# Venus Express ASPERA-4 ELS Background Data

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## *Introduction*

Data found in this archive is the 5-minute averaged instrument background corrected electron data from the Electron Spectrometer (ELS) which was flown on the Venus Express (VEx) spacecraft as part of the Analyzer of Space Plasmas and Energetic Atoms (ASPERA-4) experiment. The original ELS flight data is archived at the ESA Planetary System Archive (PSA) found at:

https://www.cosmos.esa.int/web/psa/venus-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 an averaged 5 minute background; however, it is realized that the user may feel that the flux obtained from subtraction of the 5 minute averaged background value may not be adequate. 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 VEx 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 $(\phi)$ 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

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

Any spacecraft potential correction should be made ***after*** correction for instrument background.

These questions may be found in the text as follows:

## *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 Venus Express (VEx) spacecraft as part of the Analyzer of Space Plasmas and Energetic Atoms (ASPERA-4) 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 file types: (1) background data, (2) science data, and (3) energy levels. The background data files contain the background rates and their uncertainty for each ELS sector and for the total anode, and the background data files begin with the characters ELS05BK. The science data files contain the background corrected flux spectra, and these 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.

## *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*):

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

where ***alpha = 0.028125 sec***, the instrument accumulation period.

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.

When displaying or analyzing the spectra, first determine the desired time resolution. This could be anywhere from the finest instrument resolution to some predefined time averaged 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

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

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**sigma* 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 standard deviation (*D*) is appropriate. In this archive, the time (5 min.) 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

$$\frac{counts}{cm^2 \cdot sr \cdot s \ \cdot eV}$$

An example of data read from this archive is shown in **Figure 1** for November 5, 2011 (day 309) at 07:00:00 – 07:00:04 UT.

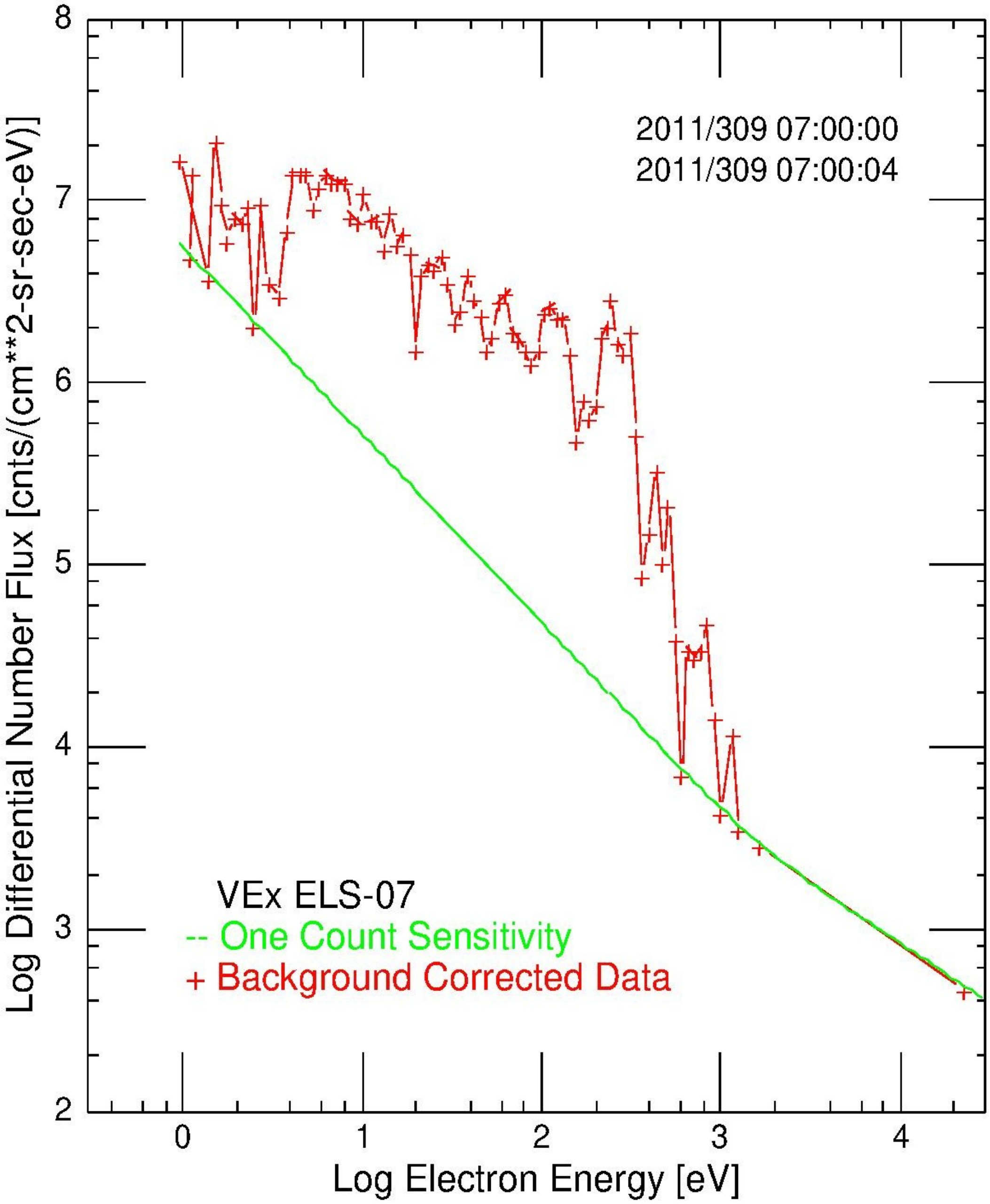

***Figure 1.*** *Corrected ELS number flux spectra for sector 07 from November 5, 2011 (day 309) between 07:00:00 and 07:00:04 UT. Data corrected for background is drawn in red with a plus symbol. This is compared to the 1 count sensitivity line shown in green. At this time, the Venus Express spacecraft is traveling through the bow shock of Venus, and the background correction is low as shown by the location of points near (but below) the sensitivity line.*

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

For background count rates, use the background data file ELS05BK. 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 November 5, 2011 (day 309) at 06:30:00 – 07:30:00 UT.

