PCA Calibration Status, RXTE User Committee, March 10, 1997

Keith Jahoda and the PCA team

1 Energy Response

Please see the poster presented at the Toronto meeting of the AAS, available from http://lheawww.gsfc.nasa.gov/users/keith/energy/response.html .

We have also made available a page which gives the user community access to the most recent matrices. The response matrix, being an analog approximation to a complex system, is subject to more and quicker changes than the digital tools (i.e. the tools that rebin and shift channels or multiply matrices). The purpose of this page is not to compete with or replace the regular GOF releases of RXTE specific software, but rather to enable those who wish the latest approximations to the response easier access. We hope that this will result in useful feedback from the community as well. The page is found at http://lheawww.gsfc.nasa.gov/users/keith/pcarmf.html .

1.1 Normalization with respect to HEXTE

Now that the HEXTE deadtime correction appears well understood (for data taken after March 1996) we can attempt to normalize the PCA and HEXTE responses. The PCA matrices are made assuming an area of $1400\,\mathrm{cm}^2$ (after accounting for collimator blockage) and Biff or Rick can provide the corresponding number for HEXTE. Joint spectral fits of the two instruments have, so far, required a free parameter to adjust the normalization between HEXTE and PCA. For PCA measurements normalized to 1, HEXTE requires a scaling of ~ 0.7. If all other features of the matrices and modelling were perfect, this implies either that the HEXTE effective area is overestimated by 30% or that the PCA area is underestimated by a similar amount. Because several efforts have been made, it is impossible to speak for everyone, but effects that have generally not been included are HEXTE pointing corrections (reduces area by a few percent), PCA deadtime (Increases area by a few percent), correction for PCA coincidences (a few percent). Use of over simplified models can also skew the relative normalizations although the HEXTE team has tried to minimize this by fitting the Crab only in the region of overlap. The relative normalization of the two instruments remains an open question.

1.2 Gain shifts at high counting rate

Users have discovered evidence of a rate dependant gain shift. The clearest evidence is the shift of a few percent in both directions in the color-color plots of ScoX1 when observed at $\sim 100,000$ good count/sec and at $\sim 60,000$ count/sec (MvdK, March 96 user committee meeting). There are at least three possible contributors to this effect:

(a) Energy dependent reflection from the collimator. The lower count rate was achieved by a $0.5°$ offset. Reflections could distort this picture. IOC data taken with the Crab nebula at a variety of off axis angles should provide adequate data to calibrate this effect. We have not yet made a systematic investigation of *reflection* effects while we are attempting to improve the *basic* response.

(b) Voltage reduction due to high rate. The high voltage supply is isolated from each anode chain by 250MΩ resistors. At high rates, the accumulated charge creates a current which flows back into the supply and creates a small voltage drop across the resistor. The result is a lower voltage, and reduced gain, at the anode. A measurement of this effect was made in the LHEA calibration facility. This effect moves everything to lower energies. This effect has been measured in the GSFC penthouse facility, but rendering the existing plot in electronic form is beyond your humble servant. Please come to the meeting! The gain shift is $\sim 2-3\%$ for rates similar to those observed for ScoX1

(c) Pulse pile up. At the highest rates, there is a non trivial chance that two events will occur on one anode within a short enough window ($\sim 1.5\mu$s) that they will be analyzed as a single event. An example is shown in figure 1 (reproduced from of Jahoda et al. SPIE 96) This effect will cause a fraction of events to be observed at an unexpectedly high channel while others are missed. This hardens the net spectrum.

We have just begun to investigate the three effects, and can give a flavor for what may come in the future. Figure 2 shows the (solid lines) the predicted ratio of gain shifted spectra of ScoX1 (Ignore the sawtooth effect on the 10% curve which represents an instability of the algorithm crossing a channel boundary. The curves were generated by taking a ScoX1 count spectrum and shifting the counts down assuming that a gain shift (prior to the ADC) is the only important effect. The key result is that the spectrum is increased in low channels and decreased in high channels. For comparison, the dotted line shows the ratio of a ScoX1 spectrum observed at a rate of 49 kHz to a similar spectrum observed at 103 kHz. (This ratio is scaled by 103/49). The effect in the lowest channels appears consistent with a gain shift. The ratio of the observed spectra at higher channels has a different behaviour than the gain shift (we need to bear in mind the possibility that we are comparing

