Calculation of effective attenuation values for THEMIS SST.

The nominal value of SST attenuation is 1/64.0, so that when the attenuation is commanded, the count rate in the detectors when attenuated should be approximately 1/64 of the unattenuated count rate. The actual value of attenuation is affected by background levels, and can be much less than 1/64, as shown in Figure 1.

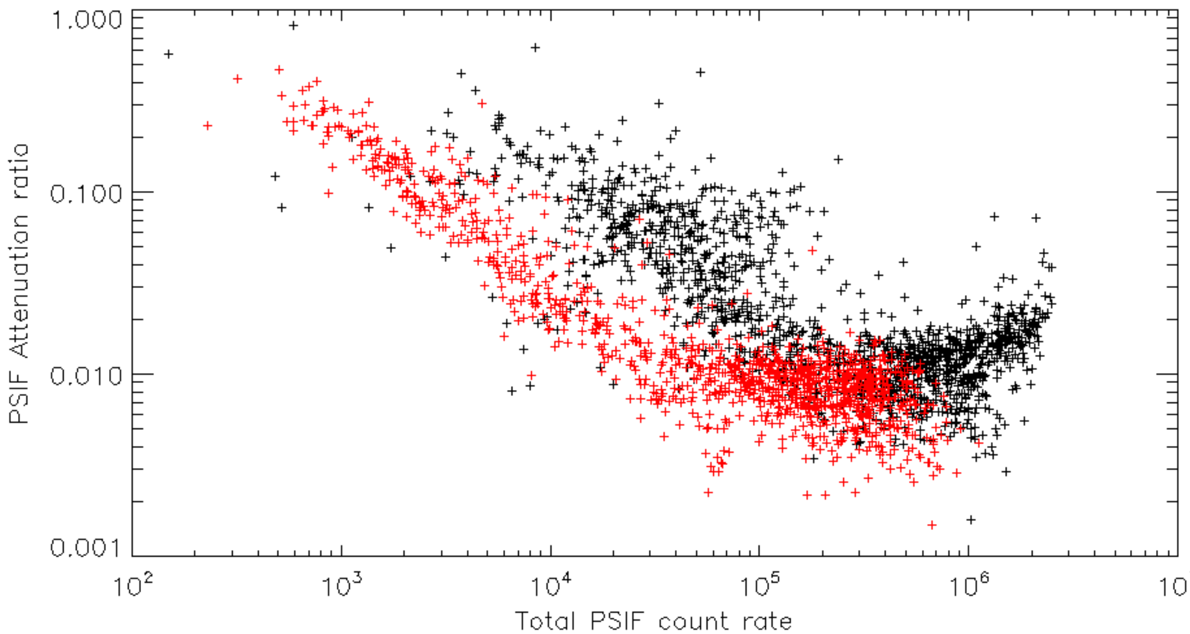

Figure 1: Effective attenuation ratio versus total PSIF (full-mode ion) count rate for attenuator transitions for THEMIS A, D, and E from 2008-01-01 to 2021-01-01. Black plus signs are out to in transitions. Red plus signs are for in to out transitions.

The effective attenuation ratio for out-in transitions can be estimated by dividing the attenuated count rate just after the transition by the count rate just prior to attenuation. For in-out transitions, estimates are obtained by dividing the count rate just before the transition by the count rate just after the transition. Attenuator motions can take as much as 30 seconds, so particularly during fast survey mode, intermediate states of partial attenuation can happen. These are ignored, and an extra 30 second buffer on each side of each attenuator transition is included in the calculation.

To test the attenuation, we created a database of every attenuator transition for the full THEMIS mission. Figure 1 shows the value of the effective attenuation ratio versus count rate for full-mode ion (PSIF) data for a sample of attenuator transitions for the inner THEMIS probes, (A, D, E) during the mission, from 2008-01-01 to 2021-03-01. Black plus signs show values for out-in transitions, and red plus signs are for in-out transitions. For this figure, the count rates have been summed over both angle and energy. The ARTEMIS probes, THEMIS B and C, are not included in this sample; for those probes, the attenuator is commanded in and out every day, and there is no effective attenuation because there are only background counts.

Since the count rate may be variable between measurements, only transitions for which the count rate on both sides where the count rate is slowly varying is counted. We define 'slowly-varying' as count rate varying less than 25% over the 30 second periods immediately before and after the ratio measurements.

The actual attenuation ratio is influenced by background level, which will reduce the effective attenuation, since background counts are not attenuated. At any given count rate, the ratio varies by more than an order of magnitude. It is clear from the plot that the relative background rate is higher (and the effective attenuation is lower) for out-in transitions than for in-out transitions, especially in the count rate range less than 1.0e5 cps. For low rates, less than 1000 cps, the attenuation ratio is greater than 0.1, reflecting the effect of a high background to incident count rate. For moderately high rates, between 1.0e5 and 1.0e6, the ratio is at a minimum value, reflecting relatively low background. The median value of the ratio for the out-in transitions in the 1e5 t o 1e6 range is 1/88, and for the in-out transitions the median rate is 1/125. So for minimal background levels, it is clear that the effective attenuaton ratio is less than 1/64, and that attenuation can be as much as twice as effective as originally expected. For the highest rates greater than 1.0e6, which almost exclusively happens for out-in transitions, the effective attenuation ratio increases, reflecting the higher background caused by intense particle events.

