Chapter 9

PCA Feasibility

To discuss the feasibility of various types of astrophysical observations with the Proportional Counter Array it is necessary to discuss both the PCA and EDS as a single system together with the constraints imposed by the XTE spacecraft systems. The principle user of telemetry capacity is the PCA/EDS combination. The amount of data this produces depends on the selected EDS Modes and is very variable.

The reader should note that many of the instrument-specific details are covered in the PCA chapter. A reader familiar with, for example, the feasibility chapter of the ASCA SIS, will notice differences between the SIS chapter and the description to be presented here in that many details vital to a proposer of an SIS observation were described in the feasibility chapter itself. The combination of the PCA and EDS requires a different approach.

9.1 PCA Count Rates

The PCA response, both energy and timing, depends on the event rate. This dependence is completely negligible when the event rate in one detector is below about 10,000 counts/sec, approximately equal to 5 Crabs. Efforts have been made to characterize the detector response for the relatively "normal" event rates. When the event rate in a detector becomes abnormally high, say, above 10,000 counts/sec, there are a number of complicating factors (see section 9.4 for details). The user is advised to keep this in mind when observing the brightest sources.

Bright galactic x-ray sources are a class of primary targets for XTE. Efforts have been made to insure that the proportional counters will function properly under intense x-ray illumination. But still the GO has to take into account the detector dead time when extremely bright sources (above 10

Crab) are to be observed. For example, a PCA detector has a dead time of 10 μs for each event, and in particular, this deadtime is of the paralyzable type. In other words, to a good approximation, the output rate and input rate are related by $r_{out} = r_{in} \exp(-r_{in} (10\ \mu s))$, which will reach a maximum of 36,000 events/sec when r_{in} = 100,000. A higher r_{in} than 100,000 events/sec will produce a lower output rate. Therefore when one is to observe any x-ray transients which will produce more than 100,000 counts/sec in one proportional counter, one has to do offset pointing in order to maximize the output event rate.

9.2 Background Determination and Sensitivity

The background in the PCA detectors, consisting of "internal" events not due to the transmission of source plus diffuse sky X-rays through the collimator, should be about the level of 1-2, 10, and 120 mCrab in count rates in the 2-10, 10-30, and 30-60 keV ranges, respectively. The spacecraft pointing will be held to an accuracy of about 10" during observations and the PCA X-ray sky backgrond will be about constant during the observation. For some percent of the spacecraft orbit, when the source direction is not occulted by the earth and the satellite is not traversing regions of high charged particle concentration, the internal background will vary by 10-20% in a predictable manner. A burst of charged particles could cause an increase in background, but it will also cause an increase in the veto rates and be identifiable. Such events are expected to be infrequent during the majority of the mission. Thus the internal background for most observations can be assumed to be known within 10% and close to the nominal values given in the section below.

The deadtime depends on background, but the contribution is expected to be sufficiently small that we think that the simple approximation of a constant 10 μs deadtime per interaction for other events in the same detector is an adequate approximation for estimating feasibility of high time resolution sensitivities.

For sources a few mCrabs in intensity, the signal to noise increases as the square root of the observing time. For sources that are a fraction of the background in an energy range of interest, uncertainty in the background determines the limiting sensitivity. For a long observation the fluctuations in the internal background will average out and the limiting sensitivity will result from the uncertainty in the sky background in a particular direction.

9.2.1 Instrumental and Cosmic Backgrounds

Results from previous proportional counter experiments suggest that the in-orbit background, during good observing times, is 2-3 times that observed in the laboratory. PCU laboratory background spectra have a continuum and several lines (see fig. 6b in the PCA Instrument description chapter (chapter 4)). The line components are due to unflagged calibration events and to residual radioactivity in the collimator. It is assumed that the line components will have the same magnitude in orbit as in the lab, and the continuum component (which is fit as a low order polynomial) will be three times larger. The accompanying figures show the background spectrum computed from laboratory data and the above assumptions for each Xenon detection layer, and summed over all five detector units. Note that these spectra have statistical error bars representative of a 1 x 10^4 sec observation. The two figures show the same data plotted versus energy and detector channel.

The cosmic background has been estimated by taking a 40 keV bremsstrahlung spectrum normalized

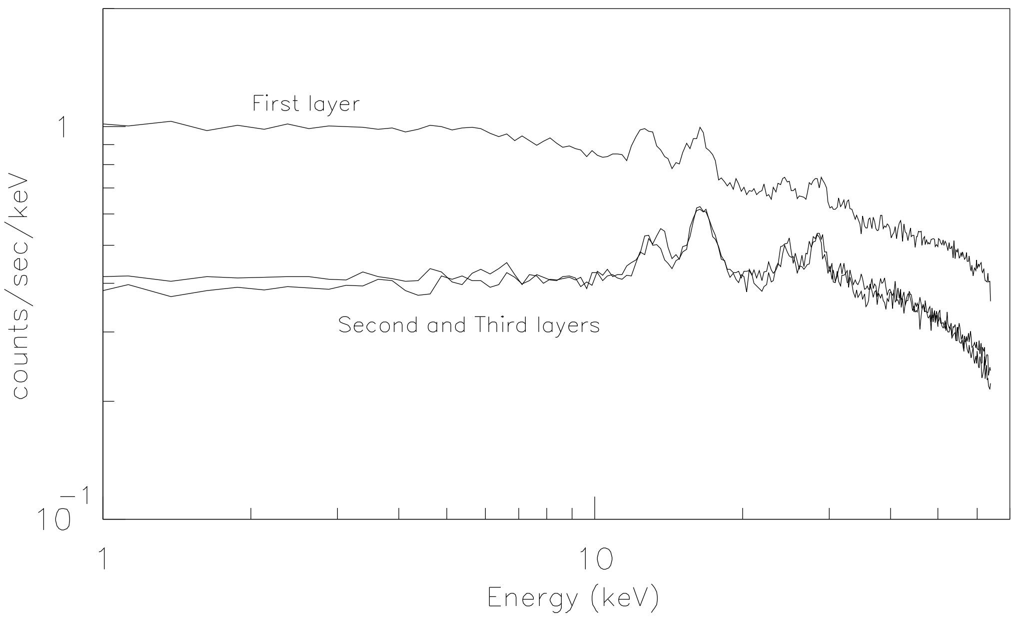


FIGURE 9.1. PCA background spectrum showing counts as a function of energy.