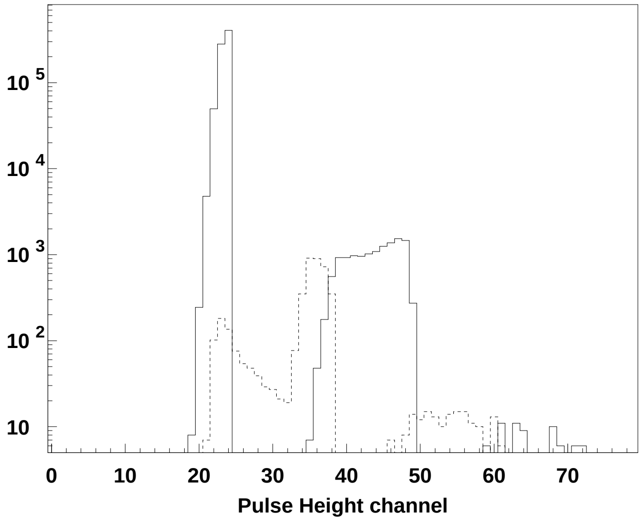

Figure 1: Pulse pile up at 8 kHz input on one anode

dissimilar spectra; the 103 and 49 kHz spectra each represent 900 seconds of data from parts of the Keith Horne observations.) This comparison will be performed with data collected in shorter intervals and with shorter separations, either with slewing data from the Horne observations (16 second resolution) or calibration data to be collected as described below (1 second resolution.)

Figure 3 shows data from the Crab observed on axis in IOC as well as observed at 1% response. The top panel shows the counts spectrum for PCU 0, first layer only for the on and off axis cases. The second panel shows the ratio of the two spectra; no background correction has been made, and this is important below channel 2 and above channel 50. The effect of reflection is that the response is increased in the lowest channels; the gradual decline above channel 15 may be related to the non subtraction of background and will be investigated further. The difference between the 103 and 49 kHz spectra in figure 2 cannot be interpretted as a collimator reflection effect, as the effect appears to have the oppostie sign.

The pileup window is pulseheight dependent, but has been measured with a typical value of 1.6μs . For typical one anode rates observed with ScoX1 of $\sim 10,000$ per sec, we expect 1.6% of the measured events to be pileup events, and have a misleadingly large pulse height. We have not yet simulated the effect on the spectrum, but will try to do so before the meeting.

We hope to have an example of the effect of pulse pile up by the user committee meeting. It is likely that we will have try to find a linear combination of gain shift, reflection, and pile-up which matches the observed behaviour.

Flight data which is potentially relevant is any data at the very highest rates (Sco X1, bursts from J1744-28, bursts from the SGR)

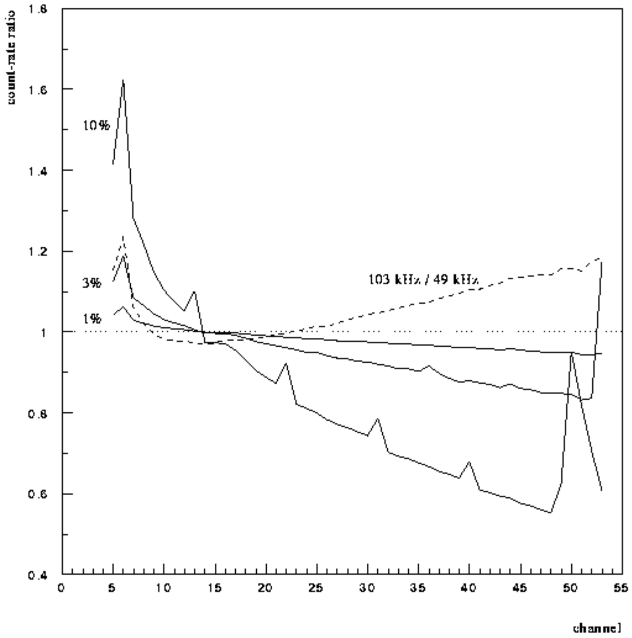

Figure 2: prediction of the relative deviation due to gain reduction

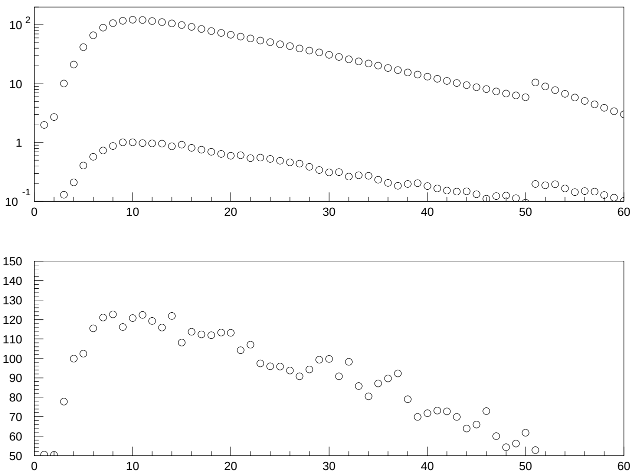

Figure 3: Crab spectra and ratio observed on axis and at about 1 degree away.

