}{N(j)} * count(j) - \frac{mean^2(j)}{N(j)} * N(j)\right] \quad (23)$$

OR

$$\sigma^2(j) = \left[\frac{1}{N(j)} \cdot \sum_{k=1}^{k=S} \sum_{i=0}^{i=laststepaboveET} C^2(j,i,k)\right] - mean^2(j) \quad (24)$$

OR

$$\sigma^2(j) = mean2(j) - mean^2(j) \quad (25)$$

where

$$mean2(j) = \frac{1}{N(j)} \cdot \sum_{k=1}^{k=S} \sum_{i=0}^{i=laststepaboveET} [C^2(j,i,k)] \quad (26)$$

In summary, the standard deviation of the background level for any averaging time period (*T*) and any energy threshold (*ET*) can be found. First, count the number of integer spectra (*S*) that occur within *T*. Then compute the following:

$$N(j) = \sum_{k=1}^{k=S} \sum_{i=0}^{i=laststepaboveET} \{1\} \quad (27)$$

and

$$count(j) = \sum_{k=1}^{k=S} \sum_{i=0}^{i=laststepaboveET} C(j,i,k) \quad (28)$$

and

$$B(j) = mean(j) = \frac{count(j)}{N(j)} \quad (29)$$

and

$$mean2(j) = \frac{1}{N(j)} \cdot \sum_{k=1}^{k=S} \sum_{i=0}^{i=laststepaboveET} [C^2(j,i,k)] \quad (30)$$

and

$$SD(j) = \sqrt{\sigma^2(j)} = \sqrt{mean2(j) - mean^2(j)} \quad (31)$$

For ELS, the accumulation time (*alpha*) for each energy step is *alpha* = 0.028125 seconds. In order to convert the average background value (*B*) or standard deviation (*SD*) from the units of count/sample (as described above) into a count rate (counts/sec), divide by *alpha*.

16. What is the threshold value and how do I use it?

The threshold value (*T1*) is the differential number flux for an instrument count of one (1). The threshold value has units of $\frac{electrons}{cm2 \cdot sr \cdot s \cdot eV}$, the same as the differential number flux. From the instrument count (*C*), the differential number flux (*DNF*) is determined by multiplying by the 1-count threshold value

$$DNF(i,j) = C(i,j) * T1(i,j) \quad (32)$$

where *i* is the energy step and *j* is the ELS sector number. For this archive, since the background is given in the units of counts/sec, multiply the background value in counts/sec by the accumulation time for a sample 0.028125 seconds to determine the background count. Thus, for the background subtracted value of differential number flux, use

$$DNF(i,j) = \left[C(i,j) - \left(0.028125 seconds * B(i,j)\right)\right] * T1 \quad (33)$$

17. How is the threshold value determined?

The threshold value represents the amount of differential number flux when the instrument registers 1 count. The 1-count threshold is determined for each energy step *i* and each ELS sector *j* by dividing a count of one (1) by the physical geometric factor ($PGF = 5.88 \times 10^{-4} \pm 0.06 \times 10^{-4}$ cm^2 *sr)*, MCP transparency ($M_T = 0.58 \pm 0.01$), protection grid transparency ($G_T = 0.81 \pm 0.02$), open area ratio (*A*), the accumulation time (*alpha* = 0.028125 s), resolution (R), the center energy (*E*), and the detector efficiency (relative ϵ_R and absolute ϵ_A). The Principal Investigator (PI) determined scaling factor (S_F) is applied to adjust the 1-count threshold for isotropic conditions:

$$T1(i,j) = \frac{1 * S_F}{PGF * M_T * G_T * A * alpha * R(j) * E(i,j) * (\epsilon_A(i,j)/\epsilon_R(i,j))} \quad (34)$$

Southwest Research Institute (SwRI) determined the physical geometric factor (PGF) through modeling and control of machining tolerances. The PGF represents the volume of space into which the instrument measures given a 100% efficient MCP sensor. The MCP transparency (M_T) was determined by the manufacture of the MCP and has an accuracy of 1%. The protection grid transparency (G_T) represents the amount of electron flux passing from the deflection section to the sensor section as this grid is used to set the minimum amount of energy an electron needs to pass to the sensor. The 1-count threshold was determined by taking into account a small gap between sectors (avoiding crosstalk between sectors). This gap is the open area ratio (A), meaning the actual size of the ELS sector is really 0.87 ± 0.01 of the anode pad area as determined by manufacture tolerance. The accumulation period (*alpha*) is specified by ELS electronics with internal timing to the microsec level, placing a tolerance of 1 microsec on the accumulation period.

Mullard Space Science Laboratory (MSSL) determined the detector resolution (R) and sensitivity (S_V) for each sector. The values of detector resolution (R) and sensitivity (S_V) along with the PI determined scaling factor (S_F) and relative efficiency (ϵ_R) for each sector are given in **Table 3**. In **Table 3**, the relative efficiency is given as a polynomial in terms of the deflection plate voltage (V). The deflection plate voltage and energy (E) are related by the sensitivity (S_V).

Table 3. ELS Flight Unit Calibration Values

ELS Anode	Sensitivity $S_V = \frac{E}{V}$	Resolution $R = \frac{\Delta E}{E}$	Scaling Factor S_F	Relative Efficiency ϵ_R
0	7.167	8.653e-2	2.632867	2141859e-6 + -6024497e-9 * V + 1794353e-11 * V^2 + -2796459e-14 * V^3 + 2543964e-17 * V^4 + -1395010e-20 * V^5 + 4532808e-24 * V^6 + -8024142e-28 * V^7 + 5954283e-32 * V^8
1	7.152	8.394e-2	1.000000	1660858e-6 + -6522166e-9 * V + 3691054e-11 * V^2 + -1073737e-13 * V^3 + 1839852e-16 * V^4 + -1977613e-19 * V^5 + 1369280e-22 * V^6 + -6096699e-26 * V^7 + 1685387e-29 * V^8 + -2630885e-33 * V^9 + 1771363e-37 * V^{10}
2	7.141	8.331e-2	0.635386	2021935e-6 + -5955053e-9 * V + 1878866e-11 * V^2 + -3736588e-14 * V^3 + 5172668e-17 * V^4 + -5034701e-20 * V^5 + 3363807e-23 * V^6 + -1488898e-26 * V^7 + 4137518e-30 * V^8 + -504663e-34 * V^9 + 4399947e-38 * V^{10}
3	7.165	8.579e-2	0.712443	1659460e-6 + -4954925e-9 * V + 1526991e-11 * V^2 + -2516840e-14 * V^3 + 2433297e-17 * V^4 + -1420192e-20 * V^5 + 4915142e-24 * V^6 + -9275283e-28 * V^7 + 7345382e-32 * V^8