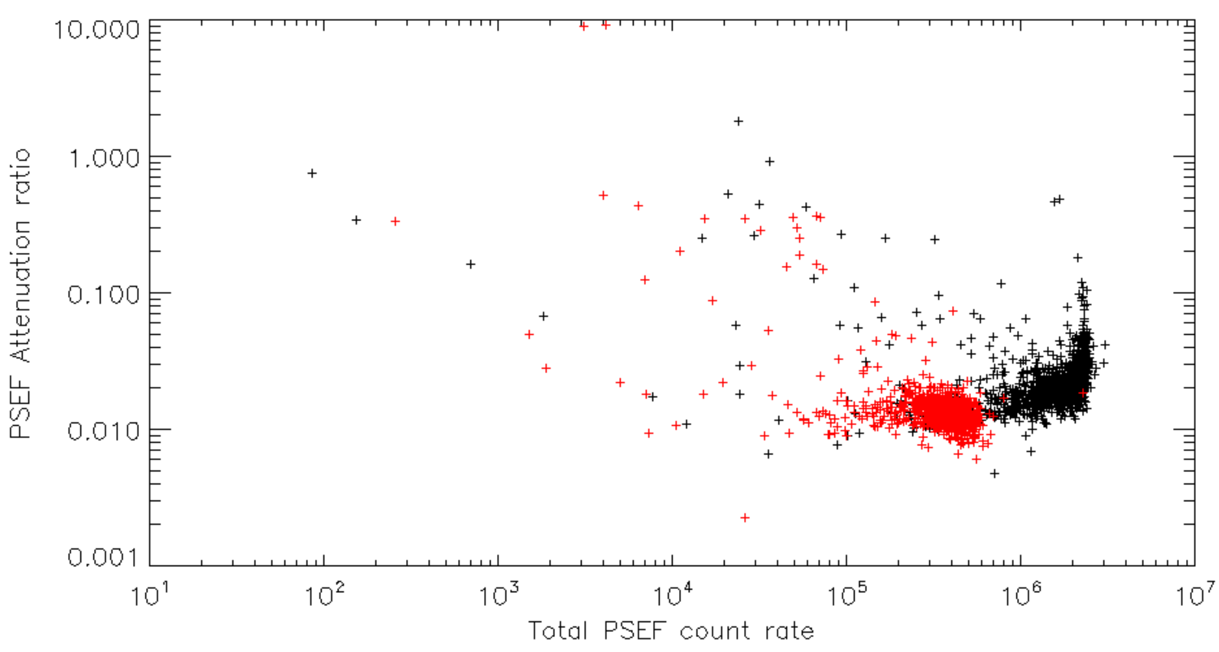

Figure 2: Effective attenuation ratio versus total PSEF (full-mode electron) count rate for attenuator transitions for THEMIS A, D, and E from 2008-01-01 to 2021-01-01. Black plus signs are out to in transitions. Red plus signs are for in to out transitions.

Figure 2 shows the same plot for electron full-mode (PSEF) data. For electrons, the attenuation is less effective than for ions; for the relatively high count rates between 1e5 and 1e6 cps, the attenuation ratios are 1/66 for out-in transitions and 1/76 for in-out transitions.

The effective attenuation ratio is a function of energy. Figure 3 shows the ratio for out-in transitions in the lowest energy channel (69keV) as black plus signs, in a middle energy channel (183 keV) as blue plus signs and a high energy channel (1171 keV) as red plus signs. For higher energies, count rates are typically lower, and the relative background level is higher, resulting in less effective attenuation. Quantization in the attenuated count rate can be seen for lower unattenuated count rates. Intervals for which the attenuated rate is zero are not shown, so the lowest value of attenuation ratio at a given rate is that for which there is only one count left. This is denoted by a dashed line on the plot. Since there is a definite energy effect, any correction that is created should be a function of energy.

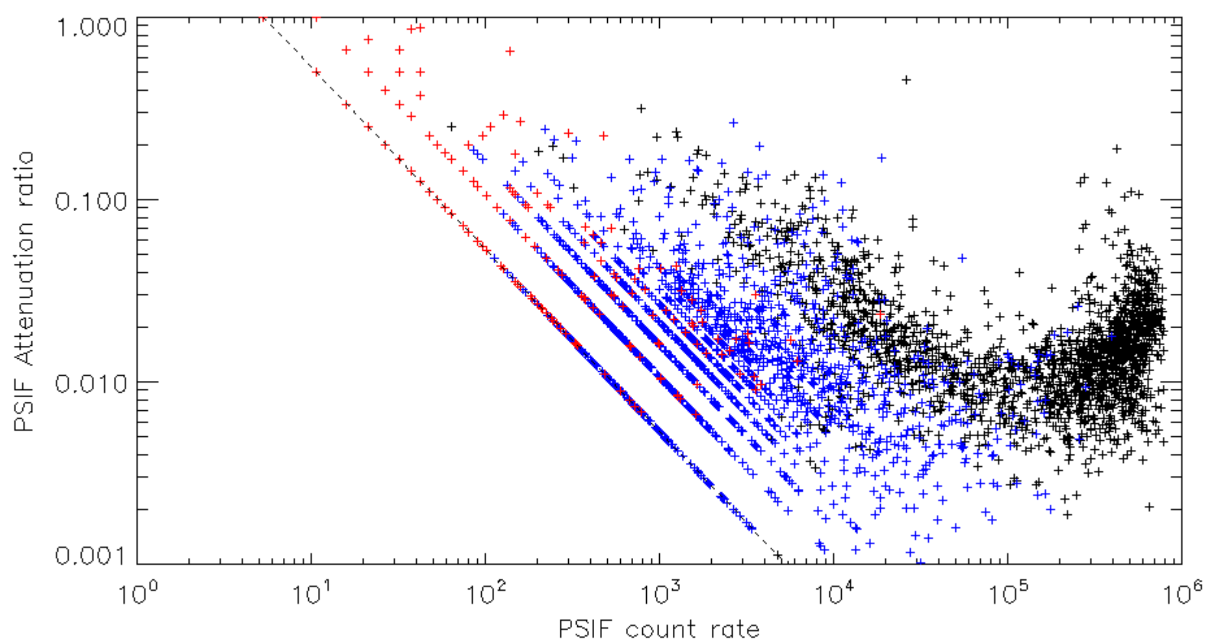

Figure 3: Effective attenuation ratio for out-in transitions versus PSIF (full-mode ion) count rate for different energies. The lowest energy channel (69keV) is shown as black plus signs, a middle range energy channel (183 keV) is shown as blue plus signs, and a high energy channel (1171 keV) is shown as red plus signs.

As mentioned earlier, the attenuation ratio is smaller for in-out transitions than for out-in transitions. This is illustrated in Figure 4, which plots the ratio for in-out transitions versus the out-in transition for each attenuator episode. Most transitions are below the blue line, which denotes equality. This will also be accounted for in the correction process.