1.3 Dirty Laundry

An embarassingly large amount of effort since the last User Committee meeting has gone into resolving a counting issue. PCA data (and HEXTE) is generated with an 8 bit pulse height which naturally runs from 0-255. An early decision was made by (among others) Keith Jahoda, Ed Morgan, and Arnold Rots that there would be no effort made in any piece of RXTE specific software to do any channel shifting; i.e. the first channel would always be zero and an ADC reading of 14 would mean the 15th channel. XSPEC, however, has always counted channels from 1, and most of the FITSIO routines for writing spectral response extensions had some hard wired assumptions about channel counting. Early releases of PCA tools (up through FTOOLS 3.6) had matrices that, when interpretted by XSPEC 9.01 (or earlier) were apparently OK. A fix to XSPEC 9.02 (and later) looks for a flag that gives the index value of the first channel. Updates were required to the FITSIO routines, the matrix generator pcarmf, and several other tools that handle the matrices including rbnrmf, gcorrmf, marfrmf, and addrmf. It is our belief that the tools and calibration data released with ftools 3.6.1 are consistent and that all channel counting issues are handled correctly.

1.4 More Dirty Laundry

The program pcarmf writes numerous non standard keywords into the header in an effort to be self documenting. Most users, however, will construct a response matrix using pcarsp, a script which causes much of this normally hidden information to be lost altogether. The tool MARFRMF removes all the nonstandard keywords and passes a minimum header through to the output. I will examine whether recording these parameter inputs as either 'COMMENT' or 'HISTORY' lines causes them to be kept. Feedback from the user committee on the importance of this issue would be appreciated.

2 Background

2.1 status

PCABACKEST v1.4h has been released as part of ftools 3.6.1 along with 3 model files. These model files are q6...v01, activ...v03, and xray...v02. The models are constructed as follows. About half of the orbits are defined as non-activation orbits. For these orbits a model which predicts the count rate and spectrum as a function of the "q6" parameter is constructed. The activation model is constructed by applying the q6 model to the activation orbits, and then parameterizing the remaining rates and spectra as a function of θ and ϕ which is a coordinate system that breaks the degeneracy of earth latitude and longitude (RXTE may cross a point on the surface of the earth either going north or south). Finally the xray model is generated by applying both q6 and activation models to blank sky data and defining the residuals as the "xray background". Due to this approach it is necessary to use a consistent set of models, since the activation model has q6 built in by construction and the xray background has both q6 and activation built in by construction.

We present evidence of some short time scale failures of the current model, examples of the average estimated background (and its usefullness) for long observations (operationally defined as 10 ksec or longer), and a criteria we plan to use to quantify the success of current and future models.

2.2 Short term failures

Figure 4 shows the measured good x-ray rate vs the q6 rate for a period of sky looking data obtained on November 1. Each data point represents 128 seconds; both q6 and X-ray rates are summed over 5 detectors; all layers are included in the X-ray rate. The data come from a three orbit span where the activation model is not defined (i.e. a region where there is no activation term according to the assumptions used in constructing the model). A loop is present in the figure, and for this data sets, the line which connects points adjacent in time runs up the lower branch and back down the higher branch. Although this interval is choosen for being a striking example (i.e. other stretches are not so bad) it is clear that there is at least one more important variable beyond q6 which is correlated to overall background rate. Searches for that variable, or a better predictor than the q6 rate alone, are underway.

Figure 5 shows a similar stretch of data collected in January 1997. These orbits are outside the boundaries of the activation model. Plotted are the

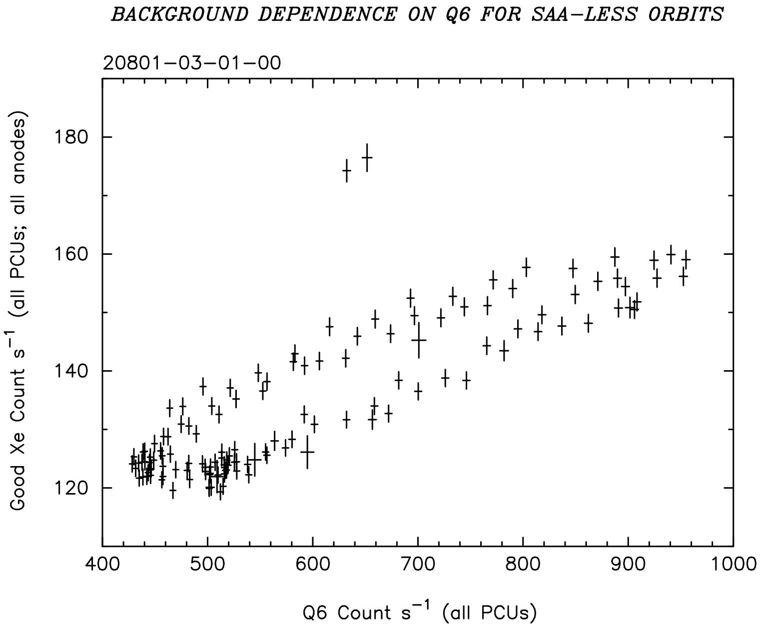

Figure 4: Total X-ray rate vs Q6 on 128 second intervals, sky looking data. See text for details