ELS Anode	Sensitivity $S_V = \frac{E}{V}$	Resolution $R = \frac{\Delta E}{E}$	Scaling Factor S_F	Relative Efficiency ϵ_R
4	7.188	8.124e-2	0.810931	1731412e-6 + -5380326e-9 * V + 1709947e-11 * V^2 + -2884332e-14 * V^3 + 2826155e-17 * V^4 + -1658431e-20 * V^5 + 5735419e-24 * V^6 + -1076440e-27 * V^7 + 8447731e-32 * V^8
5	7.625	8.480e-2	0.896400	1811691e-6 + -5230411e-9 * V + 1584896e-11 * V^2 + -2629686e-14 * V^3 + 2573125e-17 * V^4 + -1519547e-20 * V^5 + 5306596e-24 * V^6 + -1006748e-27 * V^7 + 7984914e-32 * V^8
6	7.262	8.194e-2	1.370552	9984187e-7 + 2018039e-10 * V + -3170439e-12 * V^2 + 1589455e-14 * V^3 + -3484247e-17 * V^4+ 4156025e-20 * V^5 + -2951669e-23 * V^6 + 1283619e-26* V^7 + -3351854e-30 * V^8 + 4821632e-34 * V^9 + -2933104e-38 * V^{10}
7	7.266	7.890e-2	0.928571	1593066e-6 + -2964337e-9 * V + 3217016e-12 * V^2 + 9241350e-15 * V^3 + -3138800e-17 * V^4+ 4137379e-20 * V^5 + -3044785e-23 * V^6 + 1346434e-26 * V^7 + -3552330e-30 * V^8 + 5151235e-34 * V^9 + -3156380e-38 * V^{10}
8	7.275	7.812e-2	0.665921	2097414e-6 + -3125151e-9 * V + -4329302e-12 * V^2 + 4317461e-14 * V^3 + -9923385e-17 * V^4 + 1177737e-19 * V^5 + -8280358e-23 * V^6 + 3573841e-26 * V^7 + -9293869e-30 * V^8 + 1335333e-33 * V^9 + -8131189e-38 * V^{10}
9	7.254	8.094e-2	1.000000	2062909e-6 + -4885969e-9 * V + 1427184e-11 * V^2 + -2260352e-14 * V^3 + 2111094e-17 * V^4 + -1194770e-20 * V^5 + 4024074e-24 * V^6 + -7416131e-28 * V^7 + 5754756e-32 * V^8
10	7.262	8.095e-2	0.807453	2180664e-6 + -6296202e-9 * V + 1891070e-11 * V^2 + -3064724e-14 * V^3 + 2948811e-17 * V^4 + -1724577e-20 * V^5 + 5997964e-24 * V^6 + -1138182e-27 * V^7 + 9060635e-32 * V^8
11	7.255	8.346e-2	1.000000	1603139e-6 + -8534362e-10 * V + -8667849e-12 * V^2 + 4394307e-14 * V^3 + -8845054e-17 * V^4 + 9830094e-20 * V^5 + -6619258e-23 * V^6 + 2766078e-26 * V^7 + -7009821e-30 * V^8 + 9858768e-34 * V^9 + -5896570e-38 * V^{10}

ELS Anode	Sensitivity $S_V = \frac{E}{V}$	Resolution $R = \frac{\Delta E}{E}$	Scaling Factor S_F	Relative Efficiency ϵ_R
12	7.255	8.297e-2	0.988789	2026128e-6 + -3624418e-9 * V + 1755093e-12 * V^2 + 2385497e-14 * V^3 + -6688306e-17 * V^4 + 8554336e-20 * V^5 + -6280654e-23 * V^6 + 2795381e-26 * V^7 + -7448619e-30 * V^8 + 1092352e-33 * V^9 + -6770721e-38 * V^{10}
13	7.271	7.353e-2	1.461922	4264294e-6 + -2121222e-8 * V + 8360316e-11 * V^2 + -1760020e-13 * V^3 + 2193857e-16 * V^4 + -1690439e-19 * V^5 + 8124086e-23 * V^6 + -2368735e-26 * V^7 + 3831171e-30 * V^8 + -2635711e-34 * V^9
14	7.253	7.396e-2	0.928571	1871975e-6 + -2714091e-9 * V + -1640371e-12 * V^2 + 3116431e-14 * V^3 + -7626180e-17 * V^4 + 9286905e-20 * V^5 + -6636238e-23 * V^6 + 2903883e-26 * V^7 + -7657761e-30 * V^8 + 1117466e-33 * V^9 + -6928145e-38 * V^{10}
15	7.188	8.843e-2	2.146711	1714980e-6 + -7089766e-9 * V + 3259217e-11 * V^2 + -8410868e-14 * V^3 + 1347052e-16 * V^4 + -1391524e-19 * V^5 + 9397261e-23 * V^6 + -4114030e-26 * V^7 + 1123482e-29 * V^8 + -1737531e-33 * V^9 + 1161350e-37 * V^{10}

The ELS efficiency was designed to be corrected for the temperature of the MCP sensor. However, the temperature monitor returned from the spacecraft (ELStemp) was found to not be reliable. Therefore, the room temperature (ROOMtemp = 25 ± 1 °C) during calibration was used as the ELS temperature (ELStemp = ROOMtemp). The manufacture of the MCP determined that the resistance of the MCP changed with temperature (TC) by (744 ± 1) × 10^3 ohm/°C and the resistance of the MCP (R_{MCP}) was (364 ± 30) × 10^6 ohms. This meant that the resistance change of the MCP with temperature ($R_{MCP}T$) was the same as the MCP resistance:

$$R_{MCP}T = R_{MCP} + TC \times (ELStemp - ROOMtemp) = R_{MCP}$$

The MCP sensor for ELS exists within a resistive network. The current through that network ($I_{MCP}N$) is

$$I_{MCP}N = \frac{V_{MCP}N}{R_{MCP}+R1+R4} \quad (35)$$

Where R1 = (32.2 ± 0.3) × 10^6 ohm, R4 = (10.0 ± 0.1) × 10^6 ohm, and $V_{MCP}N$ is the voltage across the MCP network given in telemetry. The value of $V_{MCP}N$ is given in **Table 4**.

Table 4. The voltage across the MCP network, $V_{MCP}N$:

Begin Date	Begin Time (UT)	End Date	End Time (UT)	MCP Voltage
23 June (174) 2003	00:00:00.000	9 July (190) 2003	18:50:00.000	0 volts
9 July (190) 2003	18:50:00.000	26 June (177) 2005	04:30:00.000	2200 volts
26 June (177) 2005	04:30:00.000	29 August (241) 2005	11:00:00.000	2282.4 volts
29 August (241) 2005	11:00:00.000	5 September (248) 2005	04:30:00.000	2200 volts
5 September (248) 2005	04:30:00.000	13 September (256) 2005	00:30:00.000	2282.4 volts
13 September (256) 2005	00:30:00.000	19 September (262) 2005	17:30:00.000	2200 volts
19 September (262) 2005	17:30:00.000	31 May (151) 2006	00:00:00.000	2282.4 volts
31 May (151) 2006	00:00:00.000	31 May (151) 2010	05:00:00.000	2352.9 volts
31 May (151) 2010	05:00:00.000	10 November (314) 2014	00:00:00.000	2423.5 volts
10 November (314) 2014	00:00:00.000	19 April (109) 2019	12:00:00.000	2494.0 volts
19 April (109) 2019	12:00:00.000	7 June (158) 2025	20:45:00.000	2564.6 volts
7 June (158) 2025	20:45:00.000	Current	Current	2653.3 volts