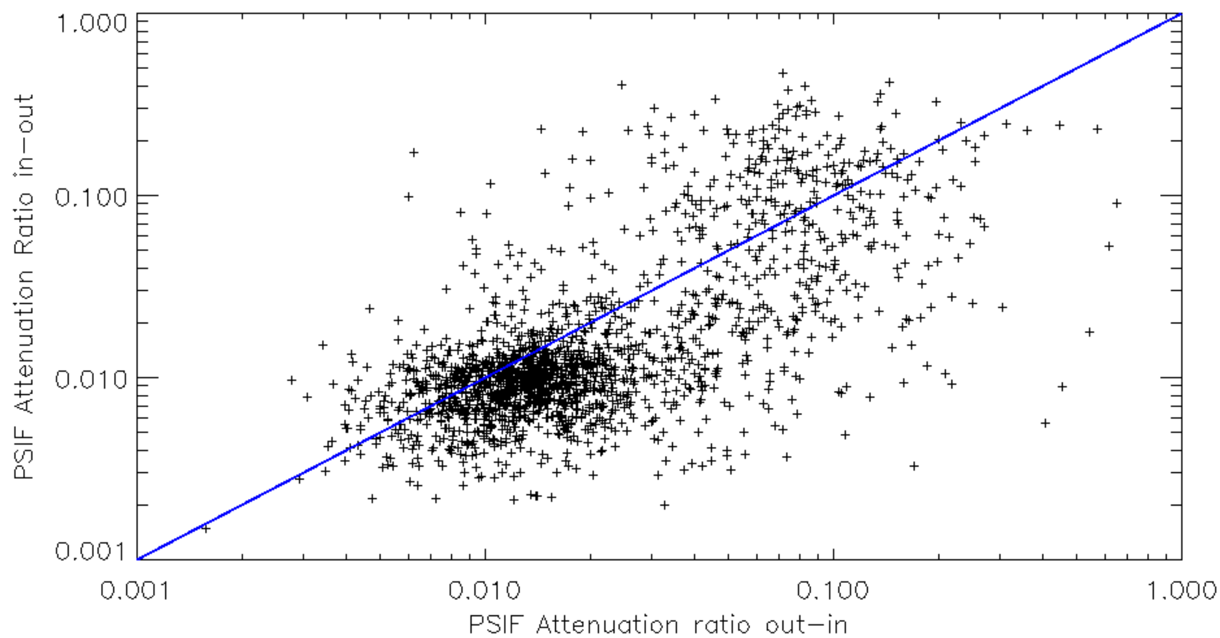

Figure 4: Attenuation ratio for in-out transitions versus out-in transitions.

Attenuation correction using THM_SST_ATT_CORRECT.PRO

The correction process, contained in the IDL program THM_SST_ATT_CORRECT.PRO, calculates an attenuation value for each attenuator episode in the input time range, and interpolates the value between transitions. This is done for each energy band separately. Only PSIF and PSEF (full-mode ion and electron) data are used in the calculation. The effective attenuation values are stored in tplot variables called "th?_psif_ratio_var" and "th?_psef_ratio_var". E.g.,

thm_sst_att_correct, 'a', '2010-04-01'

Figure 5 shows a plot of the ratio_var variables for probe A, and date 2010-04-01. Different colored lines, denote the different energy channels. For times when both attenuators are not in, the value is 1.0. For times with attenuators in, but with only one transition (i.e., at the start and end of the day), the value is an energy-independent measure based on a fit to the values of ratio versus attenuated count rate, which will be discussed below. This is a 'last-chance' value, and we would rather not have to resort to it. To avoid this, there is a keyword. The /auto_extend keyword, if set, will extend that calculation for as many as 7 days before and after the input date.

thm_sst_att_correct, 'a', '2010-04-01', dur = 1, /auto_extend

(Duration needs to be 1 day, for this option to be applied, but since the default value of the duration keyword is 1, the auto_extend is applied even if dur = 1 is not explicitly set.)

thm_sst_att_correct, 'a', '2010-04-01', /auto_extend

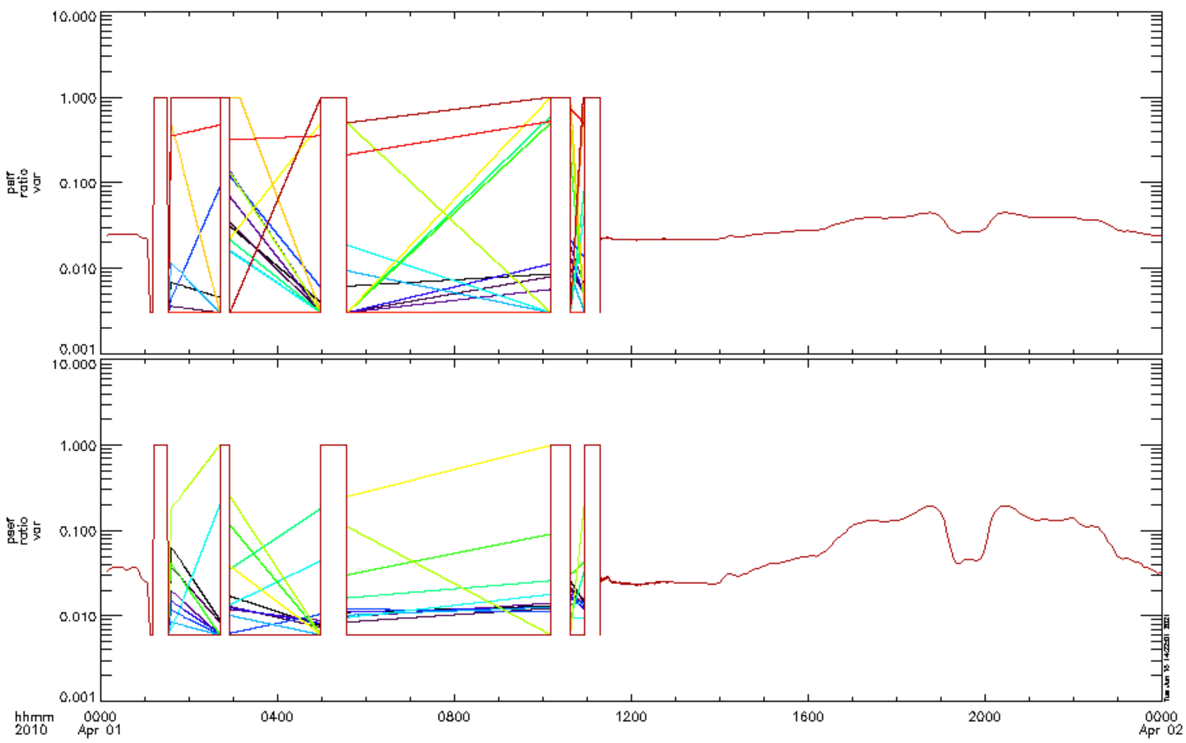

Figure 5: The effective attenuation variables, “tha_psif_ratio_var” and “tha_psef_ratio_var” for THEMIS A, 2010-04-01, a date with multiple attenuation episodes. The different colored lines are for different energy bands.Here the /auto_extend option is not used, so the corrections at the start and end of the day are independent.

For this date, the time range is extended for 1 day in both directions. Figure 6 shows the ratio_var variables when the extension is used. It can be difficult to tell what happens at each energy; Figure 7 shows the Ion ratio using three energy channels. The ratio for the lowest energy channel (69keV) is black, a middle energy channel (183 keV) is blue and a high energy channel (1171 keV) is red.