by 7 x 10^{-4}. This gives a flux of 1.6x10^{-12} erg/sec/cm^2/keV at 10 keV. Under the assumption that the PCA effective solid angle is 1 square degree this matches the flux reported by Marshall et al. (1980, ApJ, 235, 4) of 3.2 keV/sec/cm^2/sr/keV at 10 keV. For the purposes of making sensitivity estimates it is assumed that a 1 mCrab source has a spectrum with N(E) = 0.005 $E^{-1.7}$ photons/sec/cm^2 absorbed by a neutral column with N(H) = 3x10^{20} cm^{-2}.

9.2.2 Sensitivity Estimates

Using the instrumental and cosmic background estimates described previously we have computed the counting rates over three broad energy bands for each Xenon layer. These rates are given in the following table.

TABLE 9.1. Broad Band Rates (counts/sec)

	1 mCrab AGN	**Cosmic Bkgd**	**Inst. Bkgd**
2-10 keV			
layer 1	10.2	8.54	7.66
layer 2	0.52	0.47	3.16
layer 3	0.13	0.07	3.36
10-30 keV			
layer 1	1.80	1.80	15.5
layer 2	1.02	0.92	9.49
layer 3	0.66	0.56	9.38
30 - 60 keV			
layer 1	0.116	0.06	14.4
layer 2	0.086	0.06	10.7
layer 3	0.080	0.06	10.5

All entries in the table are counts/sec summed over 5 detectors for each of the indicated layers.

Using these numbers we have estimated the sensitivity in the 3 bands as a function of observing time. The sensitvity curves have been calculated assuming the signal to noise ratio is,

$$S / N = s\,T / ((s + b_c + b_i)\,T)^{1/2} ,$$

where s is the source strength (cts/sec), b_c is the cosmic background rate, b_i the instrumental background rate, and T is the length of the observation (sec). These results are displayed in the accompanying figures (Figure 9.3), one for each energy band, and for different assumed source intensities (see the figure headings). The user should be aware that source detection will be additionally complicated by fluctuations in the cosmic background, estimated to be about 10% / beam for the PCA field of view, as well as uncertainties in the instrumental background model, though these uncertainties should decrease as more is learned during the mission. Also note that the 2-10 keV curves were computed using the 1st Xenon layer only, while the curves for the higher energy bands were computed by summing all the layers.

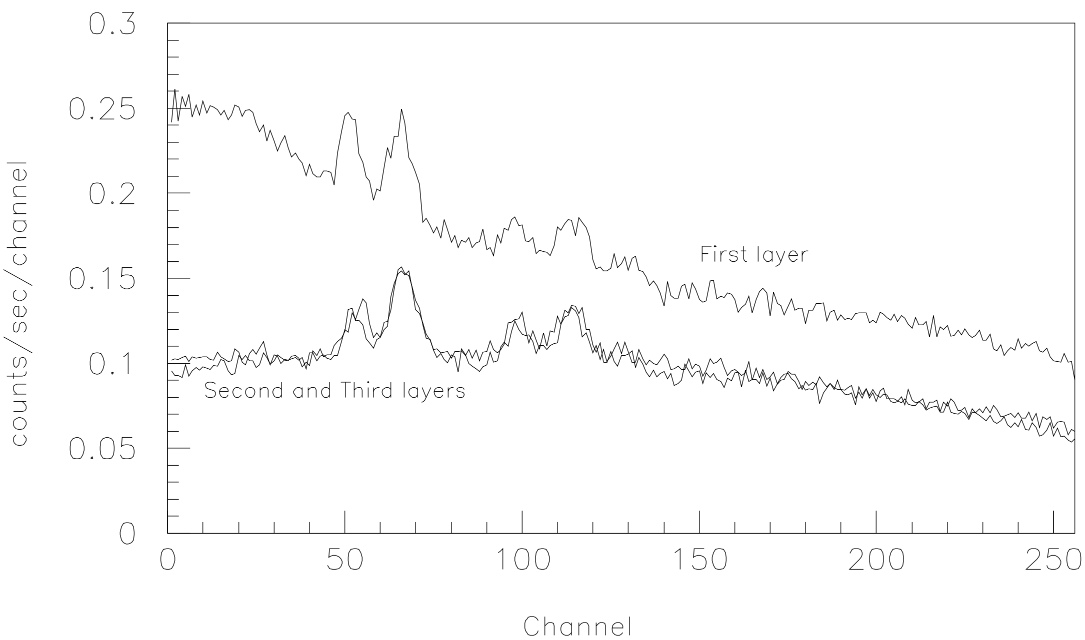


FIGURE 9.2. PCA background spectrum showing counts as a function of detector channel.

9.3 Spectral Resolution

The spectral resolution attainable with the PCA Xenon layers is approximately 18% at 6 keV and 9% at 22 keV. The propane layer has a resolution of 18% at 5.9 keV. These values will suffer some long term degradation during flight, but should remain quite good for the first two years of the mission (see also PCA Instrument Description). In principal the PCA can provide 256 channel pulse height spectra, however, in practice the final energy resolution of the data relayed to the ground will depend on several factors.