The absolute Bordoni efficiency (ϵ_A) is given by

$$\epsilon_A = 1 - exp\left(\frac{-\kappa * GEz}{GZm}\right) \quad (36)$$

where GZm is the Bordoni probability function (GZm = 0.75478701) evaluated at the peak pre-acceleration energy of Em = 210 eV and the Bordoni probability peak at Zm = 1.354388. The Bordoni resistance (κ) is given by

$$\kappa = 0.7 + \frac{R_{MCP}T * I_{MCP}N}{1000.0} \quad (37)$$

and the Bordoni energy function (GEz) is

$$GEz = \frac{1 - exp(-1.35Ez)}{Ez^{0.35}} \quad (38)$$

Ez is the normalized probability energy representation is a function of the energy of the telemetered step (E in eV) given in the files ELSHRSTEPS and ELSLRSTEPS. The form of Ez is

$$Ez = (R1 * I_{MCP}N * E)\frac{Zm}{Em} \quad (39)$$

18. Can you tell me more about the Mars Express mission?

The ELS instrument is a part of the ASPERA-3 experiment on ESA's Mars Express (MEx) mission. The ELS instrument measures *in situ* electron plasma in the Mars environment and the solar wind from 25 June (176) 2003 and as of 12 August 2025, is currently operating and returning calibrated data. Data returned from the solar wind in transit to Mars is very sparse and only occurred during operational checkout of the instrument. There are times when in the solar wind when no science data is returned, but the instrument is active. During these times, the instrument settings are not completely at their operational levels and no observed counts is the correct value for this instrument configuration which proves that no counts are returned by the instrument from spurious sources. These data are included within this archive for completeness.

The MEx spacecraft orbited Mars sampling data from an elliptical polar orbit with a periapsis which varied between 250 km and 350 km, and an apoapsis of about 10,000 km. The MEx polar orbit had pericenter which varied in location from around the north pole of Mars to around the south pole of Mars. The MEx orbit precessed, taking about 10 months to precess 180° about its semi-minor axis.

In the USA, NASA was a participant in the ESA MEx program. Through the first Discovery program Mission of Opportunity (MO), NASA supported Southwest Research Institute (SwRI) to participate in the Analyzer of Space Plasmas and Energetic Atoms (ASPERA-3) experiment on the MEx program. This included instrument construction (different components of the ASPERA-3 contingent as well as the entire ELS instrument), archiving of all MEx ASPERA-3 data in the ESA PSA/NASA PDS, and to participate in the science investigation of the ASPERA-3 experiment at Mars. SwRI constructed a flight and a flight spare unit of ASPERA-3 ELS which was supplied to the PI institution, Swedish Institute of Space Physics (IRF), for the ASPERA-3 experiment on MEx. The MEx spacecraft was successfully launched in 2003 from Baikonur by a Russian Soyuz rocket. In 2019, NASA extracted its participation in the ESA Mars Express program. Thus, even though ASPERA-3 is healthy and ELS continued to produce calibrated high-quality data from the Mars environment, this data was not archived by NASA under its Planetary Data System beyond June of 2019. For ELS data beyond June of 2019, it is archived by the Europeans in the European Planetary Science Archive (PSA) without guidance from NASA or SwRI. Some ASPERA-3 data beyond June of 2019 is publicly available at https://www.cosmos.esa.int/web/psa/mars-express.

19. Can you describe the ELS instrument?

The ELS is a spherically symmetric top hat spectrometer which weighs 300 g and operates on 650 milliwatts of power. ELS measures electron plasma through an inlet opening in the side of the detector in an azimuth of 360°. This azimuth is segmented into 16 sectors, each 22.5°-wide (numbered 00-15). The elevation acceptance angle is ± 2°. The plasma passes through the collimator region, where the electrons from angles beyond the acceptance range are removed. Plasma then enters the top hat region where spherical deflection plates separate out the electron plasma of specific energy. The selected electrons are then focused on to a microchannel plate (MCP) sensor. The electron signal is multiplied by the MCP and passed to an anode. Electrons are collected on the anode, amplified by a charge sensitive amplifier, and then counted.

The ELS sensor has several operational modes. The three classes are described by the energy sweep: 128 steps, 32 steps, and 1 step. The 1-step sweep monitors one energy level continually at a rate of 32 measurements each second. The 32-step sweep measures a 31-point energy spectrum (with one additional step for flyback) from about 9 eV to about 150 eV in 1 sec. The 128-step sweep measures a 127-point energy spectrum (with one additional step for flyback) from about 0.5 eV to about 20 keV in 4 secs.

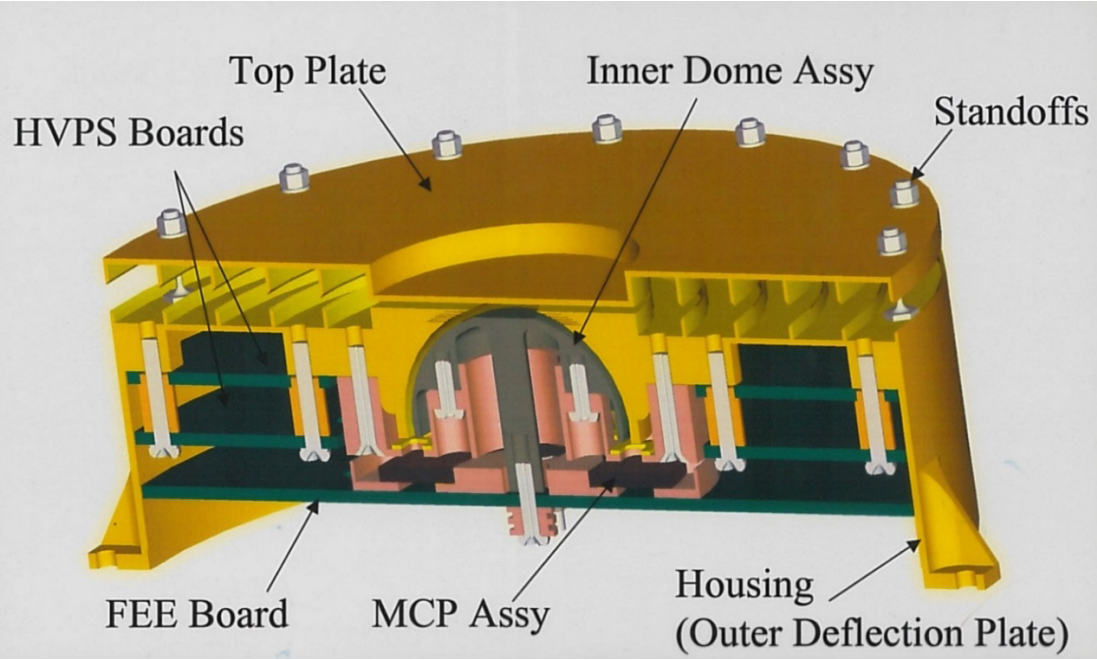


Figure 3. *Cross-section of the MEx ELS instrument showing the internal geometry. Plasma enters through the sides of the housing and travels between the collimator baffles which refine the plasma into a beam. A high voltage power supply (HVPS) generates an electric field between the top plate/outer plate and the inner dome which selects electrons. Energy selection occurs further as the electrons travel between the inner and outer domes, eventually striking the MCP assembly where the electrons are multiplied and turned into an electronic signal by the front-end electronics (FEE).*

In ELS, there are two linear power supplies, each of which have 2048 possible energy levels. One power supply covers the low energy range (LR) from 0 eV to about 150 eV and the other covers the higher energy range (HR) from 0 eV to about 20 keV. The 4096 possible values are used to select the energy sweep so that the center energy values have either a linear or log progression, or just produce a constant energy step.