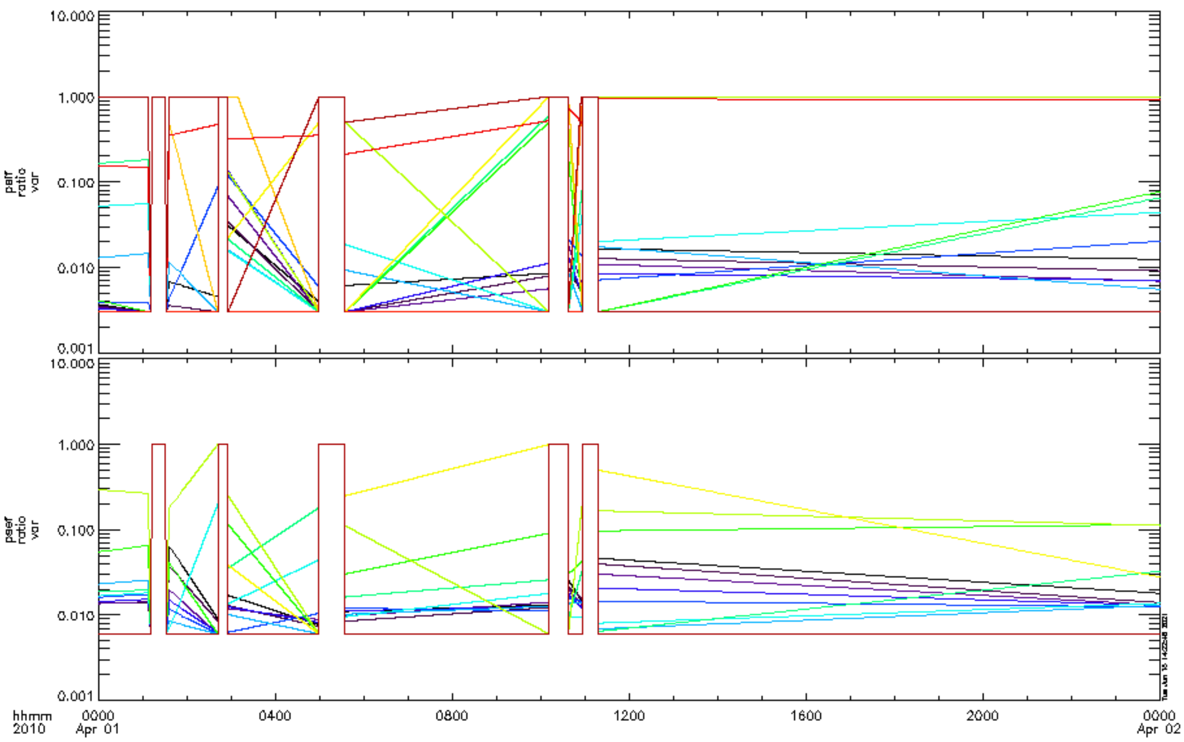

Figure 6: The ratio_var variables for THEMIS A, 2010-04-01 obtained using the /auto_extend keyword.

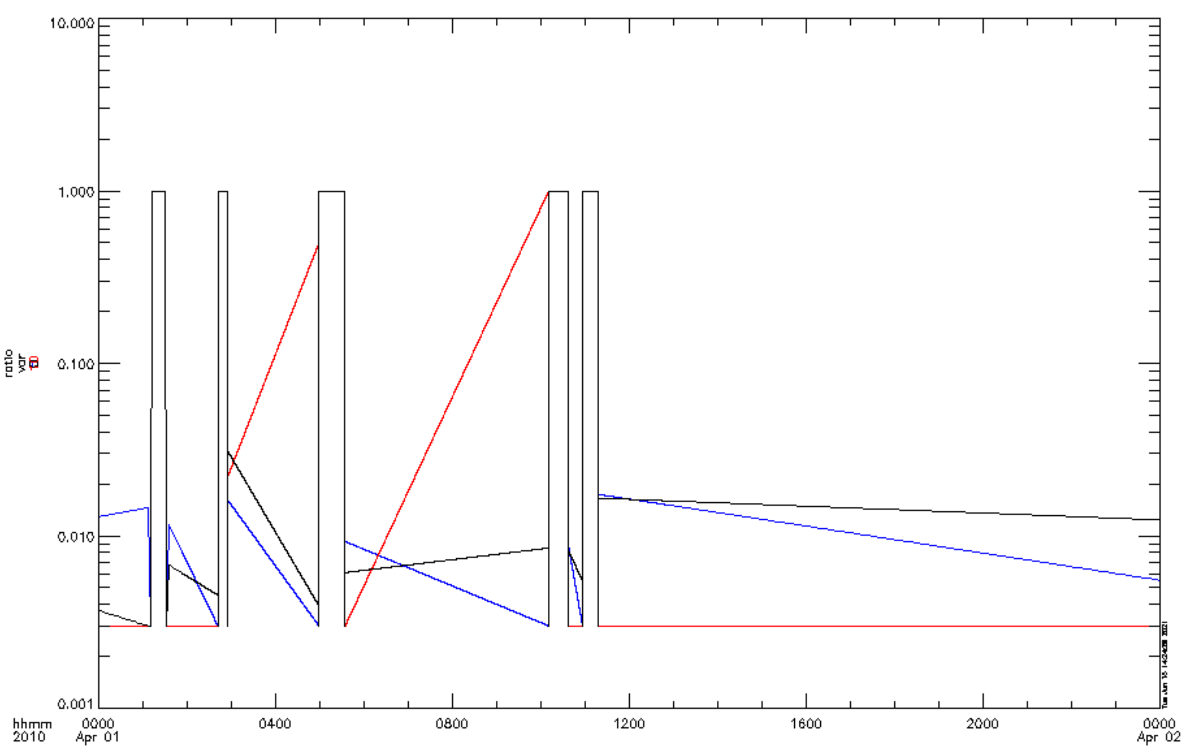

Figure 7: The psif_ratio_var variable for 69 keV (black), 183 keV (blue), 1171 keV (red)

Applying the correction in THM_PART_DIST2.PRO

Once the ratio_var variables are created, then the attenuation is applied in the program THM_PART_DIST2.PRO, which is used to return particle distributions, which are, in turn used to generate moments via THM_PART_PRODUCTS.PRO. If the variables do not exist, then the correction is ignored, and the default value of 1/64 is used.

Let's generate some moments, the following example for PSIF anf PSEF data is taken from the THEMIS L2 file generation program:

```
thm_sst_att_correct, 'a', '2010-04-01', /auto_extend

timespan, '2010-04-01'

probe = 'a'

thm_load_state, probe = probe, /get_support_data

thm_load_fit,probe=probe,coord='dsl'

thm_part_load,probe=probe,datatype='psif'

thm_part_load,probe=probe,datatype='psef'

thm_load_esa_pot,probe=probe

thm_load_mom, probe = probe, level = 'l1'
```

Yes, all of these different data types are needed.

```
thm_part_products,probe=probe,datatype='psif',$

outputs =['energy','moments'],tplotnames=ipsxx_names

thm_sanitize_l2_sst, probe, 'psif', ipsxx_names
```

The program THM_SANITIZE_L2_SST.PRO removes the data in the vicinity of attenuator transitions. Often spikes occur in SST moments due to incomplete attenuator motions, and inaccurate corrections.

```
thm_part_products,probe=probe,datatype='psef',$

outputs =['energy','moments'],tplotnames=epsxx_names

thm_sanitize_l2_sst, probe, 'psef', epsxx_names
```

Figure 8 shows a comparison of the new density calculation (top panel) with the current density values for L2 SST data (middle panel), also plotted with the values of the attenuator state, for the time range on 2010-04-01 from 04:00 to 12:00. Close examination of the density plots show large discontinuities in the original L2 density associated with attenuator state changes. These were due to the assumption that the attenuation ratio was 1/64, when in reality the value is smaller, as shown in Figures 6 and 7. These have been corrected, and hopefully the new density values are more realistic. Figure 9 shows the same plot for electron data. In this case there were not as severe discontinuities in the original L2 data, because the corrected attenuation ratio for electrons is closer to the nominal value of 1/64, but there was originally an awkward dip in density around 4:59 that has been corrected.