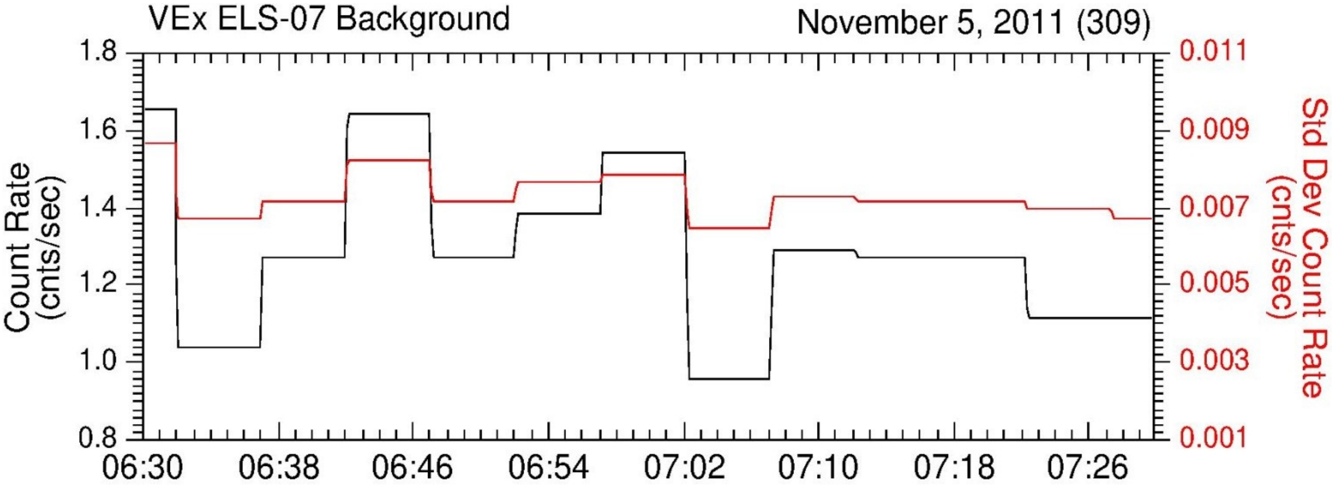

***Figure 2.*** *ELS sector 07 background count rate data (left in black) and the standard deviation of the background count rate data (right in red) are shown for November 5, 2011 (day 309). The time at the bottom is in UT as hours:minutes (HH:MM). At this time for this sensor, the background count rate data is low and the standard deviation shows only a small deviation in the background distribution. These data are from the region of transition of the solar wind through the Venus bow shock and into the Venus magnetosheath during a time of high solar wind activity.*

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 were 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.

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

The following is just an overview. Please refer to the VEX_ASPERA-4_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, depending on the file, (1) the background corrected differential number flux (ELSHRBCNF and ELSLRBCNF), or (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 $eV$.

## *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, 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, 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 instrument 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. In this archive, background values are determined from the average counts accumulated in an approximate 5 minute time period.

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

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) times the background. After this value is achieved, multiply the result by the 1-count threshold value.

## *8. How is the Background for Venus Express ASPERA-4 ELS Determined?*

The purpose of background removal in ASPERA-4 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 Venus and the characteristics of the ELS, electrons from the Venus 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-4 ELS has a fixed 0.028125 seconds of electron accumulation time (*alpha*) where the number electrons are 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-4, 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. It has been found that a good average accumulation time (*t*) of energy spectra is about *t = 5 minutes = 300 seconds*. 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-4 clock drifts and the cadence of the instrument (every 8th spectrum is missing due to operation of the data handling in the ASPERA-4 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 to 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.

$$(1)\quad Bc(j) = \sum_{k=1}^{k=S} \sum_{i=0}^{i=last\ step\ above\ ET} C_i(j)$$

$$(2)\quad Bt(j) = \sum_{k=1}^{k=S} \sum_{i=0}^{i=last\ step\ above\ ET} alpha$$

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

where the subscript *i* refers to the energy step (which runs from 0 to 126), *j* is the ELS sector, and $C_i(j)$ is the count for sector *j* at energy step *i* for *S* 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 4 (*j*=3). The counts generated from the instrument are as follows:

| 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:

$$\text{Sum} = 3 + 7 + 3 + 6 + 2 + 4 + 3 + 2 = 30$$

Then

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

or

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

and

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

$$= 80 * 0.028125 \text{ sec} = 2.25 \text{ sec}$$

so

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

Thus, for the time period *t* the background value for sector 4 (*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 Venus 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. What if I find time periods when the 5 minute average background corrected flux seems too high?

At times, the background count rate can become so low that it is not well determined by a 5 minute average and not enough background is subtracted from the raw flux. During these times, the number of counts used to determine the background can become 10 or less. 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 min (1500 sec). For these times, the user can re-compute the background with the same method as described under ***"How is the Background for Venus Express ASPERA-4 ELS Determined?"***

## 10. What if I find time periods when the 5 minute average background corrected flux seems too low?

At times, the background count rate can become so high that it is not well determined by a 5 minute average. During these times, the number of counts used to determine the 5 minute background can become 500 or more; however, it could also be that the background is rapidly changing on time scales faster that 5 minutes. 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 5 minute average over corrects data at the beginning of the 5 minute averaging period and under corrects data toward the end of the 5 minute averaging period. Another example might be when random electronic noise changes at a frequency faster than corrected for by the 5 minute average, producing spectra both too much and too little corrected at the same time within the 5 minute average period. For these times, the user can recompute the background with the same method as described under ***"How is the Background for Venus Express ASPERA-4 ELS Determined?"***

### *11. What if I find time periods when the 5 minute average background period is too long?*

This symptom occurs when the sector is very noisy and this noise changes on a time scale less than 5 minutes. This results in not enough noise being removed from different times and too much noise being removed from other times within the 5 minute average period used to compute the background. These are typically time periods when the $S$ times the number of energy steps selected for background accumulation exceeds the 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 ***"How is the Background for Venus Express ASPERA-4 ELS Determined?"***

### *12. 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 VEx ASPERA-4 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/venus-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:

$$Flux(i,j) = [C(i,j) - (B(j) * 0.028125\,\mathrm{sec})] * T1(i,j)$$

### *13. 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 has to 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 ***"How is the Background for Venus Express ASPERA-4 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 average over 5 minutes as the most representative of the background count rate.

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:

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

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.

## *14. 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 ($C_i$) 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 at 300 sec (5 min) and contains 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

Add all counts above *ET* for sector *j* for all spectra within accumulation time period of 300 seconds.

$$count(j) = \sum_{k=1}^{k=S} \sum_{i=0}^{i=last\ step\ above\ ET} C_i(j)$$

Determine how many measurements are included in the calculation of *count(j)*.

$$N(j) = \sum_{k=1}^{k=S} \sum_{i=0}^{i=last\ step\ above\ ET} \{1\}$$

Now the average (*mean*) is calculated.