A cut away view of the MEx ELS sensor is shown in **Figure *3***. The ELS data stored in the public archive is raw data in units of differential number flux, counts/(cm^2 s sr eV), from the ELS spectrometer on the MEx spacecraft. This data contains the environment signal from the Mars plasma and the internal signals generated in the instrument. There is no discussion or description of signals from penetrating radiation, or how to recover the plasma signal from the ELS data in the NASA PDS or ESA PSA archive. Comparison of background corrected data from this archive and the original data reveal how affected the measurement was to energy independent noise, as from a solar particle event or other space weather event generating penetrating radiation.

20. What is ELS Background Data?

The ELS background signal is the portion of the raw data which is internally generated within the instrument and does not reflect the Mars plasma. During its lifetime, the ELS instrument experienced several different types of contamination which altered the electron spectrum from Mars. These signals include external fluxes due to penetrating radiation caused by geophysical events like Solar Energetic Particles (SEPs), cosmic rays that penetrate through the instrument, as well as internal effects due to thermal noise generated within the MCP, outgassing of the MCP, and electronic noise. All these sources are **independent of the energy of an incoming electron** (energy independent) from the Mars environment, but these sources are **time dependent**.

21. How is the ELS Background Data Determined?

The background noise produces a signal in the MCP detector which can be determined if the MCP is not measuring electrons that had entered the ELS collimator. For the MEx ELS, this occurs when the measured electron energy is substantially above the signal created by the plasma environment. The largest geophysical signal from a normal Mars plasma is around 1 keV. Substantial plasma signal exists below an energy of 1 keV; however, the instrument continues to measure signals above 10 keV in its survey mode. Above 10 keV until the top of the ELS energy range (which is about 20 keV), there occurred about 10 energy steps when ELS was in its general survey mode (ELS had several modes of operation, but only the survey mode measured electrons with a threshold significantly above the geophysical electron spectrum). Signals which exist in the 10-20 keV energy region are taken as electrons which are generated from penetrating radiation, noise generated by the MCP, or electronic noise. This population is separately accumulated as a time dependent function and reported as a background count rate for the instrument.

22. When is ELS Background Significant?

Whether or not the background in ELS is significant depends on the energy region being examined, the time at which the electron plasma is examined, the duration of study, and the electronic and MCP noise generated by the instrument. **Figure 4** shows the influence of an SEP event at Mars which lasted for four days during 2012. This figure shows three panels. In the top panel, the electron energy flux spectra from ELS sector 04 data stored in the public archive. The center panel shows the time-dependent background count rate generated by SwRI, and the bottom panel shows the result of subtracting the background signal before complete conversion of the geophysical unit in order to recover the spectra (since the background count rate is energy independent, the true spectrum is recovered by subtraction of the background count rate from the raw data at each energy). Identical units and color ranges for both spectral panels are used in **Figure 4**. Without correcting for the background spectra, the flux values are too large, becoming a major part of the spectral signal at high energy. This is significant because flux at higher energy translates into a larger amount of energy impinging on the atmosphere, leading to an artificially high amount of ionization in the upper atmosphere than what really occurred. This will influence model atmospheric chemistry if one is simulating the effect on the atmosphere of SEPs. This will also lead to the incorrect conclusion that an SEP event deposits energy at the top of the atmosphere rather than deep within the atmosphere.

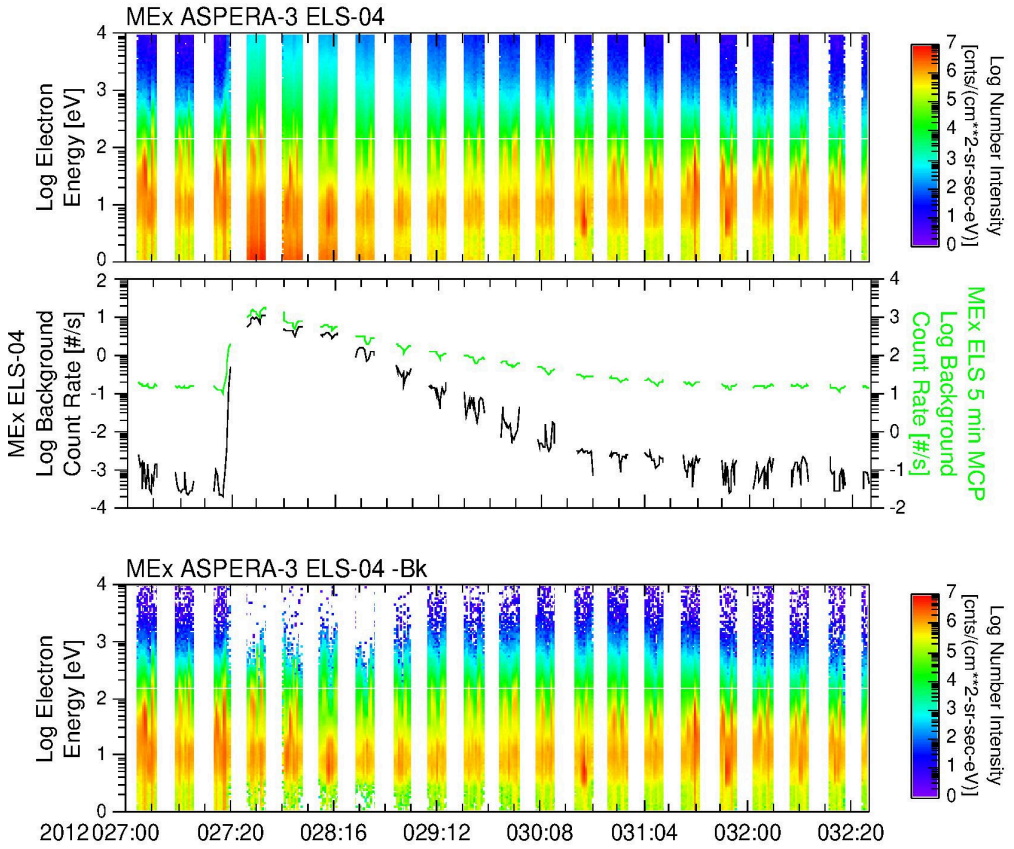


Figure 4. *Comparison of top and bottom spectrogram shows the difference between ELS spectra before and after background correction due to an SEP event. Time is shown on the bottom panel as day of year and hour of day (DDD:HH).*

23. Why do I want to correct for background in ELS?

Figure 4 shows a graphical effect of the background removal process. During background removal, one is getting rid of the portion of the instrument counts which are not due to the local electron plasma. **Figure 5** shows the energy dependence of a spectrum with (green) and without (red) background correction. This plot shows that the entire spectrum is affected by the background, not just the highest energies, since the background is energy independent.