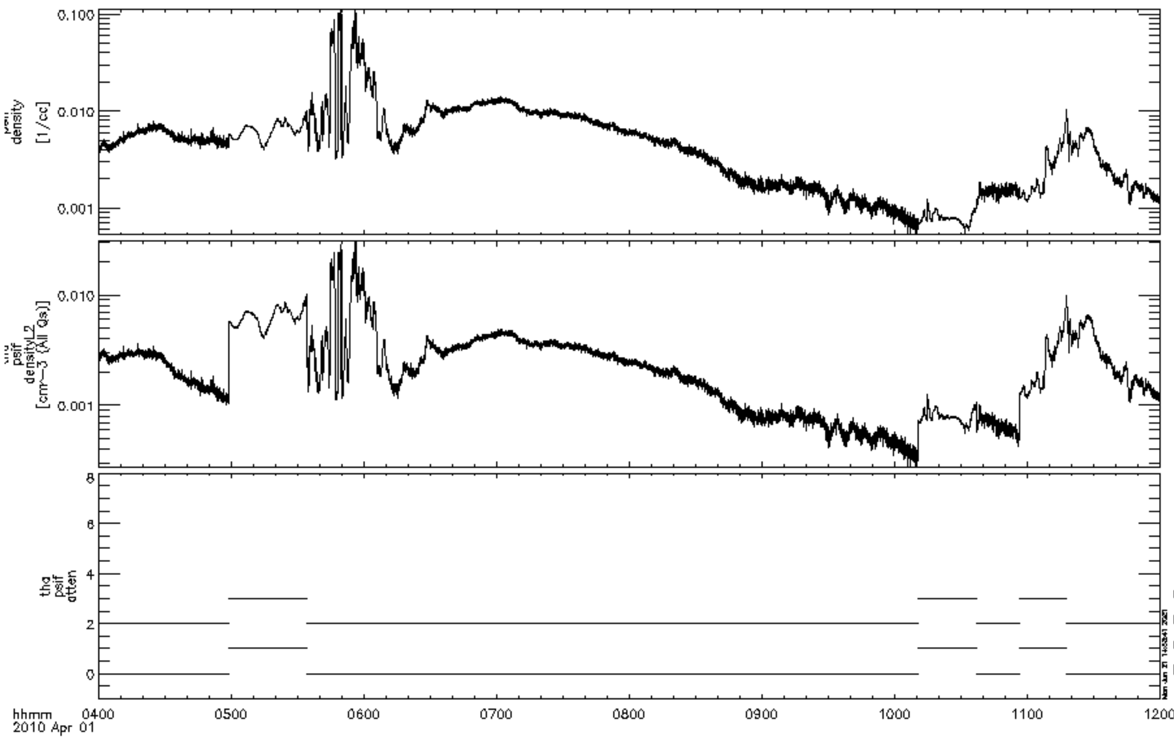

Figure 8: Top: PSIF (Ion full-mode) density with new attenuation correction, for THEMIS A, 2010-04-01, 04:00 to 12:00 UT. Middle: Current (as of June 2021) L2 density. Bottom: Attenuator state variable, values 0 and 2 are attenuators in, 1 and 3 are attenuators out.

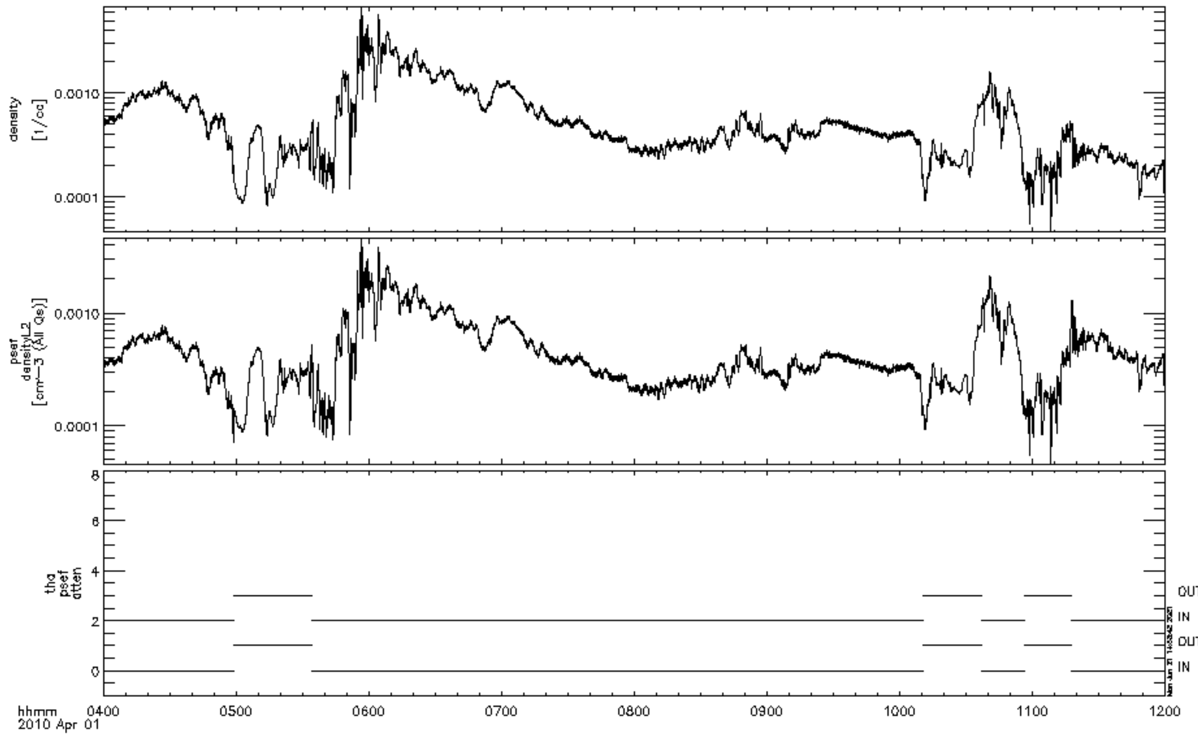

Figure 9: Top: PSEF (Electron full-mode) density with new attenuation correction for THEMIS A, 2010-04-01, 04:00 to 12:00. Middle: Current (as of June 2021) L2 density. Bottom: Attenuator state variable, values 0 and 2 are attenuators in, 1 and 3 are attenuators out.