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

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 ($\sigma^2$) is the average square of the deviation from the mean, and is also the square of the standard deviation. This can be written as:

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

$$\sigma^2(j) = \frac{1}{N(j)} \cdot \sum_{k=1}^{k=S} \sum_{i=0}^{i=last\ step\ above\ ET} [C_i(j) - mean(j)]^2$$

OR

$$\sigma^2(j) = \left[\frac{1}{N(j)} \cdot \sum_{k=1}^{k=S} \sum_{i=0}^{i=last\ step\ above\ ET} {C_i}^2(j)\right]$$

$$-\left[\frac{1}{N(j)} \cdot \sum_{k=1}^{k=S} \sum_{i=0}^{i=last\ step\ above\ ET} 2 * C_i(j) * mean(j)\right]$$

$$+\left[\frac{1}{N(j)} \cdot \sum_{k=1}^{k=S} \sum_{i=0}^{i=last\ step\ above\ ET} mean^2(j)\right]$$

OR

$$\sigma^2(j) = \left[\frac{1}{N(j)} \cdot \sum_{k=1}^{k=S} \sum_{i=0}^{i=last\ step\ above\ ET} {C_i}^2(j)\right]$$

$$-\left[\frac{2 * mean(j)}{N(j)} \cdot \sum_{k=1}^{k=S} \sum_{i=0}^{i=last\ step\ above\ ET} C_i(j)\right]$$

$$+\left[\frac{mean^2(j)}{N(j)} \cdot \sum_{k=1}^{k=S} \sum_{i=0}^{i=last\ step\ above\ ET} \{1\}\right]$$

OR

$$\sigma^2(j) = \left[\frac{1}{N(j)} \cdot \sum_{k=1}^{k=S} \sum_{i=0}^{i=last\ step\ above\ ET} {C_i}^2(j)\right]$$

$$-\left[\frac{2 * mean(j)}{N(j)} * count(j) - \frac{mean^2(j)}{N(j)} * N(j)\right]$$

OR

$$\sigma^2(j) = \left[\frac{1}{N(j)} \cdot \sum_{k=1}^{k=S} \sum_{i=0}^{i=last\ step\ above\ ET} {C_i}^2(j)\right] - mean^2(j)$$

OR

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

where

$$mean2(j) = \frac{1}{N(j)} \cdot \sum_{k=1}^{k=S} \sum_{i=0}^{i=last\ step\ above\ ET} \left[{C_i}^2(j)\right]$$

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:

$$N(j) = \sum_{k=1}^{k=S} \sum_{i=0}^{i=last\ step\ above\ ET} \{1\}$$

$$count(j) = \sum_{k=1}^{k=S} \sum_{i=0}^{i=last\ step\ above\ ET} C_i(j)$$

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

$$mean2(j) = \frac{1}{N(j)} \cdot \sum_{k=1}^{k=S} \sum_{i=0}^{i=last\ step\ above\ ET} \left[{C_i}^2(j)\right]$$

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

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*.

## *15. 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

$$DNF(i,j) = C(i,j) * T1(i,j)$$

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

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

## *16. 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 was determined by Mullard Space Science Laboratory based on the ELS sector anodes butting together. In reality, there is a small gap between sectors so that there is no crosstalk between sectors. This gap is taken into account as an open area ratio ($A$), meaning the actual size of the ELS sector is really 0.87 of the area represented in the geometric factor. The 1-count threshold is then determined for each energy step $i$ and each ELS sector $j$ by dividing a count of one (1) by the geometric factor ($G$), open area ratio ($A$), the accumulation time (0.028125 s), and the center energy ($E$):

$$T1(i,j) = \frac{1}{G(i,j) * A * E(i,j) * 0.028125}$$

Mullard Space Science Laboratory (MSSL) determined the ELS geometric factor ($G$) in units of $cm^2 \cdot sr$. Laboratory data were used to compute a polynomial with 10 coefficients describing the $\log_{10}$ of the geometric factor for each sector and energy of ELS. First, the $\log_{10}$ of each center energy ($Z$) is determined from the center energy ($E$)

$$Z(i,j) = log_{10}(E(i,j))$$

Then the log expression is used to determine the geometric factor logarithm ($GF$) using the coefficients from **Table 1** and **Table 2** with the equation as follows:

$$GF(i,j) = a0(j) + a1(j) * Z(i,j) + a2(j) * Z(i,j)^2 + \ldots + a9(j) * Z(i,j)^9$$

Lastly, the geometric factor ($G$) is uncovered when the geometric factor logarithm ($GF$) is taken as the power of 10:

$$G(i,j) = 10^{GF(i,j)}$$

***Table 1.*** *The first five geometric factor logarithm coefficients used to determine the geometric factor.*

| Sector | a0 | a1 | a2 | a3 | a4 |
|---|---|---|---|---|---|
| 0 | $-5352603 \text{x} 10^{-6}$ | $1307505 \text{x} 10^{-7}$ | $-9126436 \text{x} 10^{-10}$ | $-7406504 \text{x} 10^{-10}$ | $2872757 \text{x} 10^{-9}$ |
| 1 | $-5175138 \text{x} 10^{-6}$ | $6943707 \text{x} 10^{-8}$ | $-7619150 \text{x} 10^{-10}$ | $-5012468 \text{x} 10^{-10}$ | $2249295 \text{x} 10^{-9}$ |
| 2 | $-5102045 \text{x} 10^{-6}$ | $3401365 \text{x} 10^{-8}$ | $2308346 \text{x} 10^{-10}$ | $7900797 \text{x} 10^{-11}$ | $-6624701 \text{x} 10^{-10}$ |
| 3 | $-5190945 \text{x} 10^{-6}$ | $5666428 \text{x} 10^{-8}$ | $6808476 \text{x} 10^{-10}$ | $-1854677 \text{x} 10^{-10}$ | $-1143899 \text{x} 10^{-9}$ |
| 4 | $-5252834 \text{x} 10^{-6}$ | $7338115 \text{x} 10^{-8}$ | $2710871 \text{x} 10^{-10}$ | $5771119 \text{x} 10^{-10}$ | $-1308300 \text{x} 10^{-9}$ |
| 5 | $-5207461 \text{x} 10^{-6}$ | $4985052 \text{x} 10^{-8}$ | $-4356600 \text{x} 10^{-10}$ | $1794696 \text{x} 10^{-10}$ | $4969139 \text{x} 10^{-10}$ |
| 6 | $-5300697 \text{x} 10^{-6}$ | $6945854 \text{x} 10^{-8}$ | $1246807 \text{x} 10^{-10}$ | $2550334 \text{x} 10^{-10}$ | $-2794474 \text{x} 10^{-10}$ |
| 7 | $-5135470 \text{x} 10^{-6}$ | $3275346 \text{x} 10^{-8}$ | $2468059 \text{x} 10^{-10}$ | $-2545448 \text{x} 10^{-10}$ | $-1126245 \text{x} 10^{-10}$ |
| 8 | $-5262746 \text{x} 10^{-6}$ | $8362584 \text{x} 10^{-8}$ | $2152329 \text{x} 10^{-10}$ | $2796715 \text{x} 10^{-10}$ | $-4217520 \text{x} 10^{-10}$ |
| 9 | $-5214386 \text{x} 10^{-6}$ | $8158020 \text{x} 10^{-8}$ | $-6529375 \text{x} 10^{-10}$ | $1548566 \text{x} 10^{-10}$ | $8109318 \text{x} 10^{-10}$ |