In the particular case of **Figure 5**, the spectrum is taken from the Mars magnetosheath. The bulk of the electron density is determined at low energies. Correction shows that the electron distribution function spectrum is artificially at least an order of magnitude greater at the lowest energy, leading to an incorrect solar wind density impacting Mars at the time of the SEP event. Differences at high energies indicate an artificial amount of energy going into the upper atmosphere of Mars as described in **Figure 4**. Thus, to represent the electron plasma environment correctly, any scientist will need to correct for the ELS background.

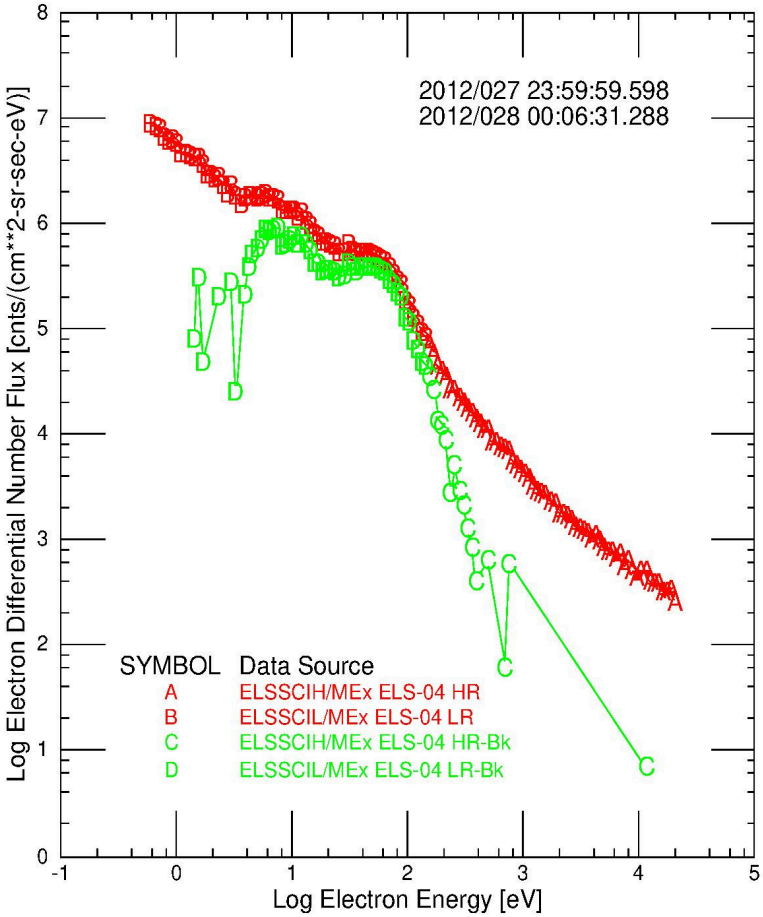


Figure 5. *The effect of the removal of the background from the electron spectrum is shown. The red line marked with an A or B shows the original electron spectrum and the green line marked with a C or D shows the electron spectrum after background contamination has been removed. The subtraction occurs at the count level before conversion to the scientific unit (in this case, distribution function).*

24. Why generate a sector dependent background noise product? Will not an anode dependent noise product accomplish the same feat?

There are times during the ELS operation when the background for each azimuth sector is different. At the beginning of the MEx mission, the amount of MCP outgassing was sector dependent, being stronger in one sector than another. In addition, there were times when the electronic noise in some sectors increased for an unknown reason. **Figure 6** (same format as **Figure 4**) shows a 20-hour time period when the electronic noise occurred. We first examine ELS sector 04. The center panel includes the background noise for sector 04 (black) and the entire 4 sec ELS MCP (green). Notice that the background level for sector 04 remains constant while the background of the MCP increased by an order of magnitude. This is indicating that there was noise in some sectors, but not in others. For the same time period, **Figure 7** shows data from sector 1. Here, sector 1 background is drawn in black in the center panel. Examination of the spectral data of sector 1 shows that all energies are affected (background is energy independent) where the largest effect is in the high energy range. Background subtraction reveals that this entire signal is artificial. Again, if the electron spectrum is used directly

without correction, a scientist would postulate the existence of a directional high energy electron plasma around Mars during this time. Thus, correction of the spectrum needs to be sector dependent so that too much or too little background is not removed, only the correct amount of background signal for the specific sector.

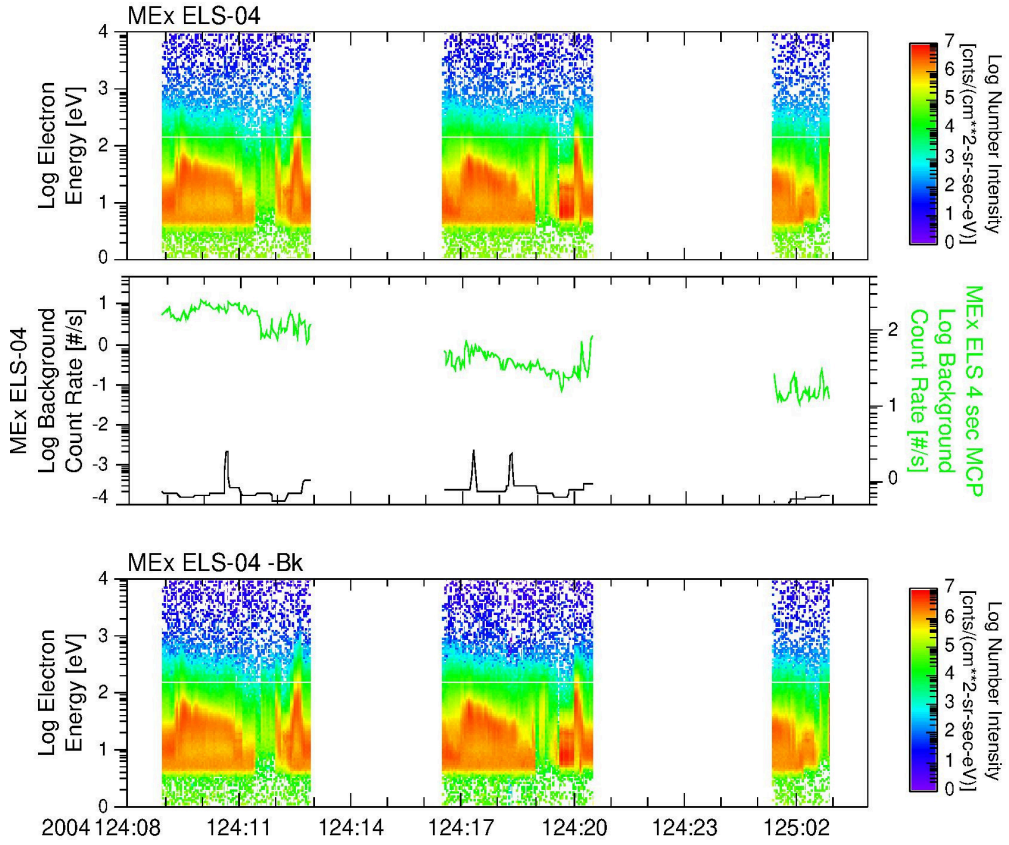


Figure 6. *Sector 04 shows a 20-hour time span when the background in part of ELS increases, while it remains steady in other parts of ELS. The center panel shows the background count rate from sector 04 is steady, but the MCP background increased (Format is the same as* ***Figure 4****). Time is shown on the bottom panel as day of year (DDD).*

25. What is the protection grid for and how does it influence the electron plasma?

The purpose of the protection grid is to block low energy electrons from reaching the MCP and saturating the detector. This can occur as the high energy tail of the thermal electron population is measured. To avoid saturating the MCP, the protection grid is set to a high voltage so that the high energy tail of the thermal electron population is rejected. This sets the effective low energy value of the measured spectrum as electrons having energies below the protection grid are not detected.