Correction example for overcorrected attenuation

So far, we have only shown an example where the nominal attenuation ratio of 1/64 is too large. There are also many cases for which, due to high background levels, the value of 1/64 is too small, and the nominal correction overcorrects for attenuation. This is shown for THEMIS C, on 2012-03-07, in Figure 10, which plots PSIF density using the new corrections, PSIF density from the original L2 file, and the attenuator states. In this case, the attenuation ratio is greater than 0.10 for all energies, and, the original L2 correction gives the large jump in density at the transition. Figure 11 shows the effect of the new correction on the energy flux variable; here the top panel shows the new corrected energy flux, while the middle panel shows the old L2 energy flux. Figures 12 and 13 show the same plots for electron density and energy flux.

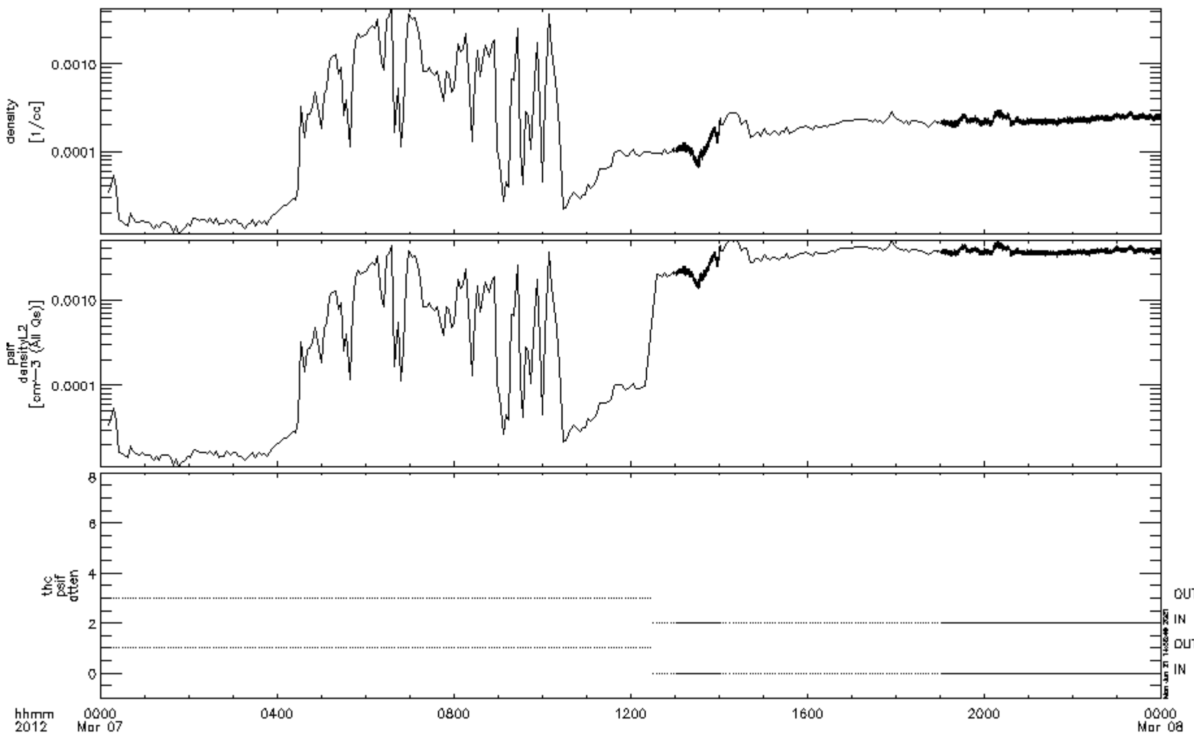

Figure 10: Top: PSIF (Ion full-mode) density with new attenuation correction for THEMIS C, 2012-03-07. Middle: Current (as of June 2021) L2 density. Bottom: Attenuator state variable, values 0 and 2 are attenuators in, 1 and 3 are attenuators out.

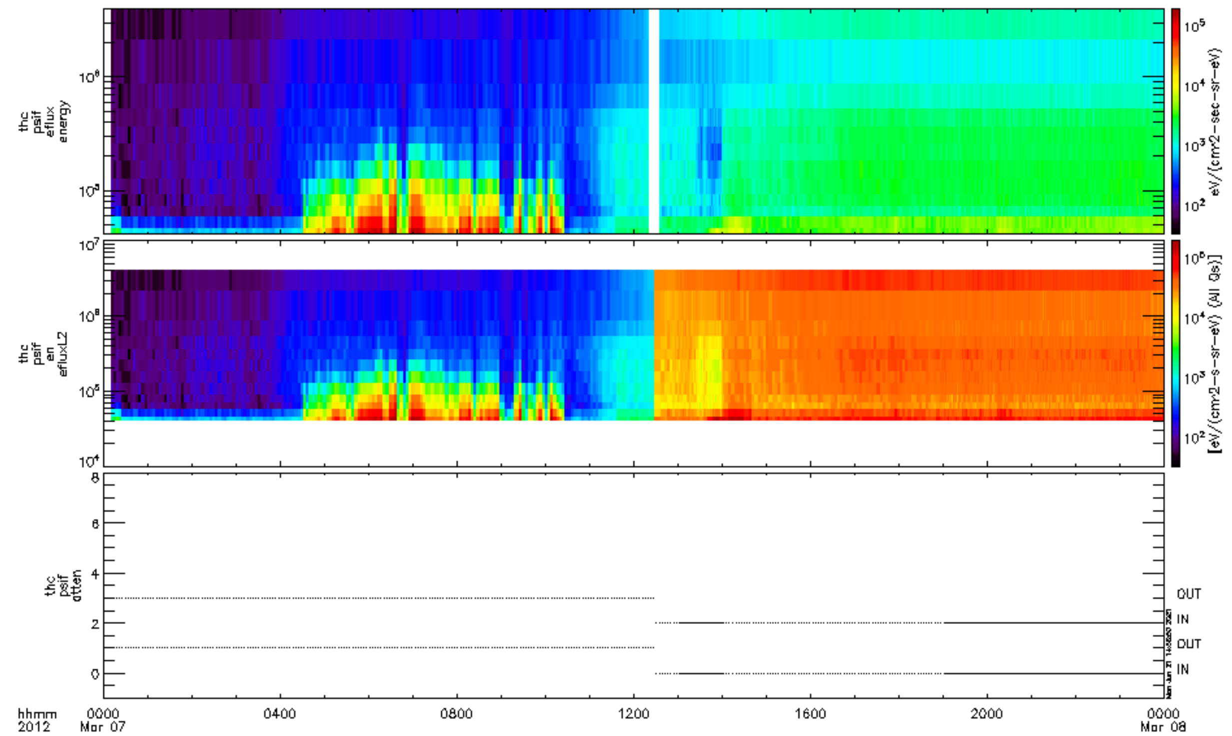

Figure 11: Top: PSIF (Ion full-mode) energy flux with new attenuation correction for THEMIS C, 2012-03-07. Middle: Current (as of June 2021) L2 energy flux. Bottom: Attenuator state variable, values 0 and 2 are attenuators in, 1 and 3 are attenuators out.

