# Explaining the HKP/EVT counts disparity

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**Abstract**

In a previous note I described the inconsistency observed between the photon count rate as recorded in the housekeeping (HKP) data and that recorded in the corresponding science (EVT) data. It was not clear at that point whether USA data was being under-reported in the EVT data or over-reported by the HKP data. It now appears that most of the "excess" counts recorded in the HKP data are not photons and should therefore not be counted as science data. It is safe to assume that USA is not losing significant amounts of science data, other than what is expected due to dead-time effects.

## Introduction

In my last note, I attempted to constrain the problem by looking at how it manifested itself in different circumstances. The most salient feature of the problem was that it seemed to be much worse (relatively speaking) when pointing off source than when pointing on source. Apparently, we were losing a larger fraction of photons coming from the background than photons coming from the source. We also noticed that the problem was worse for dim sources (such as Cas_A) than for bright ones (such as the Crab). Paradoxically, however, the problem seemed to get worse with increasing rate. These two somewhat contradictory observations can be explained if the disparity is treated not as one problem, but rather a combination of two different effects.

The first (and biggest) effect will be explained as soft electrons creeping into the HKP data (but not the EVT data). This "excess" would be roughly a constant number of counts, depending on the background environment. This effect is independent of the rate of the source we are observing and will therefore represent a much larger fraction of a low rate (such as Cas_A or even blank sky) than of a high rate.

The second (and much smaller) effect can be explained if we can show that the HKP data somehow has a shorter dead-time than the EVT data. This effect is source-dependent, and manifests itself in the form of "missing" events in the science data. These are "real" photons that are being reported by the HKP and not by the EVT data. However, this represents a very small fraction which only becomes significant at very high rates. Moreover, it is not a surprise that we are missing these events (given that the USA dead-time is what was anticipated); rather, it is a surprise that these events are showing up in the HKP data.

To illustrate how we have arrived at this conclusion I will show raster scans of several sources, showing how the problem varies as USA moves onto the source and then sweeps intermittently on and off the source.

## Cas_A

In figure 1 we see a raster scan of Cas_A, which has a relatively low count rate. The top curve shows the lightcurve produced from HKP data and the lower curve is obtained from the EVT data. In figure 2 we have subtracted the EVT count rate from the HKP count rate. We can see that there is no sign of the raster across the source. Throughout most of the observation, in fact, the difference between the HKP and EVT data is roughly constant. The increase towards the end of the observation can be correlated to an increase in the coincidence veto events (background). Given that the count rate off-source is so much lower than the count rate on-source, this constant number (HKP-EVT) represents a much larger fraction of events in the former than in the latter. More importantly, however, this indicates that this disparity we are seeing most likely does not consist of photons coming from Cas_A.

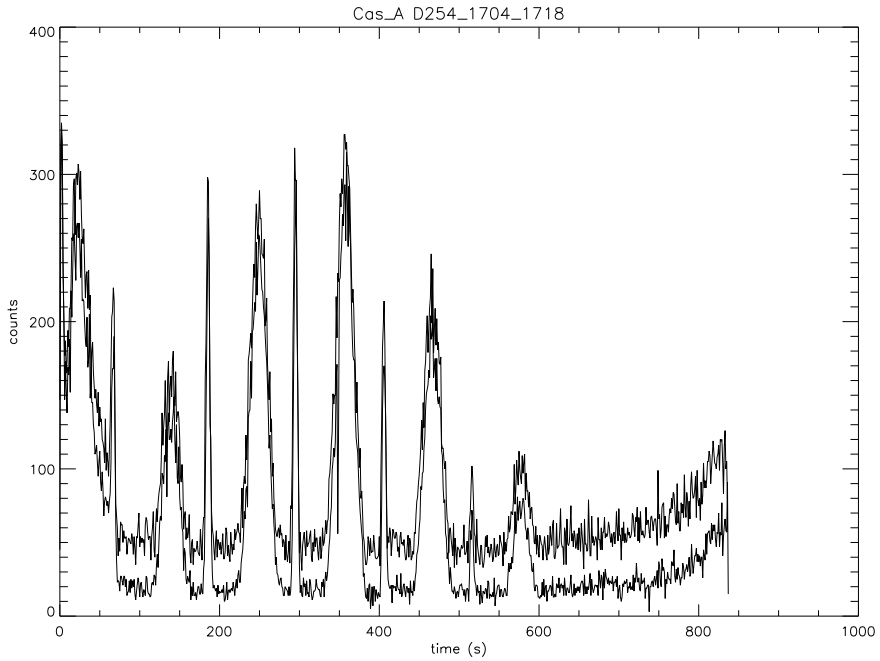


Figure 1: Cas_A Y1999_D254_1704_D254_1718: Raster Scan (HKP=top EVT=bottom)