- The gain uniformity between all PCU's
- The selected EDS mode and its energy bin remapping prescription

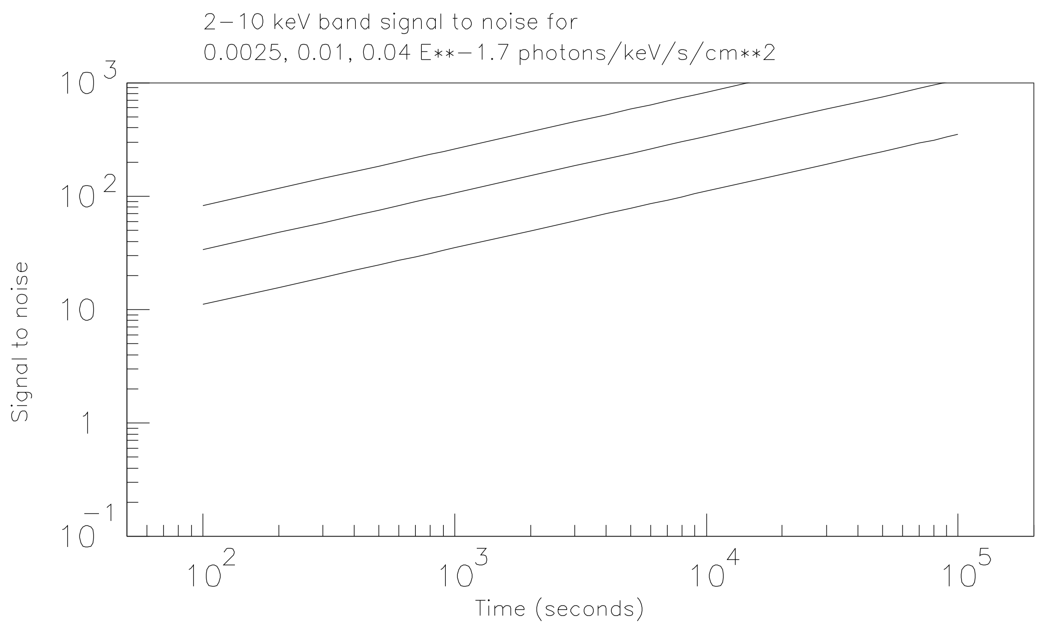


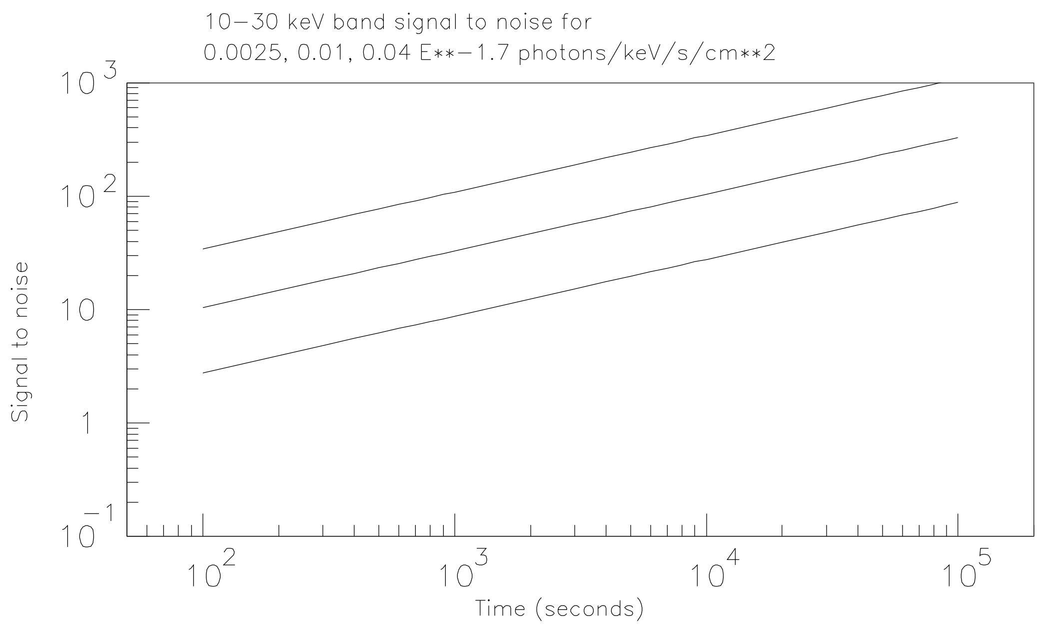
FIGURE 9.3. Plots showing the time necessary to reach a given signal to noise level.

Observers interested in spectral line searches and studies should be aware that EDS modes which do not retain the individual detector ID information will apply a gain and offset correction to all PHA values that will reduce the overall spectral resolution ultimately attainable with some modes. Observers wishing to retain the highest spectral resolution capabilites of the instrument should ensure that they receive "raw" PHA data with all detector ID information, but recognize that this may require trade-offs in temporal resolution or other observing parameters in order to remain within telemetry constraints. For more information see the PCA Instrument Description (Chapter 4).

9.4 Timing Characteristics

There are several timing characteristics of the PCA that are worthy of mention.