At Mars, the high energy tail of the thermal population was initially anticipated to be detected. Thus, at the start of the MEx mission at Mars, the protection grid was set to -5 volts to reject electrons with energies less than 5 eV. An absorption feature was predicted to exist at 1 eV, so ELS protection grid was lowered in order to detect this feature. However, it was discovered that the high energy tail of the thermal electron population was lower than the ELS threshold at measured low energies. Thus,

the protection grid voltage was set to 0 volts for most of the mission. **Table 5** shows the history of the protection grid and the possible minimum value of the detected electron energy. A mask of the minimum detectable energy has not been applied to the data in this archive. For all times when ELS is not measuring electrons above 200 eV, the protection grid is set to 0 volts. This is shown in the data as no values in the high range.

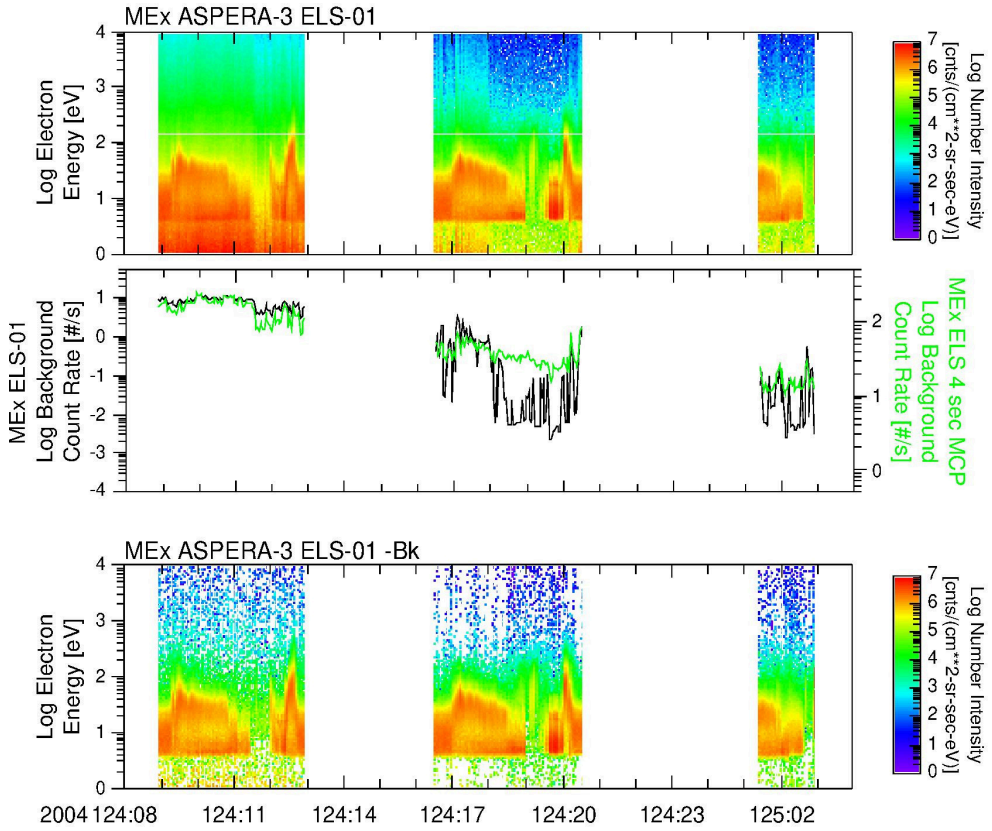


Figure 7. *This is from the same time period as* ***Figure 4*** *but shows data from sector 01. Corrections are needed to sector 01 which are up to two orders of magnitude greater than for sector 04 shown in* ***Figure 6****. This knowledge of the sector dependent background is imperative. (Format is the same as* ***Figure 6****)*

Table 5. Time history of the ASPERA-3 ELS protection grid.

Begin Date	Begin Time (UT)	End Date	End Time (UT)	Grid Voltage (volt)	Minimum Energy (eV)
23 June (174) 2003	00:00:00.000	23 August (235) 2005	21:30:00.000	-5.0	5.0
23 August (235) 2005	21:30:00.000	25 August (237) 2005	00:00:00.000	-3.75	3.75
25 August (237) 2005	00:00:00.000	26 August (328) 2005	03:10:00.000	-2.35	2.35
26 August (328) 2005	03:10:00.000	27 August (239) 2005	06:10:00.000	-0.05	0.05
27 August (239) 2005	06:10:00.000	29 August (241) 2005	11:50:00.000	0.0	0.0

Mars Express ASPERA-3 ELS Background Data

Written by: Dr. Rudy Frahm (rfrahm@swri.org)