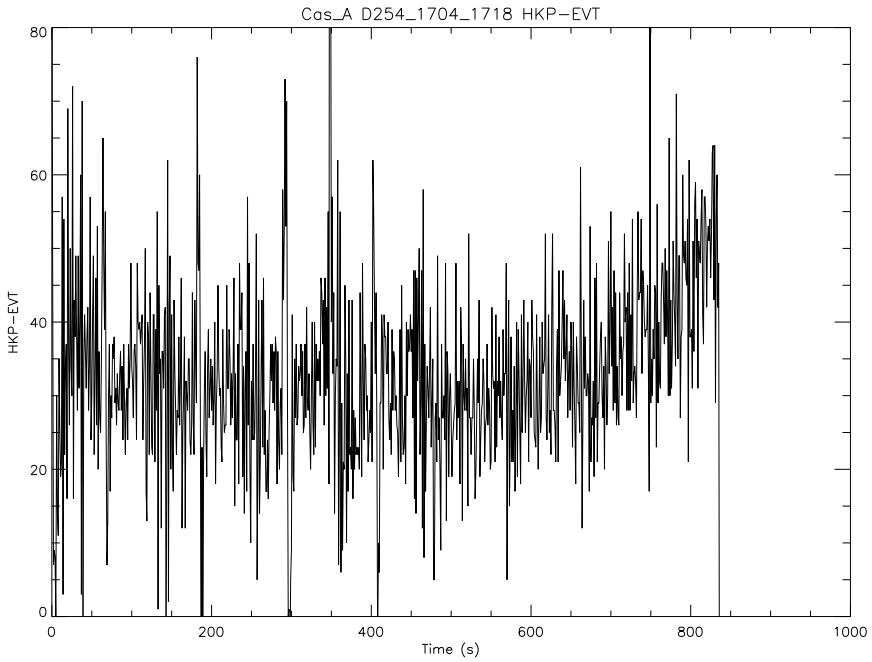


Figure 2: Cas_A Y1999_D254_1704_D254_1718: HKP - EVT

## The Crab

I next looked at raster scans of the Crab, a source which has a rate more than ten times larger than Cas_A. This should gives us an idea of how the disparity between the HKP and EVT rates behaves as the source rate increases considerably.

Figure 3 shows both the HKP and EVT lightcurves superimposed. Figure 4 shows the difference between the two lightcurves. Unlike the case of Cas_A, here we do see a sign of the raster across the source. Figure 5 is a close-up of Firgure 4, showing one sweep across the source. Two points are worth noting. First, there is a "ground-level" difference between the two lightcurves of around 30-40 counts. It should be noted that this value is of the same order as the difference we saw for Cas_A. The second point to notice is that the HKP-EVT difference increases as USA sweeps onto the source and then decreases as we sweep off. This difference is clearly correlated with the rate of the Crab in the different sweeps. In fact, in the last sweep, when the count rate is around 300 counts, this difference is imperceptible.

The large spikes that are seen in the graph result from the fact that the HKP data is taken only once every second and therefore there can be a short lag between when the HKP second begins and when the EVT second begins.

