THE HIGH ENERGY EXPERIMENT PDS ON BOARD THE BeppoSAX SATELLITE: DATA ANALYSIS AND FIRST RESULTS

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The high energy experiment PDS on board the BSAX satellite is operative in the energy band 15–300 keV. The detector is designed to have a very low instrumental background and to allow a good control of background variations using rocking collimators that periodically sample source+background and background. In fact most cosmic sources in this energy band give a count rate that is comparable or lower than that from background. The gain of the detector is stabilized by the Automatic Gain Control (AGC) and absoulte gain measurements can be performed using the Movable Calibration System. These capabilities of the hardware must be fully matched by a careful design of the SW and procedures to obtain final products (spectra, time series). We present the first results from the analysis of the Science Verification Phase observations, with emphasis on the data reduction techniques. Examples of data reduction procedures for the final observer are also presented.

1 Introduction

1.1 The Phoswich Detection System

A detailed description of the instrument and of its performances can be found elsewhere.[1] The results of on–ground calibrations were also reported.[2] Here we give a functional description of the detector, aimed to clarify the topics on PDS data analysis discussed in this paper.

The Phoswich Detection System is composed by four identical units, each of them a phoswich (PHOsphor sandWICH) composed by 3mm of NaI(Tl), acting as detector, and 50mm of CsI(Na), acting as a shield. It is operative in

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the 15–300 keV energy band. An anticoincidence system of active shields surrounds the detectors on the sides and on the front. The lateral anticoincidence shields, made of CsI(Na), are also used as a Gamma Ray Burst Monitor.[3] The calibrations of this subsystem are in progress. The results and a description of the data analysis will be the subject of a separate paper.

Two mechanical collimators, with hexagonal cells of Tantalum, limit the field of view to 1.°3 degrees. The collimators can be rocked around the neutral position to monitor simultaneously source and background. The maximum rocking angle is ±210' and four more intermediate steps are available at ±30', ±60', ±90', ±150'.

Its electronics is designed to have a maximum throughput of 4000 events s^{-1}. Events in the NaI(Tl) and in the CsI(Na) crystals are discriminated by the Pulse Shape Analyzer. It accepts or rejects events using the different decay constants of the scintillations produced in the two crystals (about 250 ns for NaI and about 600 ns and 7 μs for CsI). Programmable on-board lower and upper thresholds allow a first hardware selection of the events transmitted to ground. Further finer selections can be performed on-ground during data analysis. Histograms containing PSA spectra integrated without thresholds are also transmitted to ground, as Scientific Housekeepings, with a fixed integration time of 128s (see section 2.4).

An Automatic Gain Control system (AGC) stabilizes the gain of the instrument within 0.25% of the nominal value. This system consists of an Am^{241} source embedded in a small cylinder of plastic scintillator, viewed by a PMT, in the center of the detection plane. The radionuclide emits simultaneously a 60 keV photon and a 5.5 MeV α particle. The signal detected in the plastic scintillator due to the α particles is then used to tag simultaneous events that can be detected in the four units. These events are then used by the PDS Electronic Unit to adjust the gain. Data from the AGC system are transmitted to ground as histograms of counts vs. PHA channel integrated on 128s.

The Movable Calibration System consists of a Co^{57} source distributed along a wire. It can be used to perform a scan of the field of view, allowing a measure of the absolute gain of the four units. This procedure is intended to be used periodically for deep calibrations, and will not be used for the observations in the regular program.

1.2 PDS data management

The PDS Electronic Unit includes the Analog Processor, that performs analog data processing and digital conversion, and the Digital processor, that includes two 80C86 type microprocessors: one devoted to PDS data management and the other to instrument monitoring and commanding. Due to this architecture, the data transmission to ground is highly flexible and completely programmable. For each event qualified by the on--board logic, the available information is: energy of the event (max 10 bits), pulse shape (max 9 bits), event time (max 16 bits), unit (2 bits), anticoincidence flags (3 bits). These PDS events can be transmitted in Direct and Indirect Modes. The Direct Modes transmit each event separately, offering a number of possibilities of data selection and compression from the full 5 bytes to a minimum of 2 bytes per event. These modes are recommended for the vast majority of the sources. Each of the fields describing one event can be compressed and a number of possible combinations are allowed. This approach is intended to be very flexible and is oriented toward the needs of the observers.