- The PCA/EDS logs photon arrival times with much finer resolution than the instrumental dead time. Although not unique this is rare in comparison with previous astronomical x-ray instruments
- Since time tagging is performed separately for each PCU it is possible for the first time to search for correlations at μs time scales
- FFT's can be performed on-board or on the ground with frequencies up to ~500 kHz. This is far beyond the 0.1 - 1 kHz range of previous experiments



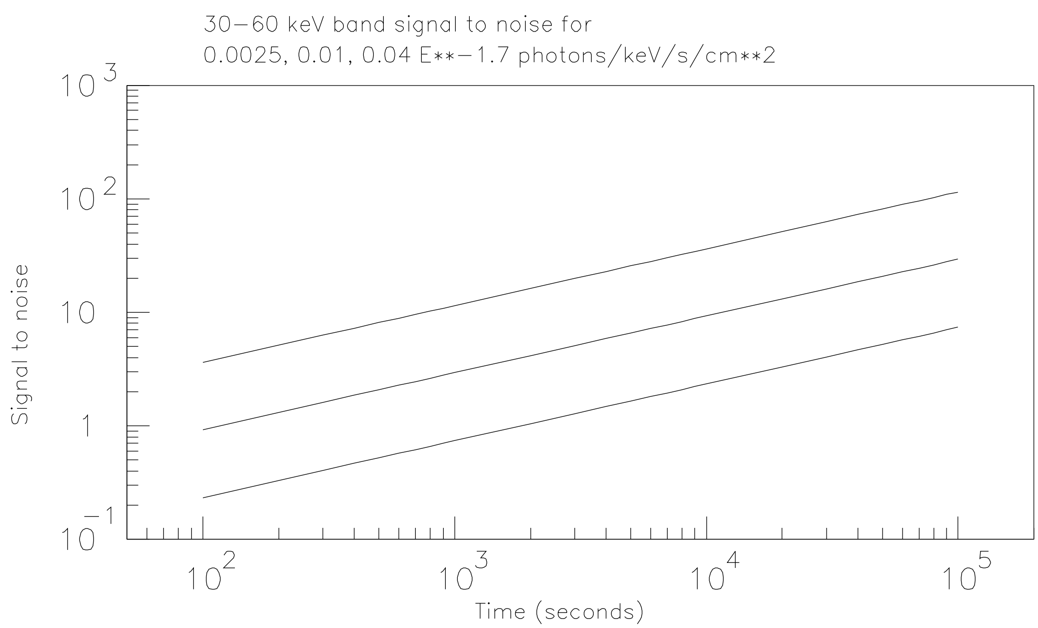


FIGURE 9.3. (continued) Plots showing the time necessary to reach a given signal-to-noise level.

In principle, the XTE/PCA instrument has been designed to allow one to study phenonmena on time scales from a couple of hours, which are set by the satellite orbital period, down to microseconds. In practice, however, a number of factors have to be properly taken into account before such a vast range of timescales can be addressed. At the writing of this document, efforts are still underway to understand and to characterize these factors. Here we briefly describe the effects that we have uncovered so far, some of which are of the general nature that exist in every other real detector, while others are rather unique to the XTE/PCA detectors. A detailed document describing the various factors will be made available at a later date.

A PCA detector has a deadtime of 10 microseconds for each event. This deadtime is of the paralyzable type. In particular, the deadtime is pulse-height dependent. In other words, a 30 keV x-ray will generate a larger deadtime than a 5 keV one. Since for the great majority of real x-ray sources, most of the detected photons have an energy of 10 keV or less , a constant deadtime is a very good approximation. This approximation is certainly valid for both energy spectral analyses and for timing analyses when the count rate is low, say less than 10,000 counts per second per detector, or when the time scale investigated is much larger, say, by a factor of ten, than the deadtime.

When the count rate becomes extremely high and/or the time scale investigated comes close or comparable to the detector deadtime of 10 microseconds, a number of otherwise innocuous effects start to become important. Among these are the following;

- The energy-dependency of the deadtime.
- The anticoincidence logic that is used to reject background starts to reject a significant number of genuine events.
- The Very-Large-Event (VLE) window, which is set to eliminate the ringing of electronics following unusally large depositions of energy by either x-rays or charged particles, shows a clear signature in the power spectrum.
- The fact that several anode chains in one detector share the same analog-digital converter (ADC) will show up as a modification to the idealization of paralyzability of the detector deadtime.
- The detector gain and resolution as a function of the count rate.

A formalism that will properly take these factors into account is being developed and will be made available at a later time.

9.5 Telemetry Limitations

All previous X-ray satellites have had various telemetry limitations and in some cases these have been particularly severe. In comparison to the earlier satellites, XTE has enormous data handling and telemetry capabilities, but there are still sometimes serious practical limitations since the detectors are so large and the detected event rates so great for the brighter sources. There are several important aspects for telemetry usage:

- The mean usage rate - how constant or predictable is the source flux

- The total expected usage - i.e, the usage summed over all EAs over the total observing time
- If the source is unexpectedly bright - how fast might the allowed capacity be filled?

A unique aspect of XTE proposals is that, in addition to requesting a specific amount of observing time, the proposer must nominate specific telemetry configurations which affect the amount of telemetry required. For many objects, particularly extragalactic ones, this will not be a difficult calculation, as the sources will be relatively weak. Even in such a situation, however, the required telemetry to achieve the proposed science must be evaluated to “free up” capacity for other proposals within that “observing day” that need large amounts of telemetry to meet their science objectives. Thus for XTE, the principal of altruism becomes a very important concept. The interspersing of “low” telemetry requirement observations between “high” requirement ones is another requirement on the scheduling program SPIKE. Any “accumulated credit” only persists until the next data dump opportunity.

9.5.1 XTE Solid State Recorder

Although the telemetry system and the on-board data recording and playback are not formally part of the joint PCA/EDS experiment some simple understanding of their principles of operation is worthwhile. The telemetry estimations are an integral part of the feasibility assessment because careless choices could result in irregular return of data packets and data being lost. Unexpected or unanticipated source behavior can also lead to data loss for bright objects.