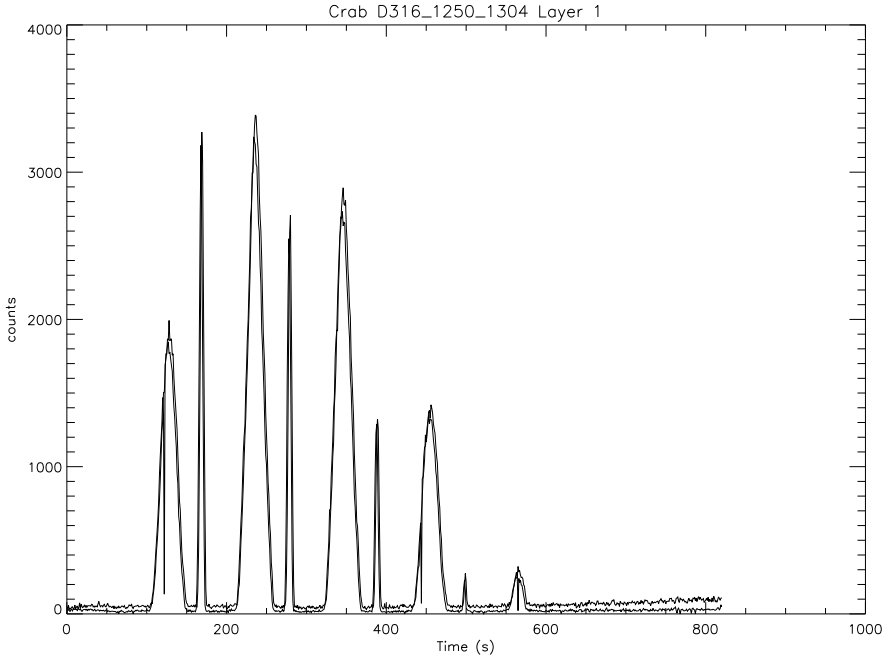


Figure 3: Crab Y1999_D316_1250_D316_1304: raster scan (HKP=top EVT=bottom)