| Sector | a0 | a1 | a2 | a3 | a4 |
|---|---|---|---|---|---|
| 10 | $-5289390x10^{-6}$ | $9102112x10^{-8}$ | $7065625x10^{-10}$ | $5110138x10^{-10}$ | $-2160060x10^{-9}$ |
| 11 | $-5104914x10^{-6}$ | $5265406x10^{-8}$ | $3377587x10^{-10}$ | $3794041x10^{-11}$ | $-9675029x10^{-10}$ |
| 12 | $-5293319x10^{-6}$ | $1358738x10^{-7}$ | $-3129184x10^{-10}$ | $-1229553x10^{-9}$ | $2534155x10^{-9}$ |
| 13 | $-5257630x10^{-6}$ | $1379781x10^{-7}$ | $-7651498x10^{-10}$ | $-1538785x10^{-10}$ | $1967013x10^{-9}$ |
| 14 | $-5234337x10^{-6}$ | $1323232x10^{-7}$ | $-1506465x10^{-9}$ | $5717763x10^{-12}$ | $2796107x10^{-9}$ |
| 15 | $-4980369x10^{-6}$ | $5196365x10^{-8}$ | $-5667548x10^{-10}$ | $4026180x10^{-11}$ | $1048430x10^{-9}$ |

***Table 2.*** *The second five geometric factor logarithm coefficients used to determine the geometric factor.*

| Sector | a5 | a6 | a7 | a8 | a9 |
|---|---|---|---|---|---|
| 0 | $-1396149x10^{-9}$ | $-1282299x10^{-9}$ | $1532595x10^{-9}$ | $-5574597x10^{-10}$ | $7046705x10^{-11}$ |
| 1 | $-1234797x10^{-9}$ | $-8192726x10^{-10}$ | $1090755x10^{-9}$ | $-4048427x10^{-10}$ | $5154896x10^{-11}$ |
| 2 | $5005751x10^{-10}$ | $9297245x10^{-11}$ | $-2524008x10^{-10}$ | $1040792x10^{-10}$ | $-1389131x10^{-11}$ |
| 3 | $1072656x10^{-9}$ | $5736873x10^{-11}$ | $-4448896x10^{-10}$ | $1959748x10^{-10}$ | $-2686858x10^{-11}$ |
| 4 | $5837479x10^{-10}$ | $4126530x10^{-10}$ | $-4881117x10^{-10}$ | $1704716x10^{-10}$ | $-2072836x10^{-11}$ |
| 5 | $-4731790x10^{-10}$ | $-3606409x10^{-11}$ | $1979883x10^{-10}$ | $-8431209x10^{-11}$ | $1127454x10^{-11}$ |
| 6 | $-2497391x10^{-11}$ | $1273985x10^{-10}$ | $-5012991x10^{-11}$ | $4072312x10^{-12}$ | $6154407x10^{-13}$ |
| 7 | $2599557x10^{-10}$ | $-6145277x10^{-11}$ | $-6014063x10^{-11}$ | $3485071x10^{-11}$ | $-5225209x10^{-12}$ |
| 8 | $5234003x10^{-11}$ | $1606296x10^{-10}$ | $-9679766x10^{-11}$ | $2054018x10^{-11}$ | $-1366561x10^{-12}$ |
| 9 | $-6664600x10^{-10}$ | $-9947211x10^{-11}$ | $3040009x10^{-10}$ | $-1233790x10^{-10}$ | $1610785x10^{-11}$ |
| 10 | $1319953x10^{-9}$ | $5079737x10^{-10}$ | $-8376027x10^{-10}$ | $3189281x10^{-10}$ | $-4079585x10^{-11}$ |
| 11 | $8060315x10^{-10}$ | $1088761x10^{-10}$ | $-3868968x10^{-10}$ | $1646313x10^{-10}$ | $-2232948x10^{-11}$ |
| 12 | $-8052393x10^{-10}$ | $-1407284x10^{-9}$ | $1395912x10^{-9}$ | $-4803347x10^{-10}$ | $5894029x10^{-11}$ |
| 13 | $-1142146x10^{-9}$ | $-9697018x10^{-10}$ | $1259313x10^{-9}$ | $-4754187x10^{-10}$ | $6164228x10^{-11}$ |
| 14 | $-1823608x10^{-9}$ | $-1036255x10^{-9}$ | $1534291x10^{-9}$ | $-5887433x10^{-10}$ | $7653697x10^{-11}$ |
| 15 | $-7154523x10^{-10}$ | $-3862360x10^{-10}$ | $5928618x10^{-10}$ | $-2299277x10^{-10}$ | $3008190x10^{-11}$ |

### *17. Can you tell me more about the Venus Express mission?*

The ELS instrument is a part of the ASPERA-4 experiment on ESA's Venus Express (VEx) mission. The ELS instrument measured the *in situ* electron plasma in the Venus environment and the solar wind from April 2006 through 2014. The VEx spacecraft orbited Venus sampling data from a polar orbit with a periapsis which varied between 250 km and 300 km, and an apoapsis of about 66,000 km. The VEx polar orbit had pericenter about the north pole of Venus and the apocenter about the south pole of Venus. The VEx orbit precessed, taking 120 days to precess 180° about its semi-major axis.

The VEx mission was constructed from flight spare instrumentation left over from the ESA Mars Express (MEx) mission. In the USA, NASA is a participant in the ESA MEx program. Through the first Discovery program Mission of Opportunity (MO), NASA supports 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. After the successful launch of the MEx spacecraft in 2003 from Bikanor by a Russian Soyuz rocket, ESA decided to conduct a similar mission to Venus. ESA decided that rather than build new instrumentation for the VEx mission, it would modify the left over MEx spare instrumentation for the higher radiation environment expected at Venus. At this time, the ESA member countries all supported the VEx mission; however, NASA opted to only allow the flight spare instrumentation from MEx to be included as part of the VEx mission without support from the USA. Thus, the unused flight spare ELS unit was modified in Europe to include the extra radiation shielding needed for the Venus environment and this became the ASPERA-4 ELS unit which was flown on VEx.

As a consequence of the NASA decision, data from the VEx mission was archived by the Europeans in the European Planetary Science Archive (PSA) without guidance from NASA or SwRI. Data from the VEx mission is now all publicly available. The VEx ELS data is archived at http://psa.esac.esa.int. The PSA ELS data consists of the telemetered ELS science packets in table ASCII form, and the calibration factors needed to construct the electron spectrum in geophysical units.

## *18. 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 had several operational modes, only three classes were used on ASPERA-4. The three classes are described by the energy sweep: 128 step, 32 step, 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 200 eV. The 128-step sweep measures a 127 point energy spectrum (with one additional step for flyback) from about 0.6 eV to about 30 keV.

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 200 eV and the other covers the higher energy range (HR) from 0 eV to about 30 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 VEx ELS sensor is shown in **Figure 3**. The ELS data stored in the public archive is raw data in units of counts/sample from the ELS spectrometer on the VEx spacecraft. This raw data contains the environment signal from the Venus 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 PSA archive.