Q6 and VLE rates, the good rates, and local models constructed by trying to fit the good rates to an a + by model where y is either the Q6 or VLE rate. Those at the meeting will see a color rendition which demonstrates that, at least in this limited data set, the VLE rate is a better predictor of the good X-ray rate than Q6 rate. It is also striking to notice that the VLE and Q6 rates are highly (but not perfectly) correlated.

2.3 Background Spectra

We present here the spectra obtained for earth looking data during the day of background observations obtained on January 1, 1997. Figure 6 shows the difference between the measured spectrum and the estimated background. By assumption these two should be identical if the model works perfectly. About 11 ksec of data are included here, and these data cover a range of times through one day, and therefore include periods when the activation model contributes and when it does not. Figure 7 shows the same data but only for the first layer. In both cases, the 5 PCU have been added together. In both cases the model accounts of $\sim$ 99% of the observed counts. There is a suggestion of a spectral feature near 5 keV in the total spectrum, but it must come from the inner layers as it does not appear in the first layer spectrum. No selection has been made, in construction of the model or the selection of these data, for whether the earth is bright or dark. Periods of enhanced electron rates have been excluded from both. The model requires that the pointing axis be within 65° of the center of the earth. The data was selected with the condition ELV .lt. 0 which allows somewhat more data to be included.

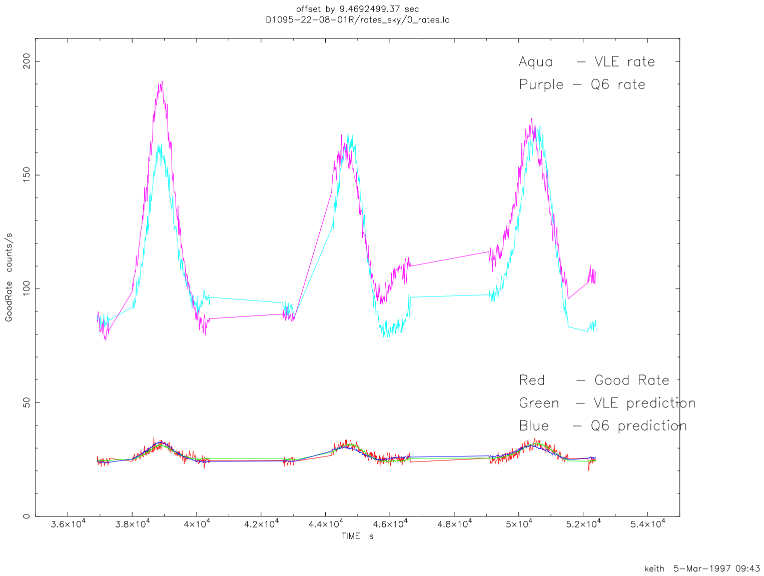

Figure 5: VLE, Q6, and Good rates along with local models

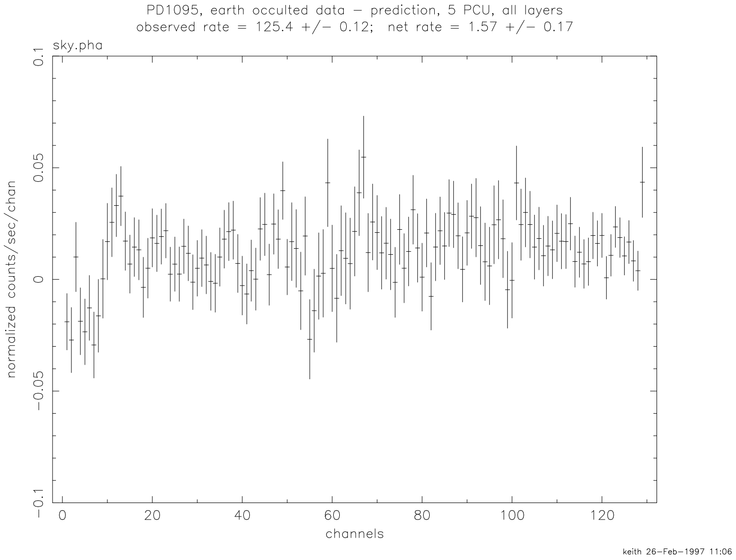

Figure 6: Occulted data minus prediction, Jan 1, 1997, all layers and all detectors