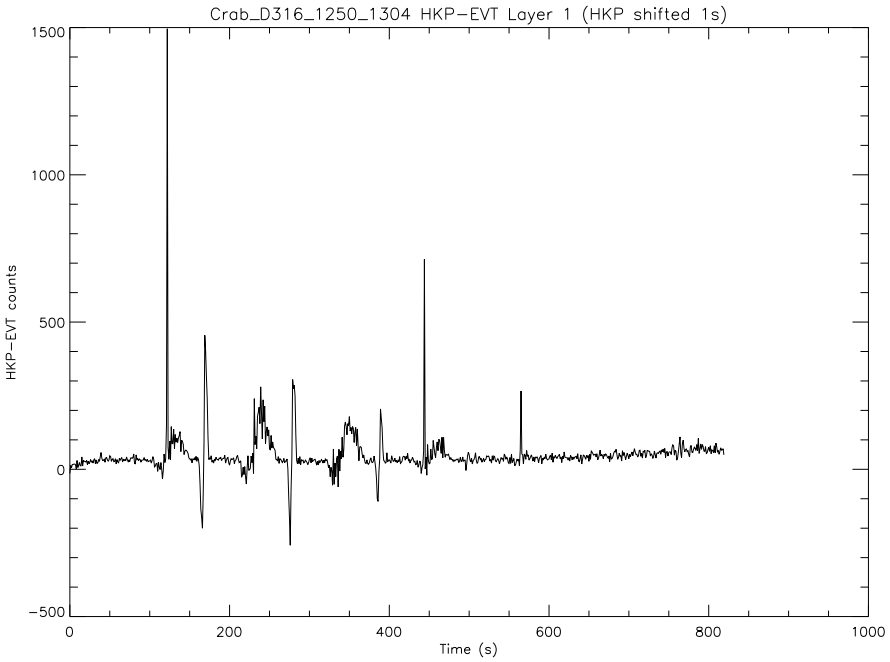


Figure 4: Crab Y1999_D316_1250_D316_1304: HKP - EVT

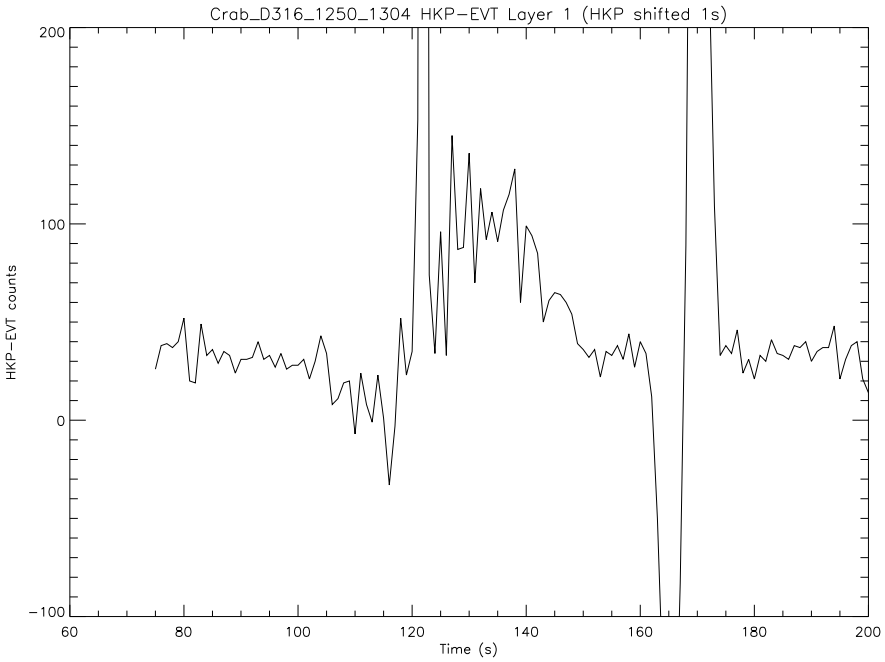


Figure 5: Crab Y1999_D316_1250_D316_1304: HKP - EVT

## Cyg_X-3 and Cyg_X-2

Next I looked at Cyg_X-3 and Cyg_X-2: two different sources, both quite variable, with rates of around 250 and 500 counts respectively. Figure 6 shows the familiar lightcurves (HKP and EVT) for Cyg_X-3. Figure 7 shows the difference between the two. I have overplotted (in dots) the (EVT) lightcurve to show where in the plot we should be expecting signs of the source. As with Cas_A, there is no sign of the source. Figure 8 shows the same as the previous figure in a slightly larger scale.

Figure 9 contains four subfigures (which I'll refer to as 1-4 starting from the top-left and going clockwise). Figure 2 shows the two (HKP and EVT lightcurves). Figure 4 shows the difference between the two. There is no sign of the raster scan, but there is a clear feature (bump?). Figure 3 shows how this feature is perfectly correlated with the total coincidence veto. To show both plots on the same scale, I have taken the HKP-EVT difference from Figure 4 and multiplied it by 15 and added 500. The curve which appears to jump in steps is the lower resolution total coincidence veto rate, which is only read once every 16 seconds. This seems to be fairly strong proof that these events that are being registered by the HKP data are actually background electrons. Incidentally, The top left figure (Figure 1) shows that this "bump" corresponds to the edge of the SAA which, as can be seen on the background maps, has an "eye-shape" sticking out as far West as -135 degrees.