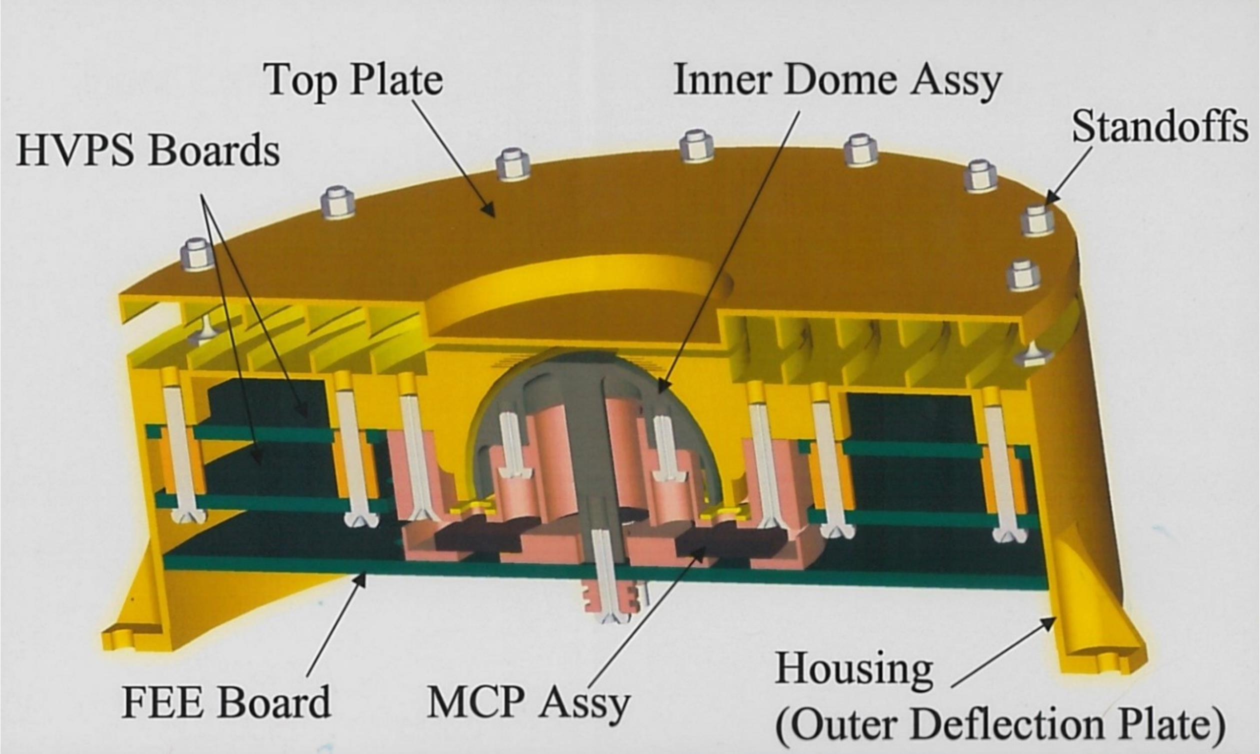

***Figure 3.*** *Cross-section of the VEx ELS instrument showing the internal geometry. Plasma enters through the sides of the housing and travels between the collimator baffles which refine the plasma into a beam. A high voltage power supply (HVPS) generates an electric field between the top plate/outer 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 they are magnified and turned into an electronic signal by the front end electronics (FEE).*

## *19. 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 Venus plasma. During its lifetime, the ELS instrument experienced several different types of contamination which altered the electron spectrum from Venus. 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 Venus environment, but these sources are **time dependent**.

### *20. 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 VEx 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 Venus 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 30 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 10-30 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.

### *21. 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 Venus which lasted for two days during 2013. This figure shows three panels. In the top panel, the electron energy flux spectra from ELS sector 06 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.

### *22. 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 solar wind just before impact with Venus. The bulk of the electron density is determined at low energies. Correction shows that the electron distribution function spectrum is artificially an order of magnitude greater at the lowest energy, leading to an incorrect solar wind density impacting Venus at the time of the SEP event. Differences at high energies indicate an artificial amount of energy going into the upper atmosphere of Venus as described in **Figure 4**. Thus, to represent the electron plasma environment correctly, any scientist will need to correct for the ELS background.