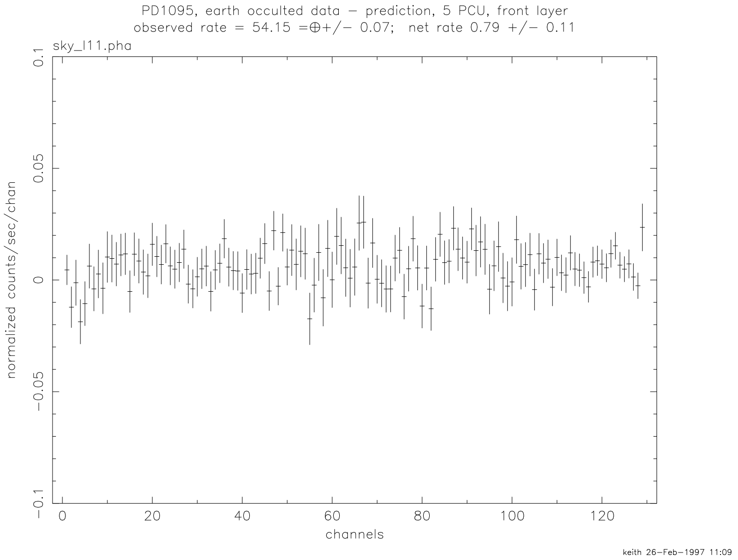

Figure 7: Occulted data minus prediction, Jan 1, 1997, front layers and all detectors

Figure 8 shows the net rate (observed minus predicted) for ADC channel 22-23 (Standard2 channels 18-19) averaged over 128 second intervals. There is some scatter within each orbit, and the overall average is greater than 0 (as it must be given the results shown in figure 6) but there is no evidence that any one orbit is substantially worse (or better) than the average. Similar graphs can be constructed for other channels, and lead to similar results.

2.4 Success Criteria

Four colleagues have articulated possible success criteria. These are

from Colleague 1:

A straight-line fit to background-subtracted blank sky shall give a reduced chi-squared of 1.2 and a count rate of 0.00 +/- 0.59 count/s (this number is for all PCUs, all anodes, all channels).

From Colleague 2:

Criterion 1: "The intrinsic (i.e. non-statistical) deviation should be less than 0.01 c/s/bin in layer 1 of the summed PCAs over the useful energy band."

Criterion 2: "The intrinsic (i.e. non-statistical) deviation should be less than 0.015 c/s/bin in layer 1 of the summed PCAs in th 2-10 keV band, and less than 0.03 c/s/bin above 10 keV"

From Colleague 3:

- the q6+activation accurate to about 10-20 counts in a 16 sec bin (i.e. to have q6+activation accurate to 1 ct/s on timescales short as 16 sec).

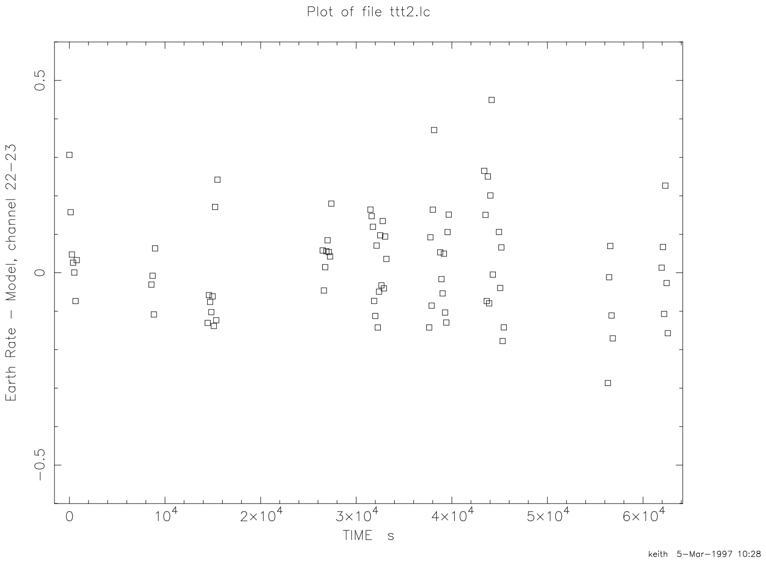

Figure 8: Light curve for background subtracted rate, channel 22-23, for earth looking data. Each symbol represents 128 seconds

There's also the matter of spectral calibration. We're also interested in changes in the spectrum, typically on timescales of 1000 sec or so. Judging by our data in hand, we'd probably need to have the q6+activation background accurate to about 0.5 cts/s/keV.

From Colleague 4:

I think a good test of the reliability of the internal model of pcabackest (either including or excluding activation) is that the shape of the cxb spectrum should be consistent with a 40 keV thermal brem within, say, 5% from 3-50 keV.