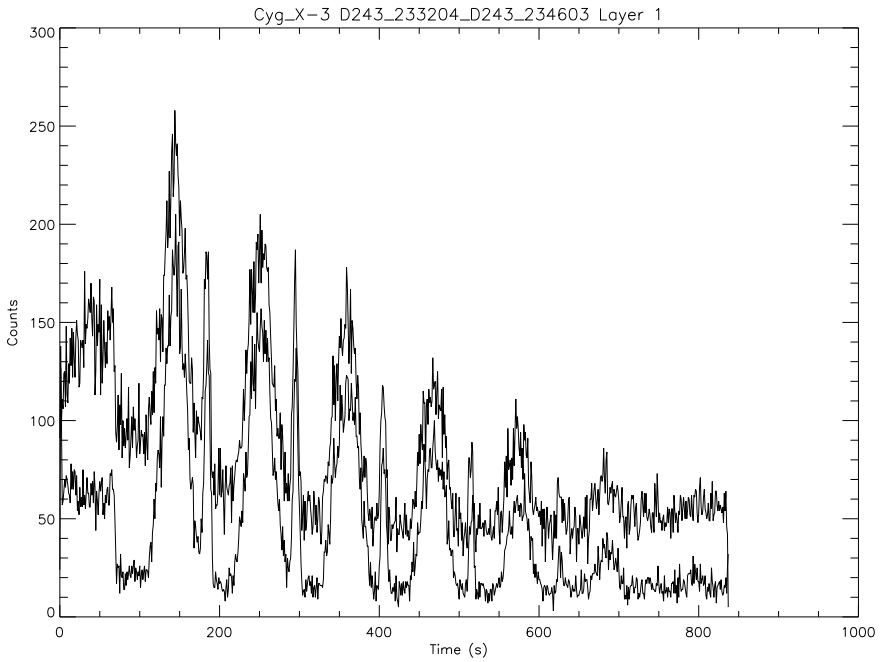


Figure 6: Cyg_X-3 Y1999_D243_2332_D243_2346: raster scan (HKP=top EVT=bottom)