The XTE spacecraft does not have a tape recorder but it does have a ~920 Mbit solid state recorder. The recorder operates in a “bucket” form with data from the PCA/EDS flowing into it while at the same time data is being removed, usually nearly continuously, for down-link through the TDRSS system. The maximum possible gap between any down-link is assumed to be 4 orbits. The Virtual Channels (VC’s) in the recorder are sized to suit typical subsystem telemetry requirements. At the mean 20 kbps EDS science rate, the 4-orbit criteria is just met in VC 6 (see below). If an observed x-ray source suffers Earth Occultation and the XTE orbit also passes through the SAA the effective permissible on source telemetry rate may approach twice the continuous average. The data flow should be quasi-continuous for most of the time, however downlink will not be continuous for a number of reasons:

- The data is in packets, some of which arrive every 128 seconds
- There is a gap in coverage between TDRSS East and TDRSS West - the so called “zone of exclusion” (ZOE). After such a period, stored data will rapidly be replayed and emptied from the recorder
- Various technical problems or Shuttle activities may delay the final arrival of packets at the SOC ground system at GSFC

The solid state recorder is operated in several virtual channels which are shared between the spacecraft systems and the various experiments as partially shown in the Table 1.1. If the mean input to a VC channel (e.g. output from EDS) is greater than its mean output to the telemetry system, which is dependant on TDRSS contacts, then that channel will fill up. VC channels can be operated in two modes. Once full each VC channel can be in:

- An overwrite mode - old data is lost
- A wait for space to be freed up mode - current data is lost

The default state for XTE science VC data will be the “wait for space” option. XTE contact with TDRSS is normally through the Multi Access (MA) service but Single Access (SSA) service must be scheduled for dumping large parts of the solid state memory at high speed. This will be required when exiting the TDRSS ZOE and for any observations producing high data rates that substantially fill the EDS science virtual channel (VC 6).

9.5.2 Summary Of Telemetry Performance

The following table summarizes the key features of the telemetry system for the PCA/EDS combination. Notice that the user selection of EA Modes in the lower part of the Table dominates the storage capacity.

TABLE 9.2. Summary of Telemetry Performance

Item	Rate kbps	Recorder Capacity Mbits	Virtual Channel (VC)	Status
PCA Housekeeping	0.7	218 (included with all spacecraft data)	1	Always present
EDS Standard Mode 1	1.2	116 (included with ASM)	4	Always present except in SAA
EDS Standard Mode 2	2.1			Always present except in SAA
Other PCA EA’s				
Normal - total average	< 20	454	6	Optional Combinations, Normally OFF in SAA & Earth Occult.
Burst < ~ 30 minutes	at 256			
Burst < ~ 15 minutes	at 512			

9.5.3 Procedure To Calculate Telemetry

The following steps are required to calculate the telemetry requirements for any particular X-ray source:

- Run `PIMMS` or `XSPEC` for the target source spectrum and intensity to get the expected PCA counting rate versus energy
- Using `recommd`, select the desired configurations (see EDS Description, chapter 7) for the 4 user-selectable EA’s and specify the total observing time.

- Adjust the 4 EAs configurations (you may use none of them; in that case, your data will appear via the two Standard Modes) to reduce or to increase the telemetry as required for the desired science return.
- Experiment a bit with the source's spectral shape and rate to determine some upper and lower bounds to the possible counting rates you might expect from the source.

When running `recommd`, it is not necessary to retain a telemetry margin for the two Standard Modes and the housekeeping because these are already allowed for. They also use VC tracks different from the tracks used for PCA/EDS science data, so only serious technical problems should cause loss of the Standard Mode data.

9.6 Feasibility Studies: Specific Examples

The best way to illustrate the capabilities of the PCA/EDS is to present some examples. The following examples have been chosen to represent a range of typical sources. Note that these examples are not necessarily complete (i.e., they do not all start from a power law index and proceed to an EDS configuration); Chapter 8 contains a more detailed description from start to finish for a faint source with an emission line. The purpose of these examples is to illustrate choosing EDS configurations and their associated telemetry for a sampling of source intensities and properties. These examples should not be used in lieu of learning how the EDS works, or about the multitude of configurations possible, nor used in lieu of a calculation.

To aide proposers in choosing appropriate EDS configurations, the tool `recommd` (pronounced "recommend") is available. (For further information about `recommd`, see Chapter 8.) `recommd` takes background-subtracted source spectra and produces a list of recommended sets of EDS configurations. The user may also specify specific spectral and timing resolution requirements, modify the duty cycle (i.e. "observation efficiency"), and emphasize certain parts of the spectrum. Among its output items, `recommd` gives the telemetry in kilobits per second (kbps) of each individual configuration. This telemetry takes account of the type of mode, the timing and energy resolution, the overheads (e.g. time markers), and (where appropriate) the count rates. In addition, `recommd` provides approximate estimates for the signal-to-noise ratios.

`recommd` suggests only Binned, Event and Single Bit configurations. The proposer may specify additional configurations (e.g. FFT mode) as may be appropriate for the science objectives. Some of the examples below feature configurations in addition to those produced by `recommd`.

`recommd` uses as input a 6 channel PCA spectrum, given in counts/s. The channel and approximate energy boundaries are given in Table 9.3. Chapter 8 illustrates how to obtain this spectrum for a particular source using either `PIMMS` or `XSPEC`. In each of our examples below, we give this 6 channel spectrum. Also, unless otherwise mentioned, we use the default input values for `recommd`'s various options, and generally seek only 2 configurations from `recommd`. Note that the default observing efficiency of 65 % is appropriate only for observations expected to be spread over many satellite orbits. Objects observed for less than an orbit, or objects near the satellite orbit poles will have efficiencies larger than this. Examples here used version 2.3 of `recommd`.

See Chapter 7 for details about the EDS modes, and Appendix 1 for further details about the EDS configurations.