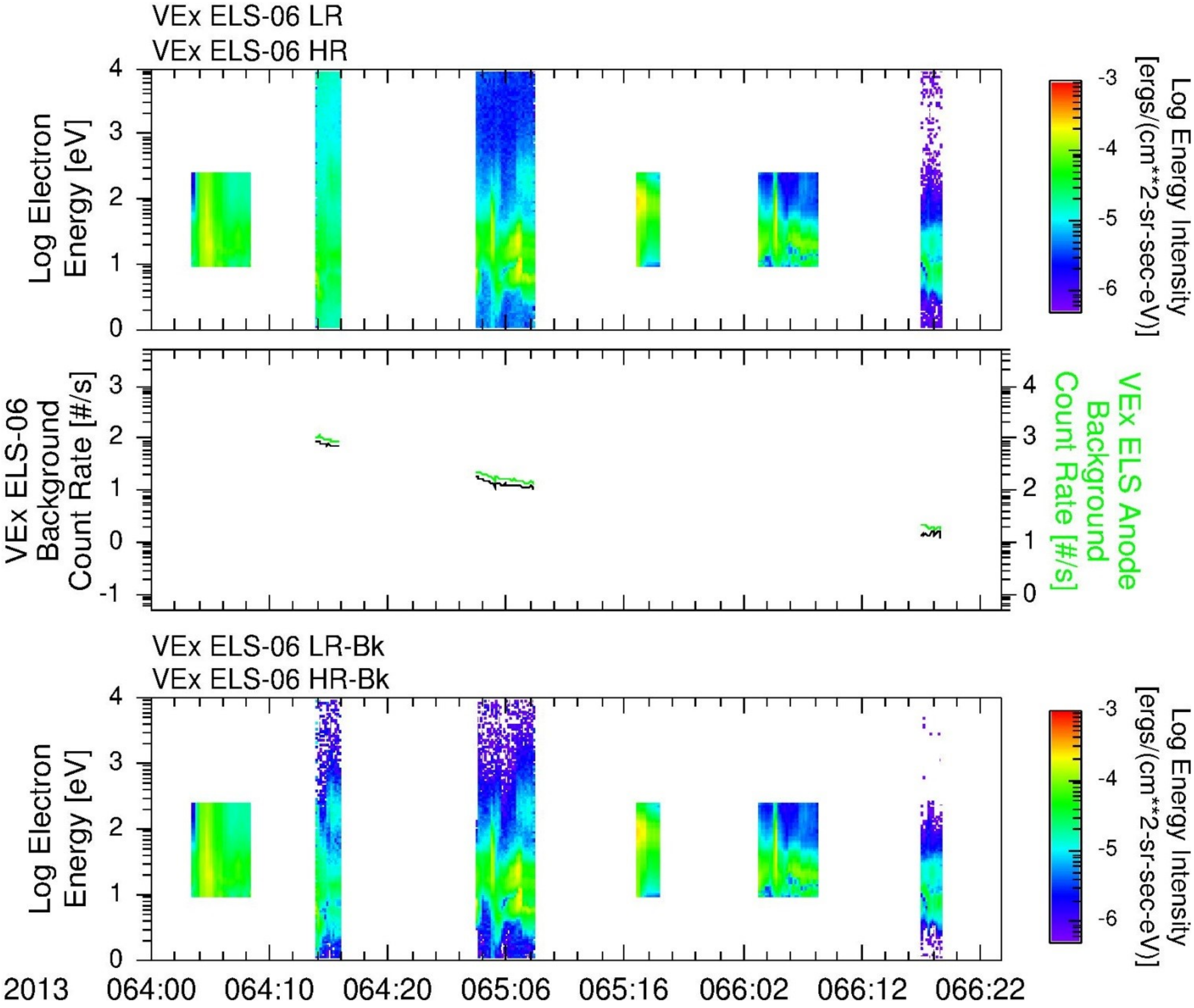

***Figure 4***. *Comparison of top and bottom spectrogram shows the difference between ELS spectra before and after background correction due to an SEP event. Time is shown on the bottom panel as day of year and hour of day (DDD:HH).*

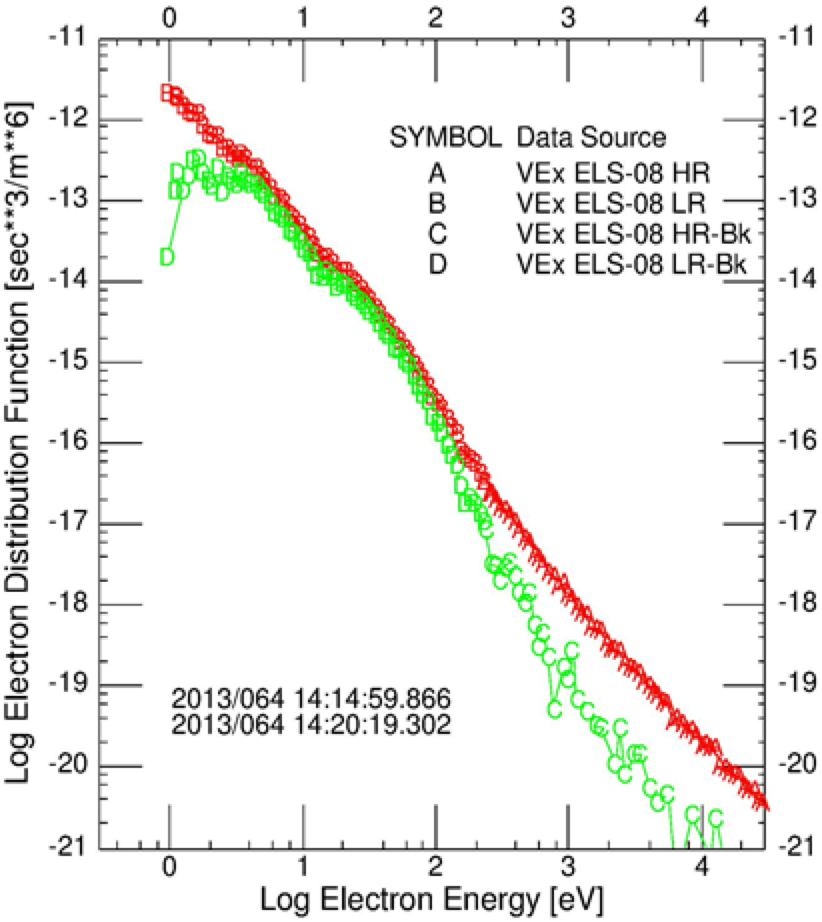

***Figure 5.*** *The effect of the removal of the background from the electron spectrum is shown. The red line marked with an A or B shows the original electron spectrum and the green line marked with a C or D shows the electron spectrum after background contamination has been removed. The subtraction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

## *23. 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 VEx 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 day time period when the electronic noise occurred. We first examine ELS sector 08. The center panel includes the background noise for sector 08 (black) and the entire ELS anode (green). Notice that the background level for sector 08 remains constant while the background of the anode increased by an order of magnitude. This is indicating that there was noise in some sectors, but not in others.