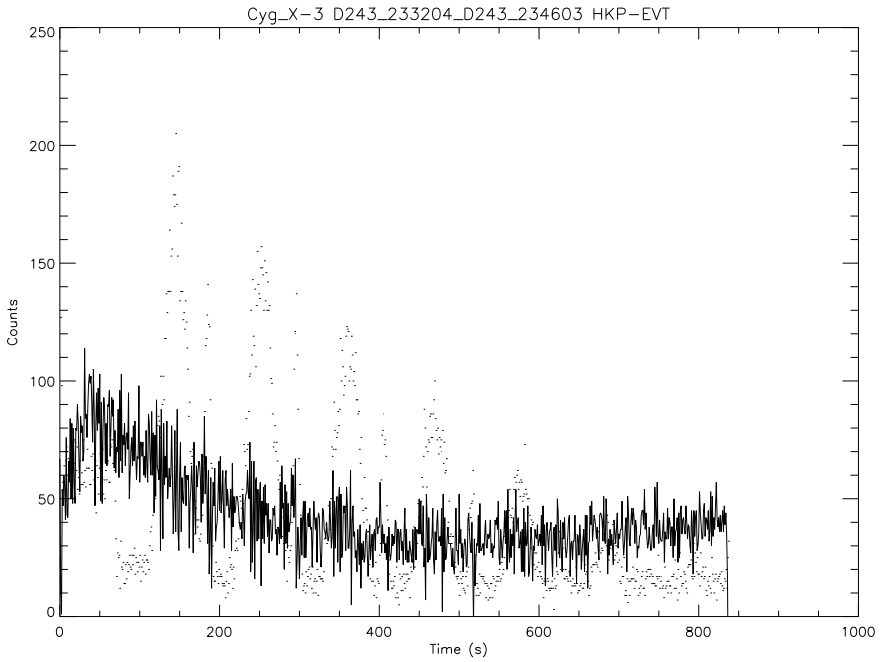


Figure 7: Cyg_X-3 Y1999_D243_2332_D243_2346: HKP - EVT

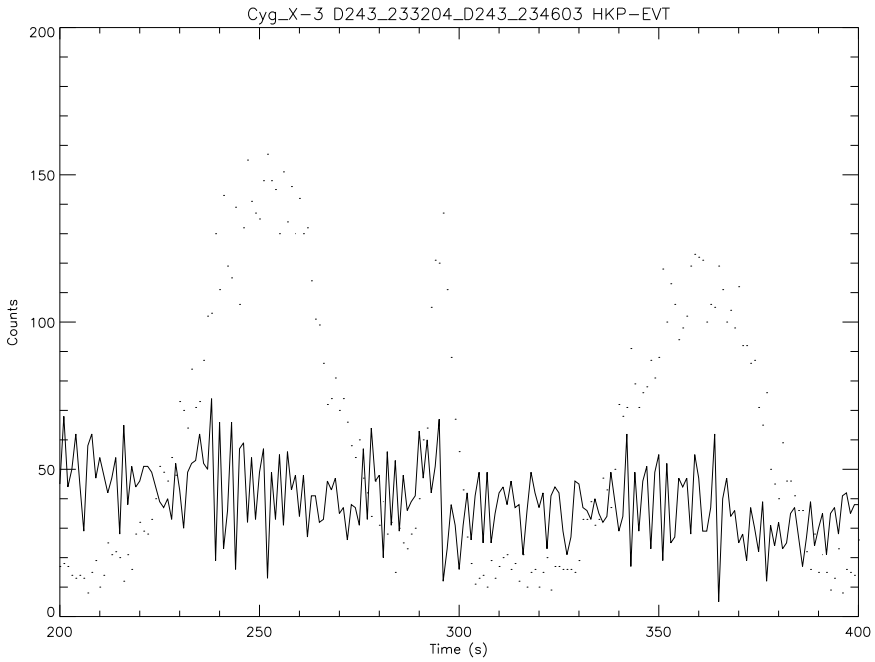


Figure 8: Cyg_X-3 Y1999_D243_2332_D243_2346: HKP - EVT

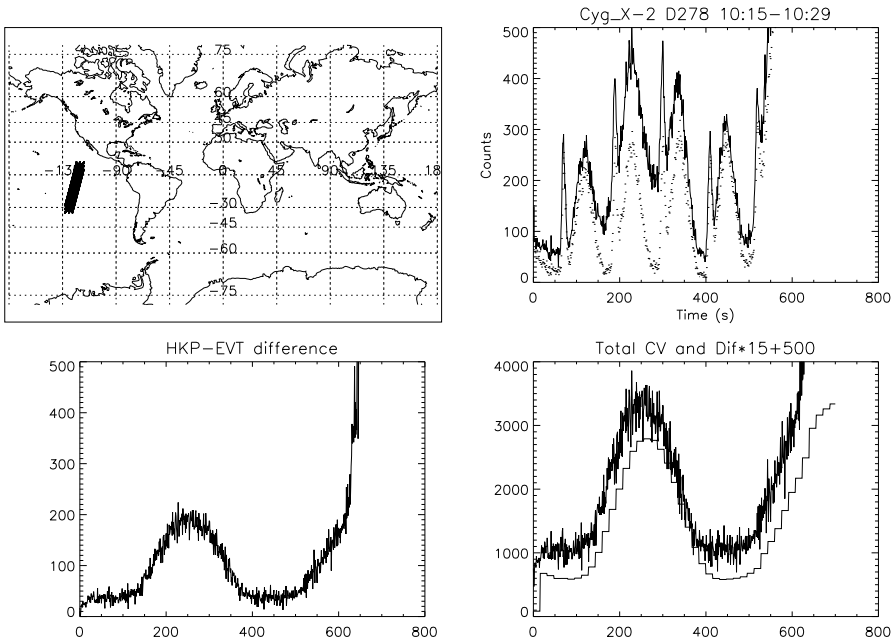


Figure 9: Cyg_X-2 Y1999_D278_1015_D278_1029: raster scan

## A (superficial) explanation of the USA electronics

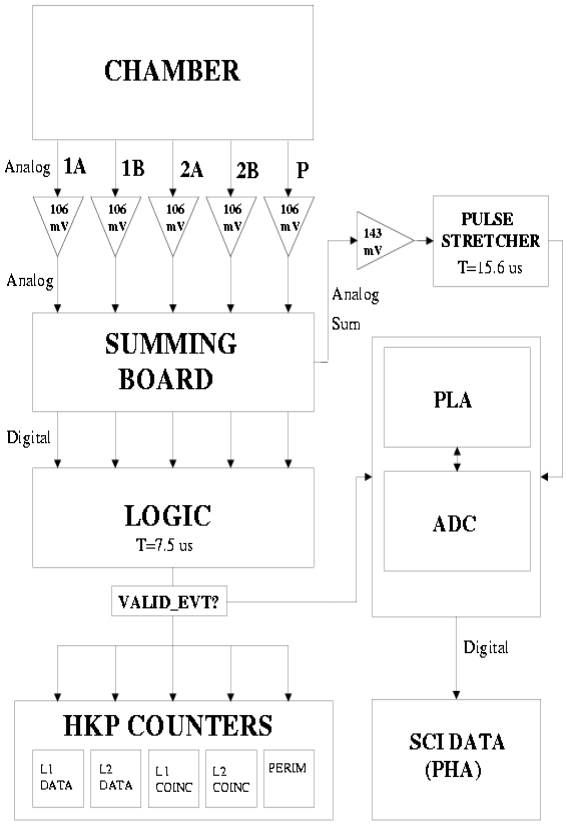


Figure 10: USA detector electronics

In figure 10 I have drawn a very simplified version of the USA electronics which will, nevertheless, hopefully illustrate where I believe the problem of the HKP/EVT disparity arises. I have arrived at this picture mainly through looking at the original circuit diagrams with Gary. There are many details which I don't understand, some of which may be relevant, which is why I recommend that people who understand the original circuit diagrams should check that the information in it is not misleading in any way.