TABLE 9.3. Channel and Corresponding Energy Boundaries for PCA 6-channel Spectra

Channels:	**0 - 13**	**14 - 17**	**18 - 23**	**24 - 35**	**36 - 49**	**50 - 249**
Energies (keV):	0.0 - 3.2	3.2 - 4.3	4.3 - 5.7	5.7 - 8.6	8.6 - 12.1	12.1 - 60.0

9.6.1 The Crab

The six-point XTE spectrum, in counts per second, for the Crab is:

Energies (keV):	**0 - 3.2**	**3.2 - 4.3**	**4.3 - 5.7**	**5.7 - 8.6**	**8.6 - 12.1**	**12.1 - 60.0**
Crab	3304	2672	3206	3626	1971	1791

These count rates were obtained using a photon index of 1.8 and an absorption of 7.1 x 10^{21} cm^{-2}. We give here three scenarios for different telemetry and timing resolution requests.

9.6.1.1 Microsec Time Resolution, 256 kbps Telemetry Rate

In this example we seek the highest time resolution, and we facilitate this by requesting a generous telemetry rate. The high telemetry rate, however, cannot be sustained for more than the satellite's orbit, so the observation will take less than an orbit. Hence, the observing efficiency is 100 %. Thus, for microsec resolution, with a telemetry request up to 256 kbps, an observing efficiency of 100%, and requesting as much spectral resolution as possible within these limits, `recommd` gives:

EDS Configuration	**Time Resolution**	**Energy Range**	**Telemetry**
E_1us_4B_0_1s	1 µs	0.0 - 60.0 keV	267.0 kbps

This single Event Mode gives hight time resolution and limited spectral resolution as a result of the timing request and of the generous telemetry allocation. It produces 4 energy channels over the entire 0 - 60 keV range. The “B” spectral channel distribution, which is recommended, is reasonable since “B” was designed for the Crab.

A good alternative is:

EDS Configuration	Time Resolution	Energy Range	Telemetry
SB_31us_0_13_500 ms	31 μs	0.0 - 3.2 keV	36.3 kbps
E_1us_1M_14_1s	1 μs	3.2 - 60.0 keV	221.8 kbps

This Event configuration provides no spectral information, but retains the detector ID for where the event occurred. If one would rather have the detector ID than some crude spectral information, this configuration would be the right choice. If the time resolution requirement were relaxed, one could have spectral information as well as detector ID.

9.6.1.2 Millisec Time Resolution, Normal (18 kbps) Telemetry Rate

If we request as much spectral resolution as possible within the telemetry limit, a time resolution of 1 ms, an observing efficiency of 65%, and give higher weight to energies between 4.35 and 8.75 keV, `recommd` produces a set of four Single Bit Mode configurations, each with 0.5 ms resolution and each covering a different energy band. The two canonical bands (c.f. Table 9.3) between 4.3 and 8.6 keV are each covered by one configuration, while the remaining configurations cover two bands apiece. The configurations, their energy bands, and their telemetry are:

EDS Configuration	Time Resolution	Energy Range	Telemetry
SB_500us_0_17_2s	500 μs	0.0 - 4.3 keV	8.2 kbps
SB_500us_18_23_2s	500 μs	4.3 - 5.7 keV	5.4 kbps
SB_500us_24_35_2s	500 μs	5.7 - 8.6 keV	5.8 kbps
SB_500us_36_249_2s	500 μs	8.6 - 60.0 keV	6.0 kbps

Note that these configurations give a summed telemetry of 25.4 kbps.

Alternatively, one might decide to ignore the high energy band and just select a single binned configuration, like:

EDS Configuration	Time Resolution	Energy Range	Telemetry
B_1ms_8B_0_49_Q	1 ms	0.0 - 12.1 keV	32.6 kbps

This covers the band 0.0 - 12.1 keV with 8 spectral channels. The large telemetry of 32.6 kbps requires good arguments to defend this configuration against the first choice.

9.6.1.3 One Second Time Resolution, Normal (18 kbps) Telemetry Rate

Here we assume 65% observing efficiency, request as much spectral resolution as possible, and assign higher weight to energies between 4.35 and 8.75 keV. `recommd`'s first choice looks perfectly suited to the task:

EDS Configuration	Time Resolution	Energy Range	Telemetry
B_250ms_128M_0_254	250 ms	0.0 - 60.0 keV	21.7 kbps

This is the quarter-second Binned configuration that covers the entire energy range with high spectral resolution; in addition, it retains detector IDs (i.e. separate histograms are collected for each of the five detectors). The higher weight does not make any difference here.

9.6.2 A Medium Intensity Source

For this example, we wish to retain moderate spectral resolution at the low energies within the nominal telemetry budget. For our spectrum we choose an absorbed power law with photon index 1.8 and absorption of 7.1 x 10^{21} cm^{-2}. With a total count rate of ~ 8400 counts/s, the 6-channel PCA spectrum is:

Energies (keV):	0 - 3.2	3.2 - 4.3	4.3 - 5.7	5.7 - 8.6	8.6 - 12.1	12.1 - 60.0
Medium Source	1289	1167	1536	1942	1187	1265

Specifying 16 energy bins and optimizing the timing resolution, `recommd` gives the following pair of configurations:

EDS Configuration	Time Resolution	Energy Range	Telemetry
B_16ms_16B_0_49_H	16 ms	0.0 - 12.1 keV	8.1 kbps
E_1us_4M_50_8s	1 µs	12.1 - 60.0 keV	23.8 kbps

If the observer desired more energy information at the higher energies, one of the other Event modes suggested by `recommd` may be chosen.

Running `recommd` with a 12 kbps telemetry allocation results in less energy information at the higher energies but with a big telemetry savings:

EDS Configuration	Time Resolution	Energy Range	Telemetry
B_16ms_16B_0_49_H	16 ms	0.0 - 12.1 keV	8.1 kbps
SB_250us_50_249_2s	250 µs	12.1 - 60.0 keV	5.5 kbps

Proposers are encouraged to look for such telemetry savings when possible.