The matter of defining success is by no means closed. Most of the illustrations in the previous section are motivated by colleague 2. We will continue to work with the informal background working group, members of the user committee, and other interested parties to create more generally usefull criteria, and attempt to measure our success in these terms. With our current approach, colleague 4 will be the last to be satisfied since our "cosmic background model" is, by construction, equal to blank sky observations minus our model of what is to be expected when loooking at the earth. The cosmic model therefore includes not only the actual cosmic background but flaws in the instrument background models. Even if our models become perfect, the cosmic background may not be correct since the earth is not strictly dark above 20 keV. (The error introduced by this assumption will be cancelled out for users who subtract both the instrumental and cosmic background models.)

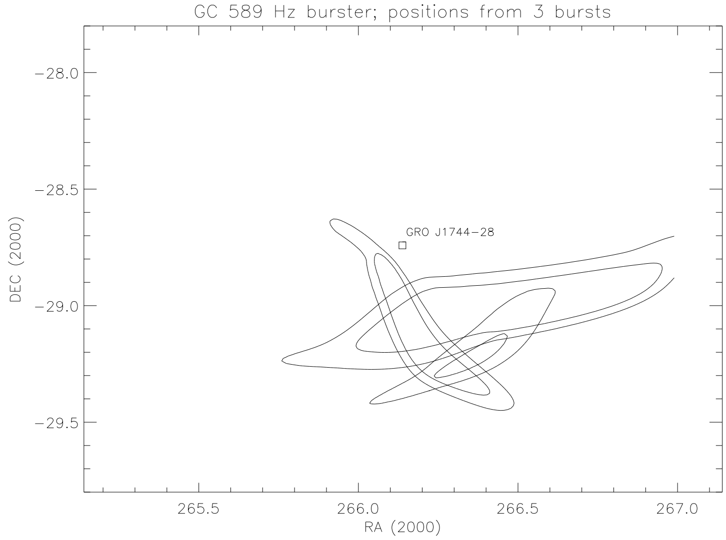

Figure 9: Confidence contours (60, 90%) for individual bursts showing 590 Hz pulsation

Table 1: PCA Pointing and Throughput Calibrations: Y_{off} and Z_{off} are the boresite offsets in the Y and Z RXTE spacecraft coordinate system. Y_{off} and Z_{off} are components of an orthonormal vector, such that $X^2_{off} = 1 - Y^2_{off} + Z^2_{off}$. The relative areas are normalized to PCU3, which has the largest throughput.

PCU	Y_{off}	Z_{off}	Relative Area
1	-0.0000385	0.000629	0.9912
2	0.0001046	0.000529	0.9947
3	-0.000050	0.000746	1.000
4	0.000294	0.00134	0.9410
5	0.000290	0.00197	0.9277

3 PCU pointing

We have succeeded in positioning bursts by using the relative counting rate and offsets for the five detectors. Three bursts observed in May and June 1996 in the vicinity of J1744-28 are known to be related since all show 590 Hz pulsations. Figure 9 shows the 60 and 90 % confidence contours for the three separate bursts. The major axis of the elipse is shifted as the orientation of the z-axis relative to J1744-28 is changing rapidly at this time of year. Figure 10 shows the 90 and 99 % confidence intervals for a combined analysis of the 3 bursts. The source at the center of the field of view, J1744-28, is strongly excluded. The relative positions and normalizations of the effective areas of the 5 detectors are given in table 1.

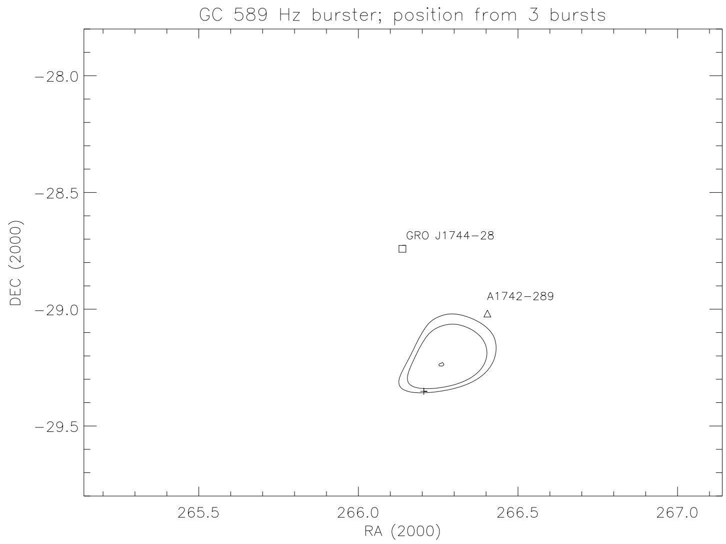

Figure 10: Confidence contours (90, 99%) for joint analysis of three bursts showing 590 Hz pulsation

4 Ongoing Calibration Observations

This section describes ongoing observations useful for calibration purposes and some observations that we plan to perform in the future.