There are five wires which carry analog signals from the proportional chamber to the electronics board. Four of the wires are woven into an array providing two layers of nine 2.8 cm square cells, each containing one anode wire running

the length of the counter. The fifth wire runs around the perimeter of the array as part of the cosmic vetoing system. The five analog signals go through their own preamplifier and discriminator (represented in figure 10 by five separate boxes labelled 1A and 1B (from layer 1), 2A and 2B (from layer 2) and P (from the perimeter). The threshold of these first discriminators is 0.106 V. The five analog signals then go into the summing board. At this point, there is an important fork in the road. The summing board outputs 5 digital signals corresponding to the 5 analog ones that went in, as well as the analog sum of these signals. The 5 digital signals go through a series of logic operations which serve to sort out whether we have a valid event or whether the event should be vetoed. The amount of time it takes the logic to process an event is 7.5 clock cycles (7.5 $\mu$s). The result of this logic is fed directly to the HKP counters which are incremented accordingly. Meanwhile, the analog sum of the five signals (1A, 1B, 2A, 2B, and P) goes its own way, through the pulse stretcher, which stretches the signal to a nominal length of 15.6 $\mu$s. This pulse stretcher has its own discriminator threshold, which happens to be 0.143 V (not 0.106 V). The pulse stretcher gives the ADC enough time to process each event. The Programmable Logic Array (PLA) performs the logic operations which (among other things) decides whether we have a valid event or not. The ADC finally outputs the science data (PHA channel).

## Conclusion

The two different discriminator thresholds (0.106V vs 0.143V) mean that there is a window (between 0.106V and 0.143 V) where photons or particles will come in, produce a signal which will register in one part of the circuit but not in the other. In my previous note I estimated the number of photons that would fall between this particular range of energies (which I estimated to lie between .24 Kev and .31 Kev) for several source energy spectra (including the background) and arrived at the conclusion that these would amount to less than 1 count per second. However, the number of (soft) electrons in this window can be several orders of magnitude larger. As we have seen from raster scans of the crab, not all the difference between the HKP and EVT data can be attributed to background electrons. Some of this difference must be, indeed, attributed to photons coming from the source which are somehow "lost" by the science data. The fraction of photons being lost, as we have seen, is quite small. In fact, for sources like Cas_A, Cyg_X-2, or Cyg_X-3 it is not even noticeable. These differences can attributed to the different dead-time experienced by the HKP counters relative to that experienced by the science data. The signals which end up incrementing the HKP counters go only through the summing board and some digital veto logic, which introduce dead-time of approximately 7.5$\mu$s. These signals never go through the pulse stretcher. On the other hand, the signal which ends up incrementing the science data counters first needs to go through the pulse strecher (which introduces a dead-time of around 15.6$\mu$s) in order to give the ADC enough time to perform its calculations and obtain (assuming the valid_evt flag is active) a PHA value for the incident photon. The following table summarises how different incident rates result in different observed rates for the two different dead-times mentioned. As can be seen, for a rate of around 500 (similar to Cas_A), this difference amounts to only 2 counts/sec. However, for a rate of 4000 (similar to the Crab), the difference is of the order of 100 counts/sec.

| Incident Rate | $\tau$=7.5 $\mu$s | $\tau$=15.6 $\mu$s | Difference |
|---|---|---|---|
| 250 | 249.5 | 249.0 | 0.5 |
| 500 | 498.1 | 496.1 | 2 |
| 750 | 745.8 | 741.3 | 4.5 |
| 1000 | 992.5 | 984.6 | 8 |
| 1500 | 1483 | 1466 | 18 |
| 2000 | 1970 | 1939 | 31 |
| 2500 | 2454 | 2406 | 48 |
| 3000 | 2934 | 2866 | 68 |
| 4000 | 3883 | 3765 | 120 |