9.6.3 Weak Source, Low Telemetry Requirement

This source is covered in Chapter 8 as a demonstration of the use of `PIMMS`, `XSPEC`, and `recommd`.

9.6.4 Very Bright Source, High Telemetry Requirement

The following describes the EDS feasibility of observing a very bright TOO with the intensity and spectrum of A0620-00 (V616 Mon, Nova Mon). The spectral parameters used are

- power law_1, index = 4.70
- power law_1 normalization = 3500.0
- power law_2, index = 2.0
- power law_2 normalization = 0.20
- absorption column = 3.2 x 10^{21} cm^{-2}

The predicted count rates in counts/sec in the canonical PCA energy bands from `XSPEC` for the above parameters are:

Energies (keV):	0-3.2	3.2 - 4.3	4.3 - 5.7	5.7 - 8.6	8.6 - 12.1	12.1 - 60.0
X-ray Nova	80,553	31,633	19,877	9224	1809	545

With this input, `recommd` produces a list of pairs of Event and Binned modes, with the Event mode taking the higher energies. From the list, we choose a Binned mode which favors time resolution over energy resolution at the low energies. To catch the high energy tail, an Event mode with more channels is chosen. In addition to these, we have added two FFT modes, which together provide spectra and cross spectra for timescales between 1 microsecond and 4 ms.

EDS Configuration	Time Resolution	Energy Range	Telemetry
B_4ms_8A_0_49_H	4 ms	0.0 - 12.1 keV	16.3 kbps
E_4us_16M_50_8s	4 µs	12.1 - 60.0 keV	12.1 kbps
F_1us_12_249_16s	1 µs	0.0-3.2, 3.2-60.0	3.4 kbps
F_125us_12_249_16s	125 µs	0.0-3.2, 3.2-60.0	1.8 kbps

Utilizing 210 kbps and an observing efficiency of 100 %, the EDS modes and the corresponding telemetry rates produced are:

EDS Configuration	Time Resolution	Energy Range	Telemetry
B_2ms_8A_0_23_H	2 ms	0.0 - 5.7 keV	32.6 kbps
E_16us_64M_24_1s	16 µs	5.7 - 60.0 keV	192.2 kbps

D_1us_0_249_128_1s_F	1 µs	0.0 - 60.0 keV	2.5 kbps
F_31us_0_12_249_16s	31 µs	0.0-3.2, 3.2-60.0	2.9 kbps

Again, the Binned and Event configurations were chosen from the output of recommd, using the same criteria as for the 36 kbps case. Note that the summed telemetry for a set of configurations need only be less that the requested telemetry allocation divided by the observing efficiency. We replaced one of the FFT modes with a Delta-Binned mode to facilitate auto-correlation calculations at the smallest time scales. The disadvantage with the 1-µs FFT mode is the large dead-time associated with the mode. The disadvantage with the Delta-Binned mode is that it doesn't give the cross-spectra. In our two examples of available telemetry, we show both to illustrate the trade-offs. The final decision should be made in light of the the science goals.

9.6.5 Periodic Signal Detection

In this example, we first compute the 5-sigma detection limits for periodic signals in "Bright" and "Faint" sources. We compute these empirically by creating fake light curves using the FTOOLs `FAKELC` and `ADDSINE`. The dc level, which represents all sources of background and the steady component of the source, can be created using the FTOOL `FAKELC`. This dc level is created without adding noise. The sinusoidal variation can then be added using the FTOOL `ADDSINE`. Poisson statistics are applied to the summed dc and sinusiodal intensity. (See Chapter 8 for further details about `FAKELC` and `ADDSINE`). The resulting light curve may be analyzed using the `DPS` function in `XRONOS`, which gives the confidence level for detection of a signal (see Chapter 8 for information about `XRONOS`). `DPS` allows the user to specify the length of the FFT and to sum the resulting FFTs when appropriate. We chose FFT lengths that gave the greatest sensitivity to detected periods.

Table 9.4 gives the 5-sigma detection limits for various periods in both the Bright and Faint sources. The "Obs. Time" is the total length of the light curve, in seconds. The lengths of the light curves are such that each has ~1600 complete cycles of the period. Light curves are of contiguous data, without data gaps. The Bright dc level corresponds to an ~0.5 Crab source in the PCA, while Faint corresponds to a source intensity of ~ 6 mCrab in the PCA. The PCA background of 90 cts/s is included in the Bright and Faint dc levels.

TABLE 9.4. Amplitudes of Sinusoidal Variations Giving 5σ Detections

Period	Bright (8000 cts/s)	Faint (190 cts/s)	Obs. Time
33.47 ms	100 cts/s	18 cts/s	54 s
0.856 s	35 cts/s	5 cts/s	1380 s
3.57 s	15 cts/s	1.5 cts/s	5790 s

Note that the 1.5 cts/s amplitude of the 3.57 s period in the Faint source corresponds to a peak-to-peak modulation of 3% relative to the background-subtracted source count rate.

We next choose EDS modes. First, we use `XSPEC` to obtain the 6-channel PCA spectrum. Using a power law with a photon index of 1.05, and a column of 3×10^{21} cm^{-2}, and scaled approximately to our Bright and Faint source levels, we obtain

TABLE 9.5. PCA 6 Channel Spectrum for the Bright & Faint Source

Energies (keV):	0-3.2	3.2-4.3	4.3-5.7	5.7-8.6	8.6-12.1	12.1-60.0
Bright	657	695	1081	1758	1414	2305
Faint	8.3	8.8	13.7	22.2	17.9	29.1

Note that that the background counting rate **is not** included in the spectral channels given above. This is because `recommd` assumes the input spectrum is from the source only, and will add the background itself. Inputting this into `recommd`, using the default 65 % efficiency, specifying at least 10 microsecond timing, optimizing the energy resolution, we choose the following EDS configurations:

Intensity	EDS Configuration(s)	Timing Resolution	Energy Range	Telemetry
Bright	SB_62us_0_249_500ms	62 µs	0.0 - 60.0	24.8 kbps
Faint	GoodXenon1_16s	1 µs	0.0 - 60.0	5.2 kbps
	GoodXenon2_16s	1 µs	0.0 - 60.0	5.2 kbps

The GoodXenon configurations use 2 EAs to give 256 energy channels with detector and layer ID in 1 microsecond time bins. Note that to maximize the timing resolution within the telemetry request, the Bright source level sacrifices all energy information. The count rate is low enough for the Faint source that both timing and energy information can be maximized via the GoodXenon configurations.