4.1 Background Observations

We are currently performing background observations for ~ 1 day per month near the beginning of each month. The current method involves repeat visits to 5 high latitude points chosen more or less at random over the sky. The intention is to create a long and non-interrupted stretch of public data with a wide variety of background conditions. Brief interruptions for monitoring observations are allowed. An abbreiated human readable timeline for the March 1997 observations is included here.

```
1997:063:07:47:00 100079222 OBSERVATION 20801-02-05-00 START
      PI: PUBLIC
  SOURCE: BACKGROUND_POINT_#2
  TARGET: RA=60.000000 DEC=2.000000 ROLL_BIAS=-8.3 SLEW_RATE=6.0
     EDS: GOODXENON1_16S
          GOODXENON2_16S
          E_32MS_256M_0_255_2LLD_1S
          Standard1b
          Standard2g
          E_32MS_256M_Alpha_2LLD_1S
   HEXTE: E_8US_256_DX1F (LLDA=DEF DWELLA=DEF ROCKA=DEF)
          E_8US_256_DX1F (LLDB=DEF DWELLB=DEF ROCKB=DEF)
```

```
...
1997:063:12:27:00 100096022 OBSERVATION 20801-02-05-00 END



1997:063:12:27:00 100096022 OBSERVATION 20801-03-05-00 START
      PI: PUBLIC
  SOURCE: BACKGROUND_POINT_#3
  TARGET: RA=138.000000 DEC=15.000000 ROLL_BIAS=-17.2 SLEW_RATE=6.0
...
1997:063:17:28:00 100114082 OBSERVATION 20801-03-05-00 END



1997:063:17:28:00 100114082 OBSERVATION 20801-04-05-00 START
      PI: PUBLIC
  SOURCE: BACKGROUND_POINT_#4
  TARGET: RA=235.000000 DEC=10.000000 ROLL_BIAS=-8.5 SLEW_RATE=6.0
...
1997:063:22:11:00 100131062 OBSERVATION 20801-04-05-00 END



1997:063:22:11:00 100131062 OBSERVATION 20345-01-18-00 START
      PI: ALAN P. MARSCHER
  SOURCE: OJ_287
  TARGET: RA=133.704193 DEC=20.108601 ROLL_BIAS=-14.4 SLEW_RATE=6.0
...
1997:063:22:51:00 100133462 OBSERVATION 20345-01-18-00 END



1997:063:22:51:00 100133462 OBSERVATION 20801-01-05-00 START
      PI: PUBLIC
  SOURCE: BACKGROUND_POINT_#1
  TARGET: RA=5.000000 DEC=-67.000000 ROLL_BIAS=-9.1 SLEW_RATE=6.0
...
1997:064:00:06:00 100137962 OBSERVATION 20801-01-05-00 END
```

There are several things to note:

(a) For March we obtained less than one day of background observation. (This elapsed time observing background has been larger on the other days).

(b) There is a brief interruption for a monitoring observation. We have agreed that this is in general acceptable.

(c) The mode E_32MS_256M_Alpha_2LLD_1S provides a calibration line 4.1 keV, the Xenon L-escape line, which can be separated by layer of each

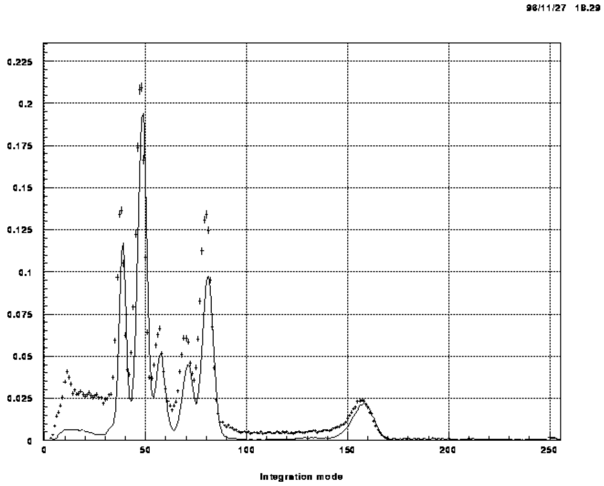

Figure 11: Calibration spectra with 1 and 2 LLD

detector. Figure 11 shows the calibration spectrum obtained from Standard 1 data (these are clean, i.e. 1 LLD events) and the spectrum obtained from the special mode. When separating the data by detector and layer, about one days data are required to get a significant measurement of the Xenon L line, but this is now happening once per month. The mode which returns all the 2 LLD events which do not have the calibration flag set is less useful, and will be discontinued once we have the capability to choose transparent mode data for a single detector.