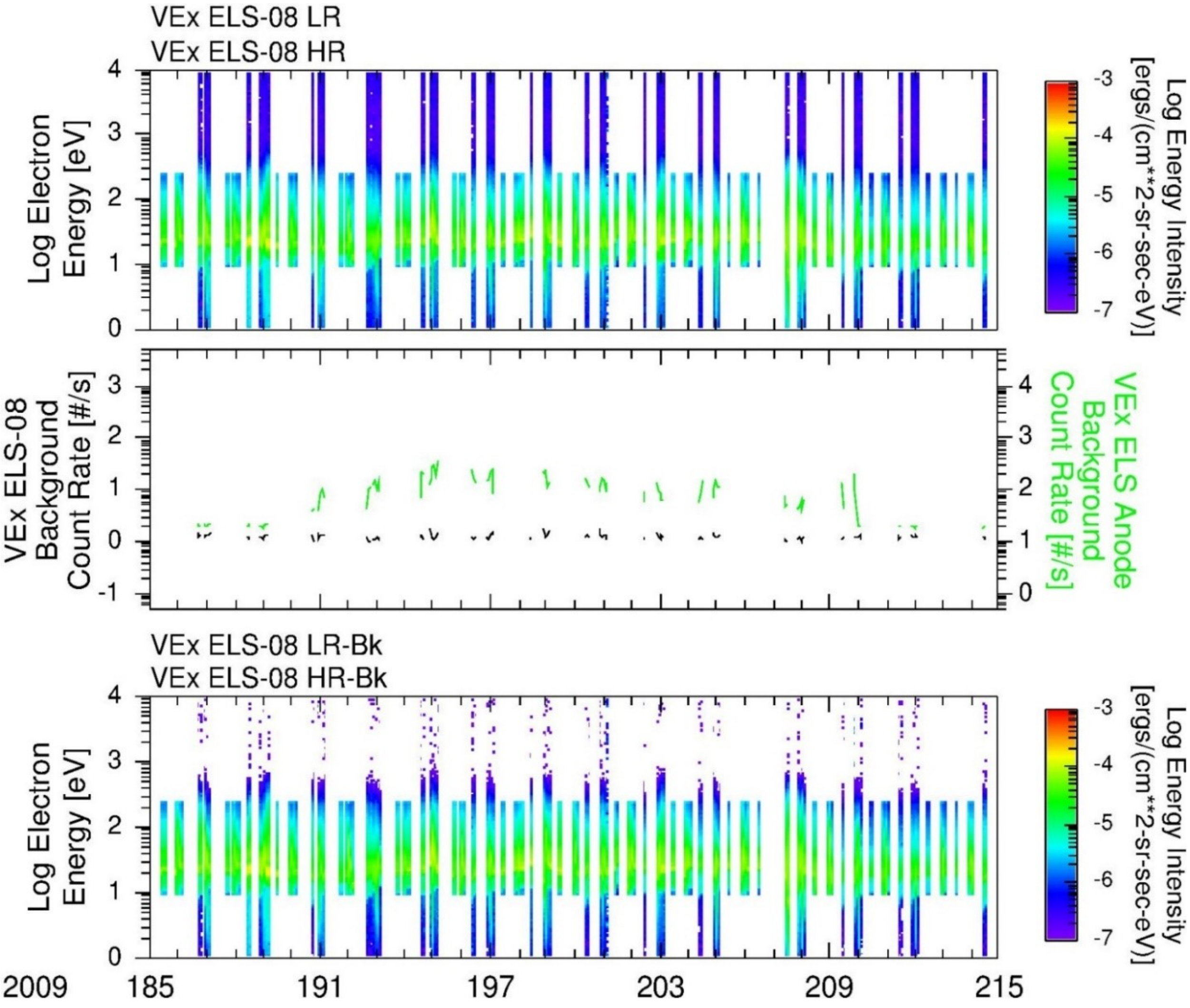

***Figure 6.*** *Sector 08 shows a 20 day time span when the background in part of ELS increases, while it remains steady in other parts of ELS. The center panel shows the background count rate from sector 08 is steady, but the anode background increased (Format is the same as* ***Figure 4****). Time is shown on the bottom panel as day of year (DDD).*

For the same time period, **Figure 7** shows data from sector 14. Here, sector 14 background is drawn in black in the center panel. Examination of the spectral data of sector 14 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 Venus 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.

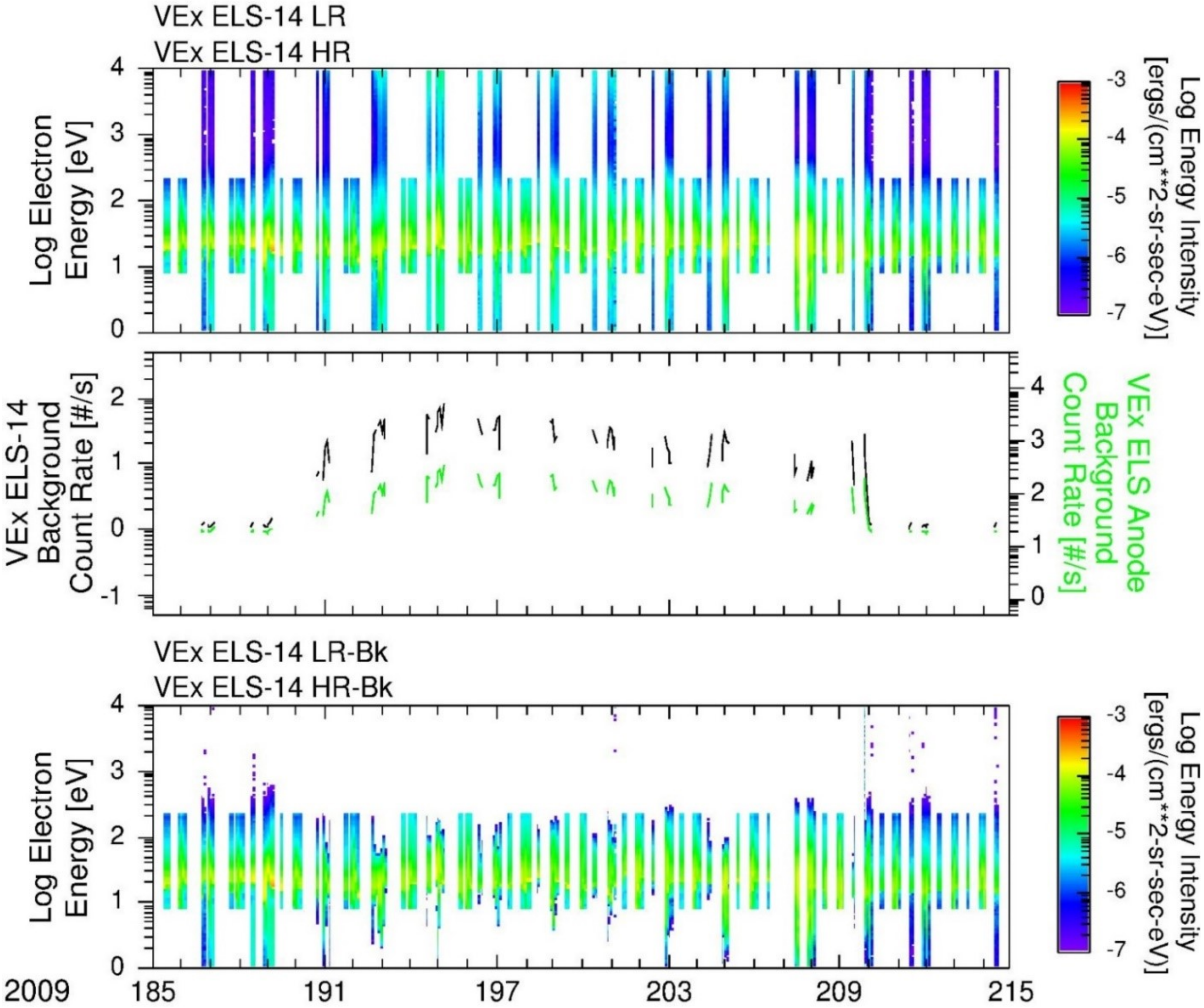

***Figure 7.*** *This is from the same time period as Figure 4, but shows data from sector 14. Corrections are needed to sector 14 which are up to two orders of magnitude greater than for sector 08 shown in* ***Figure 6****. This knowledge of the sector dependent background is imperative. (Format is the same as* ***Figure 6****)*

## *24. How do I convert the archived units to other geophysical quantities?*

The corrected flux stored in this archive as Differential Number Flux 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 are 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 $j$. So we will use the format $E_j$(eV) as referring to the Energy of step $j$ 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:

$$E_j(\text{ergs}) = 1.602\times10^{-12}\ \text{ergs/eV} \times E_j(\text{eV})$$

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:

$$E_j(\text{Joules}) = 1.602\times10^{-19}\ \text{Joules/eV} \times E_j(\text{eV})$$

Since electrons are being measured, the conversion to the velocity (V) 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:

$$V_j(\text{cm/s}) = \sqrt{2 \times \frac{E_j(ergs)}{9.11\times10^{-28}\ g}}$$

or in MKS units of m/s by:

$$V_j(\text{m/s}) = \sqrt{2 \times \frac{E_j(Joule)}{9.11\times10^{-31}\ kg}}$$

From the archive, the Differential Number Flux ($DNF_j$) for the Energy step $j$ is given as:

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

The Differential Number Flux at step $j$ can also be converted into the CGS unit of $\frac{electrons}{cm^2{\cdot}s{\cdot}sr{\cdot}ergs}$

using:

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

or into the MKS unit of $\frac{electrons}{m^2{\cdot}s{\cdot}sr{\cdot}Joules}$

using:

$$DNF_j\left(\frac{electrons(counts)}{m^2{\cdot}s{\cdot}sr{\cdot}Joules}\right) = DNF_j\left(\frac{electrons(counts)}{cm^2{\cdot}s{\cdot}sr{\cdot}eV}\right) \times \frac{10000cm^2}{m^2} \times \frac{1eV}{1.602\times10^{-19}Joules}$$

To convert the Differential Number Flux into Differential Energy Flux ($DEF_j$) in units of $\frac{ergs}{cm^2{\cdot}s{\cdot}sr{\cdot}eV}$

at step $j$, 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):

$$DEF_j\left(\frac{ergs}{cm^2{\cdot}s{\cdot}sr{\cdot}eV}\right) = E_j(ergs) \times DNF_j\left(\frac{electrons(counts)}{cm^2{\cdot}s{\cdot}sr{\cdot}eV}\right)$$

This is a mixture of units and still needs to be converted into the CGS unit of $\frac{ergs}{cm^2{\cdot}s{\cdot}sr{\cdot}ergs}$

using:

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

The Differential Energy Flux unit of $\frac{Joules}{cm^2 \cdot s \cdot sr \cdot eV}$ for step $j$

can also be determined similarly from the Differential Number Flux:

$$DEF_j\left(\frac{Joules}{cm^2 \cdot s \cdot sr \cdot eV}\right) = E_j(Joules) \times DNF_j\left(\frac{electrons(counts)}{cm^2 \cdot s \cdot sr \cdot eV}\right)$$

Similarly, the MKS unit of $\frac{Joules}{m^2 \cdot s \cdot sr \cdot Joules}$ for the Differential Energy Flux at step $j$ can be found by:

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

The last class of function that is important is the electron Distribution Function. The electron Distribution Function at step $j$ (DF$_j$) is related to the electron Differential Number Flux by the factor of $\frac{M^2}{2 \times E_j}$, where M is the mass of the electron. To determine the Distribution Function at step $j$ in the CGS units of $\frac{s^3}{cm^6 \cdot sr}$, just use the CGS Energy and Differential Number Flux functions in the CGS form:

$$DF_j\left(\frac{s^3}{cm^6 \cdot sr}\right) = DNF_j\left(\frac{electrons(counts)}{cm^2 \cdot s \cdot sr \cdot ergs}\right) \times \frac{(9.11 \times 10^{-28}\ g)^2}{2 \times E_j(ergs)}$$

In terms of MKS, the unit of the electron Distribution Function is $\frac{s^3}{m^6 \cdot sr}$

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

$$DF_j\left(\frac{s^3}{m^6 \cdot sr}\right) = DNF_j\left(\frac{electrons(counts)}{m^2 \cdot s \cdot sr \cdot Joules}\right) \times \frac{(9.11 \times 10^{-31}\ kg)^2}{2 \times E_j(Joules)}$$

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 14, 22, 23 |
| $E'$ | Page 1 | eV | Potential Corrected Energy | |
| $\phi$ | 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 2 | electrons/sec | Background Count Rate | Pages 7, 8, 9, 10, 11, 13 |
| $T$ | Page 2 | sec | Averaging Time | Pages 3, 10, 11, 13 |
| $j$ | Page 2 | index | ELS Sector | Pages 3, 7, 8, 9, 10, 11, 12, 13, 14 |
| $i$ | Page 2 | index | ELS Energy Step | Pages 3, 7, 8, 9, 10, 11, 12, 13, 14 |
| $C$ | Page 2 | electrons | Raw Count | Pages 6, 7, 8, 9, 10, 11, 12, 13 |
| $Cb$ | Page 2 | electrons | Background Corrected Count | Page 3 |
| *alpha* | Page 2 | 0.028125 sec | Step Accumulation Time | Pages 6, 7, 8, 13 |
| $T1$ | Page 2 | electrons/(cm$^2$ sec sr eV) | 1-count Differential Number Flux Threshold | Pages 3, 9, 10, 13, 14 |
| $D$ | Page 3 | electrons | Average Standard Deviation | |
| $SD$ | Page 3 | electrons/sec | Background Standard Deviation | Pages 10, 11, 13 |
| *sigma* | Page 3 | Multiple Units | Standard Deviation | |
| $ET$ | Page 6 | eV | Energy Threshold | Pages 7, 10, 11, 12, 13 |
| *beta* | Page 6 | 0.003125 sec | Latency | |
| $t$ | Page 6 | sec | Background Accumulation Time | Pages 7, 8, 9 |
| $S$ | Page 3 | number | Number of Spectra | Pages 7, 8, 9, 10, 11, 12, 13 |

| Symbol | First Appears | Unit | Definition | Appears Other Places |
|---|---|---|---|---|
| *Bc* | Page 7 | electrons | Background Collected Counts | Page 8 |
| *Bt* | Page 7 | electrons | Background Collected Time | Page 8 |
| *k* | Page 3 | number | index | Pages 8, 11, 12, 13 |
| *MT* | Page 10 | number | Level of Significance | |
| *Flux* | Page 9 | electrons/(cm$^2$ sec sr eV) | Maximum Differential Number Flux | Page 10 |
| *mean* | Page 10 | electrons/sec | Average Background | Pages 11, 12, 13 |
| *N* | Page 11 | number | Step Count | Pages 12, 13 |
| *count* | Page 10 | electrons | Total Selected Count | Pages 11. 12, 13 |
| $\sigma^2$ | Page 11 | [electrons/sec]$^2$ | Variance | Pages 12, 13 |
| *mean2* | Page 12 | [electrons]$^2$ | Square Average Count | Page 13 |
| *DNF* | Page 13 | electrons/(cm$^2$ sec sr eV) | Differential Number Flux | Pages 23, 24 |
| *A* | Page 14 | ratio | Active Area | |
| *G* | Page 14 | number | Log Geometric Factor | |
| *Z* | Page 14 | number | Log Energy | |
| *GF* | Page 14 | cm$^2$ sr | Geometric Factor | |
| *V* | Page 23 | m/s or cm/s | Electron Velocity | |
| *DEF* | Page 23 | ergs/(cm$^2$ s sr eV) or<br>Joules/(cm$^2$ s sr eV) | Differential Energy Flux | |
| *DF* | Page 24 | s$^3$/(m$^6$ sr) or<br>s$^3$/(cm$^6$ sr) | Electron Distribution Function | |
| *M* | Page 24 | g or kg | Electron Mass | |