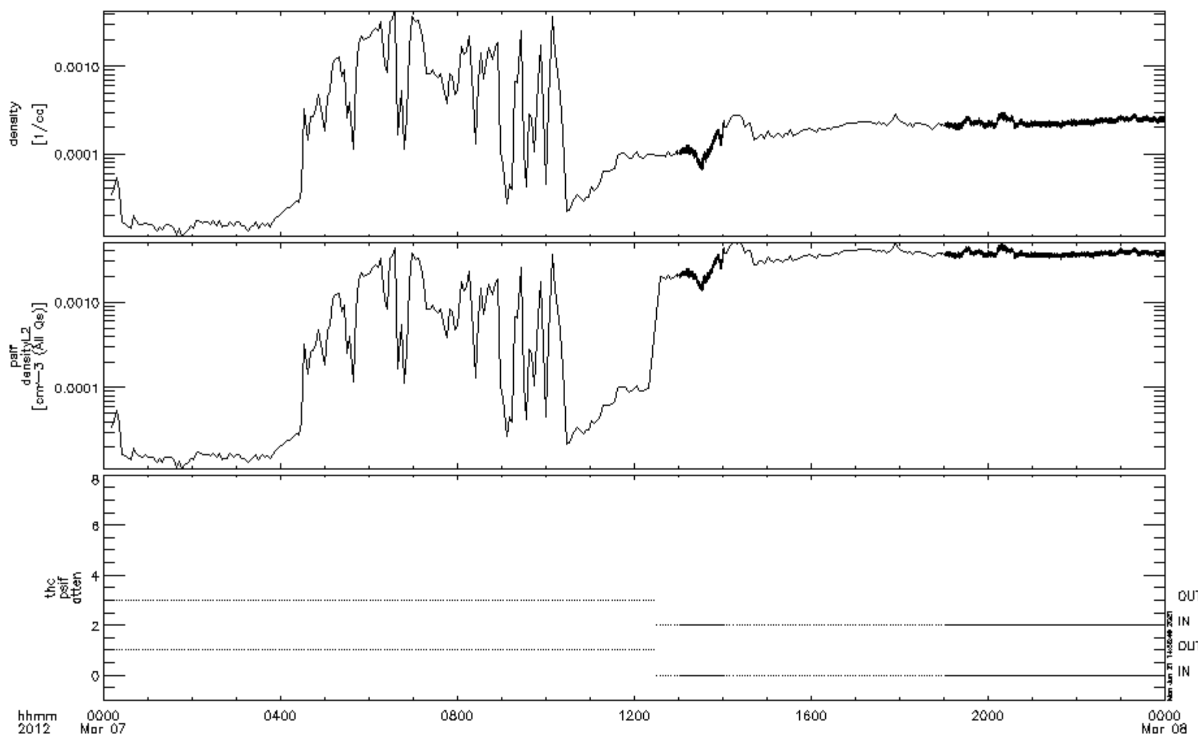

Figure 12: Top: PSEF (Electron full-mode) density with new attenuation correction for THEMIS C, 2012-03-07. Middle: Current (as of June 2021) L2 density. Bottom: Attenuator state variable, values 0 and 2 are attenuators in, 1 and 3 are attenuators out.

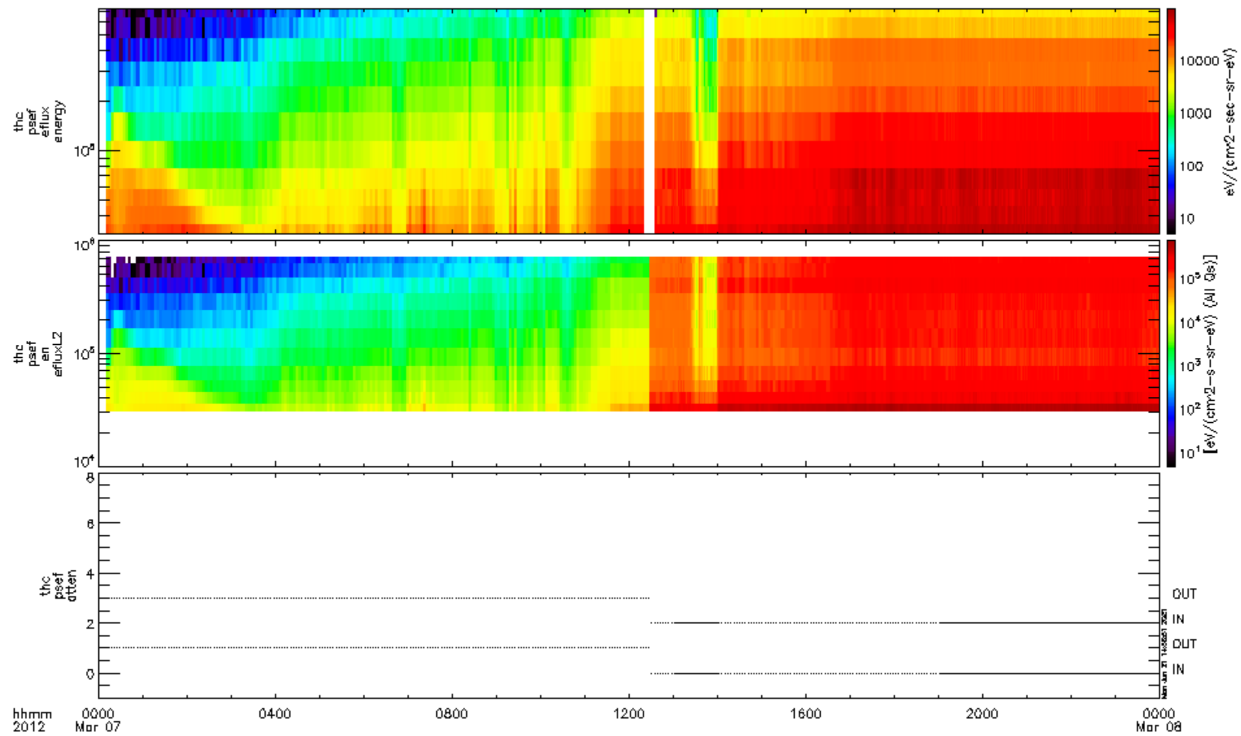

Figure 13: Top: PSEF (Electron full-mode) energy flux with new attenuation correction for THEMIS C, 2012-03-07. Middle: Current (as of June 2021) L2 energy flux. Bottom: Attenuator state variable, values 0 and 2 are attenuators in, 1 and 3 are attenuators out.