4.2 Crab

An approved AO-1 proposal monitors the Crab pulsar plus nebula about once every two weeks. The primary aim of the proposal was to monitor the time evolution of the pulse shape and pulse phase, although it was recognized at the outset that these data would also provide a useful check of the stability of the energy response. Figure 12 shows the fit and residuals for data from one detector that was obtained over 9 months. The yellow line is poorly normalized due to the inclusion of slew data; for all pha files the model is the same and only the normalization is allowed to be free. The shape of the residuals are similar, which is a measure (not yet quntified) of the time stability of the energy response. I intend to repropose the monitoring observations for AO-3, again partly for the usefullness as in monitoring the response. (Though these data are not formally public, I will share them with anyone who is interested.)

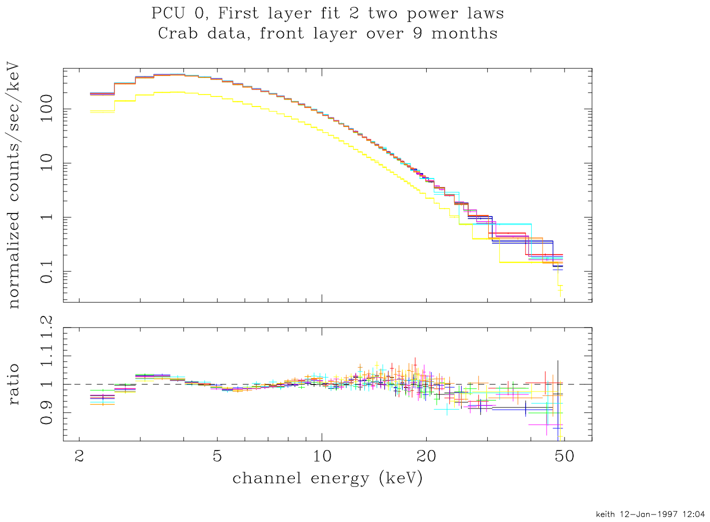

Figure 12: Fits and residuals to Crab data over a 9 month interval

5 Planned calibration Observations

Background and Crab observations will continue. New modes will be added to the background observations. Special observations of ScoX1 will be made to help calibrate the energy response at high rate; these observations involve, at first, a slight modification to observation planning. There is also the possibility of additional calibration observations.

5.1 Background

Background observations have been performed, so far, with the Good Xenon modes. Transparent modes have not been used to to the high telemetry burden. However, we are planning new modes that are modified transparent, where the modification is that only data from one detector is sent down. Such modes (running in 3 EAs) will generate 40-50 kbps per second, which while high, can be sustained over a day of background observations. There are at least two uses for such data:

(a) Michiel van der Klis has identified a non white component of the power spectrum at high frequencies. Characterization of this component is currently is necessary if measurement of the continuum power at kHz frequencies are to be made. While we do not understand the origin of this noise, our dead time model is based on analyses of x-ray signals. In fact all signals contribute to the dead time, and a power spectral analysis of the full signal train (i.e. transparent data) may shed some light here. The detectors are sufficiently similar that data from one detector should provide a template suitable for the entire PCA. We would collect this data during background pointings.

(b) The same data can be used to search for correlations between various types of background events. Although the Standrad 2 records every event, the binning is on 16 second intervals. We don not know if we will find anything useful in such an analysis, but it seems worth taking a look.

5.2 Spectral calibration at high rate

Under the assumption that ScoX1 is a stationary source (demonstrably false!) we could calibrate rate dependent effects by slewing slowly on source and comparing the spectra obtained at different counting rates. The same experiment can be performed by switching to the Standard2_1s mode and slewing on source at the usual rate. This will provide a dozen or more samples of the spectrum, at high signal to noise, at different rates. ScoX1 is often in a state which is approximately stationary (i.e. not on the flaring branch) on timescales of seconds. Our first attempt will be to use the time slewing onto ScoX1 for already approved observations (primarily those of MvdK) to perform these experiments. It is possible that we would also schedule a special calibration observation where we slew back and forth across the source; the need for this remains an open question.

A sketch of what these observations might look like:

```
-- RXTE position --------     ---------  DATA modes ---------------------------

  RXTE not yet near ScoX1                                                           T
                              -   Turn on MvdK 10061 modes, replace Standard2       I
                                  with Standard2_1s (fast timing modes in several   M
                                  broad bands)                                      E
                                                                                    |
  Slew onto ScoX1 at rate TBD                                                       |
                                                                                    |
  Arrive at ScoX1                                                                   |
                              -   go back to Standard2 (gap, probably of 16 sec     |
                                   in Standard2 only, no need to reset other modes) |
                                                                                   \|/
  collect 10 ksec of data                                                           .
   for 10061 proposal

                              -   Change again to Standard2_1s, keep other modes running

  slew away from ScoX1

                              - terminate 10061 modes, go back to Standard2

  resume normal operation
```