Begin Date	Begin Time (UT)	End Date	End Time (UT)	Grid Voltage (volt)	Minimum Energy (eV)
29 August (241) 2005	11:50:00.000	5 September (248) 2005	12:00:00.000	-4.9	4.9
5 September (248) 2005	12:00:00.000	13 September (256) 2005	01:10:00.000	-2.5	2.5
13 September (256) 2005	01:10:00.000	3 October (276) 2005	05:00:00.000	-4.9	4.9
3 October (276) 2005	05:00:00.000	4 October (277) 2005	07:50:00.000	0.0	0.0
4 October (277) 2005	07:50:00.000	11 October (284) 2005	01:00:00.000	-4.9	4.9
11 October (284) 2005	01:00:00.000	12 October (285) 2005	04:00:00.000	0.0	0.0
12 October (285) 2005	04:00:00.000	21 November (325) 2005	11:20:00.000	-4.9	4.9
21 November (325) 2005	11:20:00.000	22 November (226) 2005	14:10:00.000	0.0	0.0
22 November (226) 2005	14:10:00.000	28 November (332) 2005	04:30:00.000	-4.9	4.9
28 November (332) 2005	04:30:00.000	29 November (333) 2005	07:20:00.000	0.0	0.0
29 November (333) 2005	07:20:00.000	12 December (346) 2005	19:25:00.000	-4.9	4.9
12 December (346) 2005	19:25:00.000	13 December (347) 2005	20:30:00.000	0.0	0.0
13 December (347) 2005	20:30:00.000	19 December (353) 2005	10:50:00.000	-4.9	4.9
19 December (353) 2005	10:50:00.000	20 December (354) 2005	13:45:00.000	0.0	0.0
20 December (354) 2005	3:45:00.000	26 December (360) 2005	04:05:00.000	-4.9	4.9
26 December (360) 2005	04:05:00.000	27 December (361) 2005	07:00:00.000	0.0	0.0
27 December (361) 2005	07:00:00.000	3 January (003) 2006	00:00:00.000	-4.9	4.9
3 January (003) 2006	00:00:00.000	4 January (004) 2006	15:40:00.000	0.0	0.0
4 January (004) 2006	15:40:00.000	16 January (016) 2006	10:40:00.000	-4.9	4.9
16 January (016) 2006	10:40:00.000	17 January (017) 2006	15:00:00.000	0.0	0.0
17 January (017) 2006	15:00:00.000	7 February (038) 2006	20:15:00.000	-4.9	4.9
7 February (038) 2006	20:15:00.000	8 February (039) 2006	23:10:00.000	0.0	0.0
8 February (039) 2006	23:10:00.000	13 February (044) 2006	11:00:00.000	-4.9	4.9
13 February (044) 2006	11:00:00.000	14 February (045) 2006	13:35:00.000	0.0	0.0
14 February (045) 2006	13:35:00.000	20 February (051) 2006	04:00:00.000	-4.9	4.9
20 February (051) 2006	04:00:00.000	20 February (051) 2006	12:40:00.000	0.0	0.0
20 February (051) 2006	12:40:00.000	28 February (059) 2006	00:20:00.000	-4.9	4.9
28 February (059) 2006	00:20:00.000	28 February (059) 2006	08:50:00.000	0.0	0.0
28 February (059) 2006	08:50:00.000	13 March (072) 2006	11:00:00.000	-4.9	4.9
13 March (072) 2006	11:00:00.000	8 May (128) 2006	11:00:00.000	-2.0	2.0
8 May (128) 2006	11:00:00.000	Current	Current	0.0	0.0

26. How do I convert the archived units to other geophysical quantities?

The corrected flux stored in this archive as Differential Number Flux is in units of electrons/(cm^2 s sr eV) and the electron energy is stored in units of eV. Although there is an infinite number of units that are popular, some useful conversions are described in this section. Different units can be achieved using similar techniques. Higher order manipulation of the electron spectrum is either performed in units of CGS or MKS (also called SI units). One needs to make sure that whatever the unit system being used for higher order calculations, all values are in the same unit system.

For each energy step, we will denote its index value as *i*. So, we will use the format E_i(eV) as referring to the Energy of step *i* in units of eV. In order to convert the Energy from eV into ergs for CGS units (handy for further calculations in CGS units), just take the energy and multiply by the conversion factor from eV to ergs:

$$E_i(ergs) \;=\; E_i(eV) \times 1.602 \times 10^{-12}\,\frac{ergs}{eV} \tag{40}$$

In order to convert the Energy into MKS units or SI units (handy for further calculations of the spectrum in MKS units), take the energy in eV and use the conversion factor to Joules:

$$E_i(Joules) \;=\; E_i(eV) \times 1.602 \times 10^{-19}\,\frac{Joules}{eV} \tag{41}$$

Since electrons are being measured, the conversion to the velocity (V_i) of the electron can be determined, which is handy for manipulating the electron velocity distribution. This can be determined for CGS units of cm/s by:

$$V_i(cm/s) \;=\; \sqrt{2 \times \frac{E_j(ergs)}{9.11\times10^{-28}g}} \tag{42}$$

or in MKS units of m/s by:

$$V_i(m/s) \;=\; \sqrt{2 \times \frac{E_j(Joule)}{9.11\times10^{-31}kg}} \tag{43}$$

From the archive, the Differential Number Flux (DNF_i) for the Energy step *i* is given as:

$$DNF_i\left(\frac{electrons(counts)}{cm^2\cdot s\cdot sr\cdot eV}\right) \tag{44}$$

The Differential Number Flux at step *i* can also be converted into the CGS unit of

$$\frac{electrons}{cm^2\cdot s\cdot sr\cdot ergs} \tag{45}$$

using:

$$DNF_i\left(\frac{electrons(counts)}{cm^2\cdot s\cdot sr\cdot ergs}\right) = DNF_i\left(\frac{electrons(counts)}{cm^2\cdot s\cdot sr\cdot eV}\right) \times \frac{1eV}{1.602\times10^{-12}ergs} \tag{46}$$

or into the MKS unit of

$$\frac{electrons}{m^2 \cdot s \cdot sr \cdot Joules} \tag{47}$$

using:

$$DNF_i\left(\frac{electrons(counts)}{m^2 \cdot s \cdot sr \cdot Joules}\right) = DNF_i\left(\frac{electrons(counts)}{cm^2 \cdot s \cdot sr \cdot eV}\right) \times \frac{10000 cm^2}{m^2} \times \frac{1eV}{1.602 \times 10^{-19} Joules} \tag{48}$$

To convert the Differential Number Flux into Differential Energy Flux (DEF_i) in units of

$$\frac{ergs}{cm^2 \cdot s \cdot sr \cdot eV} \tag{49}$$

at step *i*, just take the Differential Number Flux and multiply by the energy in ergs (handy to determine the energies at which the electrons are showing more flux):

$$\mathrm{DEF}_i\left(\frac{ergs}{cm^2 \cdot s \cdot sr \cdot eV}\right) = E_i(ergs) \times DNF_i\left(\frac{electrons(counts)}{cm^2 \cdot s \cdot sr \cdot eV}\right) \tag{50}$$

This is a mixture of units and still needs to be converted into the CGS unit of

$$\frac{ergs}{cm^2 \cdot s \cdot sr \cdot ergs} \tag{51}$$

using:

$$\mathrm{DEF}_i\left(\frac{ergs}{cm^2 \cdot s \cdot sr \cdot ergs}\right) = \mathrm{DEF}_i\left(\frac{ergs}{cm^2 \cdot s \cdot sr \cdot eV}\right) \times \frac{1eV}{1.602 \times 10^{-12} ergs} \tag{52}$$

The Differential Energy Flux unit of

$$\frac{Joules}{cm^2 \cdot s \cdot sr \cdot eV} \tag{53}$$

for step *i* can also be determined similarly from the Differential Number Flux:

$$\mathrm{DEF}_i\left(\frac{Joules}{cm^2 \cdot s \cdot sr \cdot eV}\right) = E_i(Joules) \times DNF_i\left(\frac{electrons(counts)}{cm^2 \cdot s \cdot sr \cdot eV}\right) \tag{54}$$

Similarly, the MKS unit of

$$\frac{Joules}{m^2 \cdot s \cdot sr \cdot Joules} \tag{55}$$

for the Differential Energy Flux at step *i* can be found by:

$$\mathrm{DEF}_i\left(\frac{Joules}{m^2 \cdot s \cdot sr \cdot Joules}\right) = \mathrm{DEF}_i\left(\frac{Joules}{cm^2 \cdot s \cdot sr \cdot eV}\right) \times \frac{10000 cm^2}{m^2} \times \frac{1eV}{1.602 \times 10^{-19} Joules} \tag{56}$$