Correction for times with no available transitions:

The program THM_SST_ATT_CORRECT only will look for transitions for 7 days before and after the input date. If the attenuators are in for a longer time period the effective attenuation is estimated from the attenuated count rate. This estimation is not energy dependent, so this is not as useful an approximation. Figure 14 is a plot of the log of the effective attenuation ratio versus log of attenuated counts. The yellow line is a linear fit with two breaks that is fit to the median values of the attenuation ratio. This fit is used when there is no pair of attenuation transitions available for interpolation. Figure

15 shows the same fit for electron data.

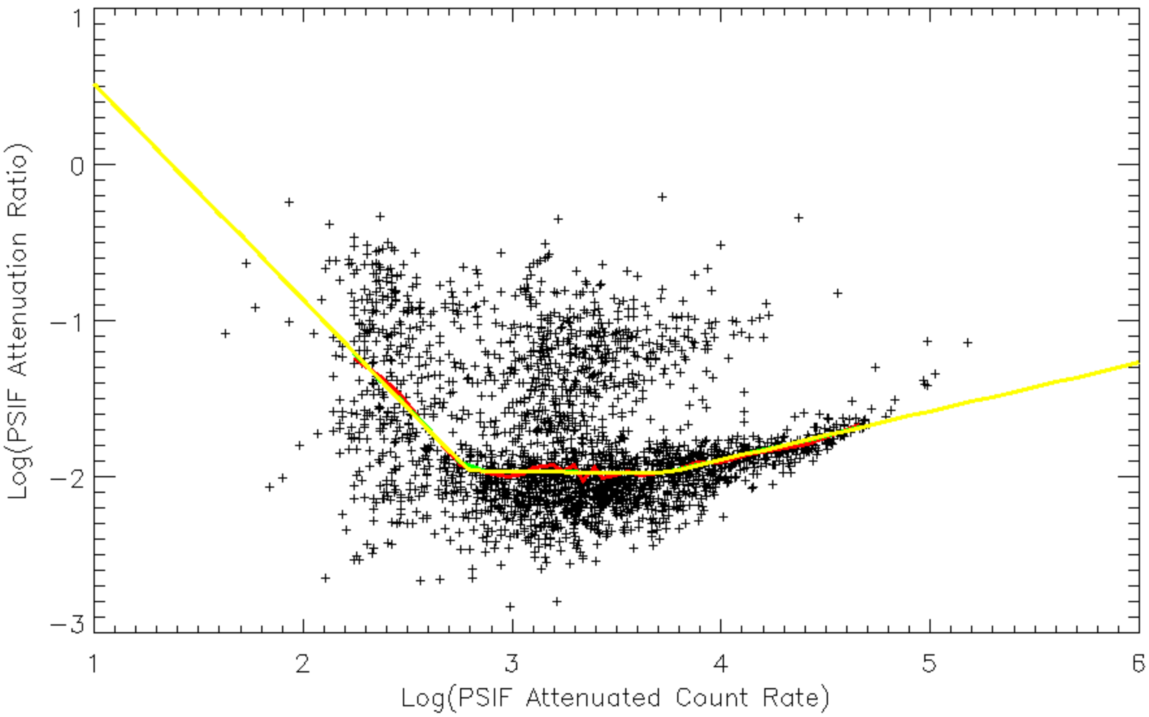

Figure 14: Effective attenuation ratio versus total PSIF (full-mode ion) *attenuated* count rate for attenuator transitions for THEMIS A, D, and E from 2008-01-01 to 2021-01-01. Both in-out and out-in transitions are included. The yellow line is a fit to the median values of the data sample, and is used for the correction.

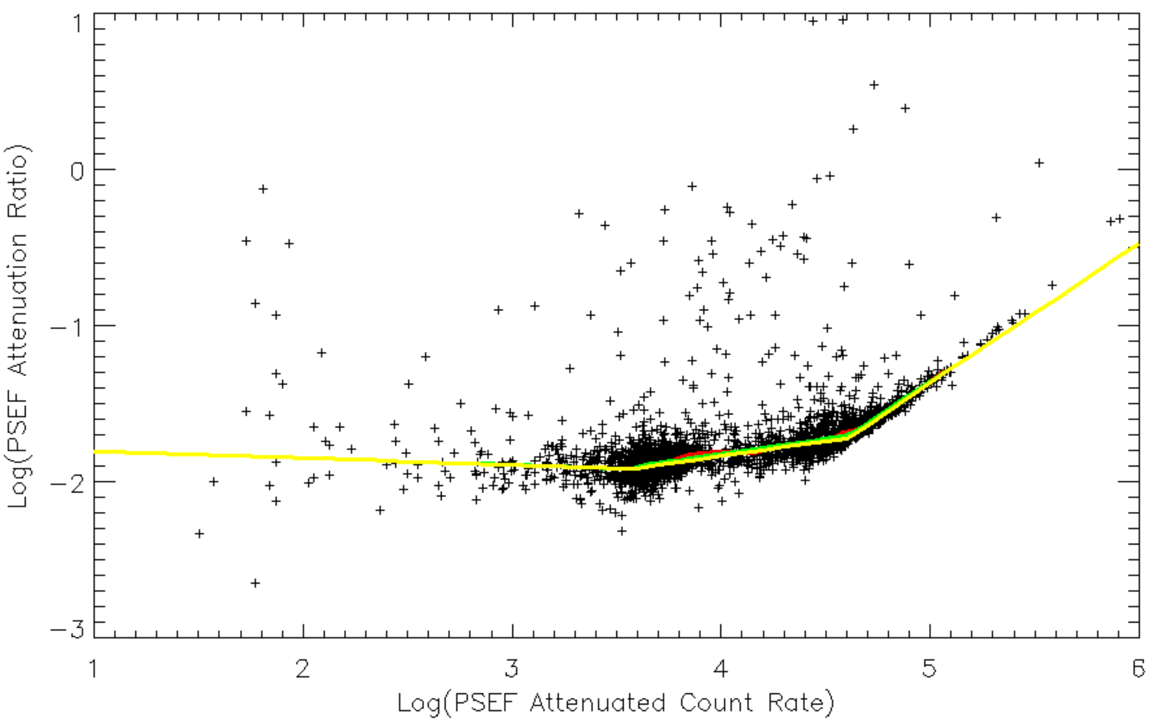

Figure 14: Effective attenuation ratio versus total PSEF (full-mode electron) *attenuated* count rate for attenuator transitions for THEMIS A, D, and E from 2008-01-01 to 2021-01-01. Both in-out and out-in transitions are included. The yellow line is a fit to the median values of the data sample, and is used for the correction.