In addition, for P = 33.47 ms, it is also appropriate to choose an FFT mode. Because the FFT mode performs 2 FFT's from different energy ranges, the particular configuration must be chosen considering the spectrum. The energy split may be dictated from the science objectives (e.g. searching for hard lags), or from counting statistics considerations. Choosing the split at the first channel, and choosing the timing resolution so as to get sufficient number of cycles (5) in the FFT's 256-pt transform, an appropriate FFT configuration woud be:

F_4ms_0_12_249_64s

The telemetry for the FFT mode is negligible, ~ 0.3 kbps. The other periods are too large to be reasonably detectable using the FFT mode.

9.6.6 QPO Observation and FFTs

9.6.6.1 General considerations

If the event rate is high and the desired time bin size is small, the EDS FFT mode can be used to search for periods efficiently within the telemetry constraints. However, because the FFT mode analyzes time series in fixed lengths of 256 bins, the frequency resolution and Nyquist frequency may not always be suitable for a particular science objective. On the other hand, if the time bin size is large (e.g. on the order of milliseconds), one can send down all the time series in a Binned mode and compute the FFT offline.

9.6.6.2 Determining the time bin size

Two factors may be considered for determining the time bin size: (a) the Nyquist frequency, i.e. the highest frequency to be examined, and (b) the telemetry rate constraint. The bin size should be the larger of these:

$$T_b = \max(1 / (2 F_{nyquist}), N_b N_e / R_t),$$

where $F_{nyquist}$ is the Nyquist frequency, N_b the number of bits of storage allocated for each time bin, N_e the number of energy bands, and R_t the maximum telemetry rate.

9.6.6.3 Determining the number of points per FFT

There are two factors that determine the number of points in one FFT: (a) the desired frequency resolution, and (b) the event rate.

If the width of the QPO is W_{qpo}, one desires to have N_{pix} frequency pixels to charaterize the QPO peak. Then the number of points in the FFT should be

$$N_{fft} > N_{pix} / (2 T_b W_{qpo}).$$

On the other hand, one should have at least a few, say, $N_{ph} = 10$, photons for each time series. This demands the $N_{fft} > N_{ph} / (R_0 T_b)$, where R_0 is the estimated event rate. The number of data points to be analyzed in the FFT is then

$$N_{fft} = \max(N_{pix} / (2 T_b W_{qpo}), N_{ph} / (R_0 T_b)).$$

9.6.6.4 Determining the duration of the observation

The average QPO power contained in a typical Fourier frequency is

$$P = (rms^2 N_b R_0 T_b) / N_{pix}.$$

This power is computed using Leahy's normalization, in which white noise has a power P = 2. The *rms* is the fractional root-mean-square variation relative to the dc level. To obtain a 5-sigma detection, we require

$$P / (2 / \sqrt{N_s}) > 5,$$

where N_s is the total number FFT's to average. Thus we have

$$N_s > (10\, N_{pix} / (rms^2\, N_b\, R_0\, T_b))^2$$

9.6.6.5 An Example

Suppose a source has the following characteristics:

- Count rate: 3314 counts/sec (200 mCrab)
- QPO Frequency: 50 Hz
- QPO Peak Width: 5%, i.e., FWHM = 5 Hz
- Fractional RMS: 2 %

We select a Nyquist frequency of 250 Hz, resulting in a binning of T_b = 2 ms. To have 20 pixels under the 5 Hz peak, we require 20 / (2 x 2ms x 5Hz) = 1000 bins in each FFT. Rounding off to the nearest integer power of 2, we have N_{fft} = 1024. Thus each time series is 1024 x 2ms = 2.048 sec long, which on average would have ~ 6700 events in it. Each bin will contain, on average, 13 events. If we further split the light curve into different energy bins and use 4 bits for each bin, the Binned mode telemetry per energy bin is:

4 bits / bin x 1024 time bins / 2.048 secs = 2 kbps.

Using the formula for N_s from above, we have

$$N_s > (10 \times 20 / (2\%^2 \times 1024 \times 3314 \times 2\text{ms}))^2 = 5427$$

Thus the total observation is: 5427 x 2.048 = 11,115 secs.

To determine appropriate EDS modes, we first note that the requirement of N_{fft} = 1024 bins eliminates the possibility of using any of the FFT modes, which construct FFT's based on 256-point time series. We also note that a 12 ksec observation will likely encounter only two earth-occultations. Hence we set the observing efficiency at 75 %. Using a 200 mCrab source with a Crab-like spectrum, the count rates in the canonical PCA bands are:

Energies (keV):	**0 - 3.2**	**3.2 - 4.3**	**4.3 - 5.7**	**5.7 - 8.6**	**8.6 - 12.1**	**12.1 - 60.0**
200 mCrab	661	534	641	725	394	358

Specifying 2 ms timing resolution and optimizing the energy resolution, `recommd` gives the following EDS configurations:

EDS Configuration	**Time Resolution**	**Energy Range**	**Telemetry**
B_2ms_8B_0_49_Q	2 ms	0.0 - 12.1 keV	16.3 kbps
E_16us_64M_50_8s	16 μs	12.1 - 60.0 keV	9.1 kbps