The last class of function that is important is the electron Distribution Function. The electron Distribution Function at step *i* (DF_i) is related to the electron Differential Number Flux by the factor of

$$\frac{M^2}{2\times E_i} \tag{57}$$

where M is the mass of the electron. To determine the Distribution Function at step *i* in the CGS units of

$$\frac{s^3}{cm^6\cdot sr} \tag{58}$$

just use the CGS Energy and Differential Number Flux functions in the CGS form:

$$DF_i\left(\frac{s^3}{cm^6\cdot sr}\right) = DNF_i\left(\frac{electrons(counts)}{cm^2\cdot s\cdot sr\cdot ergs}\right)\times\frac{(9.11\times10^{-28}g)^2}{2\times E_i(ergs)} \tag{59}$$

In terms of MKS, the unit of the electron Distribution Function is

$$\frac{s^3}{m^6\cdot sr} \tag{60}$$

Similarly, use the MKS Energy and Differential Number Flux functions in the MKS form:

$$DF_i\left(\frac{s^3}{m^6\cdot sr}\right) = DNF_i\left(\frac{electrons(counts)}{m^2\cdot s\cdot sr\cdot Joules}\right)\times\frac{(9.11\times10^{-31}kg)^2}{2\times E_i(Joules)} \tag{61}$$

As a side note, the energy unit is usually kept in both the numerator and denominator of the Differential Energy Flux unit. This is because they represent different quantities where both carry the energy unit. The numerator of the Differential Energy Flux has the energy being measured; however, in the denominator is the width of the measured energy range allowed into the electron instrument.

Table of Symbols and Definitions

Symbol	First Appears	Unit	Definition	Appears Other Places
E	Page 1	eV	Measured Energy	Pages 15, 19
E'	Page 1	eV	Potential Corrected Energy	
ϕ	Page 1	volt	Spacecraft Potential	
J	Page 1	electrons/(cm^2 sec eV)	Measured Number Flux	
J'	Page 1	electrons/(cm^2 sec eV)	Potential Corrected Number Flux	
B	Page 3	electrons/sec	Background Count Rate	Pages 8, 9, 11, 13, 15
T	Page 3	sec	Averaging Time	Pages 4, 11, 13, 14
j	Page 3	index	ELS Sector	Pages 4, 8, 9, 11, 13, 14, 15
i	Page 3	index	ELS Energy Step	Pages 4, 8, 9, 11, 13, 14, 15, 28, 29, 30
C	Page 3	electrons	Raw Count	Pages 8, 11, 13, 14, 15
Cb	Page 3	electrons	Background Corrected Count	
alpha	Page 3	0.028125 sec	Step Accumulation Time	Pages 7, 8, 9, 11, 13, 15
T1	Page 3	electrons/(cm^2 sec sr eV)	1-count Differential Number Flux Threshold	Pages 4, 11, 13, 15
D	Page 4	electrons	Average Standard Deviation	
SD	Page 4	electrons/sec	Background Standard Deviation	Pages 12, 13, 15
S	Page 4	number	Number of Spectra	Pages 7, 8, 9, 10, 11, 13, 14, 15
k	Page 4	number	index	Pages 9, 13, 14, 15
ET	Page 7	eV	Energy Threshold	Pages 8, 13, 14, 15
beta	Page 7	0.003125 sec	Latency	

Symbol	First Appears	Unit	Definition	Appears Other Places
t	Page 7	sec	Background Accumulation Time	Pages 8, 9, 10, 11, 12
Bc	Page 8	electrons	Background Collected Counts	Page 9
Bt	Page 8	electrons	Background Collected Time	Page 9
Flux	Page 11	electrons/(cm^2 sec sr eV)	Maximum Differential Number Flux	Page 13
MT	Page 12	number	Level of Significance	Page 13
mean	Page 13	electrons/sec	Average Background	Pages 14, 15
N	Page 13	number	Step Count	Pages 14, 15
count	Page 13	electrons	Total Selected Count	Pages 14, 15
σ^2	Page 13	[electrons/sec]^2	Variance	Pages 14, 15
X	Page 13	number	Multiplier	
mean2	Page 14	[electrons]^2	Square Average Count	Page 15
DNF	Page 15	electrons/(cm^2 sec sr eV)	Differential Number Flux	
A	Page 15	ratio	Open Area Ratio	Page 16
GF	Page 15	cm^2 sr	Physical Geometric Factor	Page 16
M_T	Page 15	number	MCP Transparency	Page 16
G_T	Page 15	number	Grid Transparency	Page 16
R	Page 15	ratio	Resolution	Page 16
ϵ_A	Page 15	number	Absolute Efficiency	Page 19
ϵ_R	Page 15	number	Relative Efficiency	Page 16
S_F	Page 15	number	Scaling Factor	Page 16
S_V	Page 16	eV/volt	Sensitivity	

Symbol	First Appears	Unit	Definition	Appears Other Places
V	Page 16	volt	Plate Voltage	
ELStemp	Page 18	°C	ELS Temperature	
ROOMtemp	Page 18	°C	Lab Temperature	
TC	Page 18	ohm/°C	Temperature Change in Resistance	
R_{MCP}	Page 18	ohm	MCP Resistance	
$R_{MCP}T$	Page 18	ohm	Temperature Dependent MCP Resistance	Page 19
$I_{MCP}N$	Page 18	amp	Network Current	Page 19
$V_{MCP}N$	Page 18	volt	Network Voltage	Page 19
R1	Page 18	ohm	Network Resistor 1	Page 19
R4	Page 18	ohm	Network Resistor 4	
GZm	Page 19	number	Bordoni Probability Function	
Em	Page 19	eV	Pre-acceleration Energy	
Zm	Page 19	number	Bordoni Probability Peak	
κ	Page 19	number	Bordoni Resistance	
GEz	Page 19	number	Bordoni Energy Function	
Ez	Page 19	number	Energy Probability	
E_i	Page 28	erg, Joule, or eV	Energy Step	Pages 29, 30
V_i	Page 28	cm/s or m/s	Velocity Step	
DNF_i	Page 28	$\frac{electrons(counts)}{cm^2 \cdot s \cdot sr \cdot eV}$ or $\frac{electrons(counts)}{cm^2 \cdot s \cdot sr \cdot ergs}$ or $\frac{electrons(counts)}{cm^2 \cdot s \cdot sr \cdot Joules}$	Differential Number Flux Step	Pages 29, 30

Symbol	First Appears	Unit	Definition	Appears Other Places
DEF_i	Page 29	$\frac{ergs}{cm^2 \cdot s \cdot sr \cdot eV}$ or $\frac{ergs}{cm^2 \cdot s \cdot sr \cdot ergs}$ or $\frac{Joules}{cm^2 \cdot s \cdot sr \cdot eV}$ or $\frac{Joules}{cm^2 \cdot s \cdot sr \cdot Joules}$	Differential Energy Flux Step	
M	Page 30	g or kg	Electron Mass	
DF_i	Page 30	$\frac{s^3}{cm^6 \cdot sr}$ or $\frac{s^3}{m^6 \cdot sr}$	Electron Distribution Function	