The Indirect Modes accumulate on board histograms of counts vs. PHA channel with programmable integration time, two choices in the number of PHA channels (128 and 256) and two choices of bits per histogram cell (8 and 16). Histograms containing high resolution (down to 1 ms) time series can be transmitted in parallel. These modes can be used for sources extremely bright, for which the Direct Mode transmission of data can saturate the available telemetry.

A set of engineering housekeepings (HV, temperatures, some ratemeters, status words, collimator position) is always produced by the instrument and sent to ground.

When the instrument is in Scientific Mode, also other Scientific Housekeepings are produced and transmitted. In this data stream there are the PSA and FCS spectra cited above, spectra from each lateral shield, integrated on 128 s, and a more complete set of ratemeters, including some accumulated at different points of the Analog Processor analysys chain.

The two sets of PDS HK are intended to give the maximum information to monitor the health and the performance of the instrument.

2 PDS data analysis

2.1 The data analysis environment

PDS SW was developed since 1994 in the framework of the XAS data analysis system. We refer to the paper presented in this Workshop on XAS for a complete description of the data analysis system.[4] The development first involved a set of programs and procedures to analyze and archive data coming from the PDS ground test equipment and check–out systems.[5,6,7] This development was almost entirely completed within the first months of 1995.

The SW was tuned for the operative phase starting from the first months of 1996. Now it is under completion and extensive testing. The PDS data analysis for the in–flight data is fully integrated in the XAS data analysis environment for SAX. Here we focus on the data reduction and analysis procedures more typical of PDS.

2.2 Analysis of calibrations – archives

The analysis of PDS on–ground and in–flight calibrations is being analyzed and archived with a set of tools that evolved since their first release for ground calibrations in late 1994[7]. A careful design prevented extensive reprocessing of data and the archive tools can consistently manage products, in term of results of data analysis, both from ground calibrations and from in–flight data.

The archive is based on the commercial relational database INGRES(tm). Results, coming from data analysis as ASCII tables, are stored in the database, in which the suitable tables were defined. The archived data can then be retrieved and used for further analysis.

Two tools for data display and analysis were developed using IDL(tm), a commercial product from RSI. A general purpose tool, *xasplot*, is intended for data display mainly of spectra and time series as histograms and for their analysis. It has also the capability to display XAS images. A dedicated tool for the analysis of PDS "pseudo–images", *xasimage*, was also developed. This second tool allows a more advanced analysis of PDS pseudo–images (see Section 2.4).

2.3 Procedures for the general observer

The default procedures for the general observer are designed to check the performance of the instrument during the observation, to make a standard pre–analysis of PDS housekeepings, to obtain standard products as spectra and time series. We are now (october 1996) testing some of these procedures.

A non exhaustive list of checks that we suggest that the observer makes routinely for a PDS observation are:

a) check of the performance of the Pulse Shape Analyzer using PSA spectra (see section 2.4)

b) check of the performance of the Automatic Gain Control (AGC) system using FCS spectra (see section 2.4)

c) check of the variations in the values of the phoswich high voltages (driven by AGC)

d) check of the count rates in the anticoincidence subsystems

These checks shall be performed by dedicated shell scripts that schedule all the relevant program to extract data products and to analyze them. This analysis will produce a set of good time windows to define the intervals where subsequent analysis should be done. After these checks are completed, the user can start to create the data products needed in the scientific analysis of the observation. As an example, we describe the procedure to obtain net source spectra.

PDS background is monitored using its rocking collimators. Each collimator is mounted above two phoswich units and can be rocked around its neutral position (Section 1.1), that usually is the pointing direction toward the source. The default collimator cycle consists of four dwells at 0^o , +210', 0^o , –210'. Each dwell lasts 96 s as default and can be as short as 50 s. When a collimator is in its neutral position (on–source), the other is monitoring the background (±off–source). The background is sampled very frequently, and there are always two phoswich detectors on source and two monitoring background. The collimator cycle (also called "collimator law") is fully programmable and can be changed at the needs of the observer.

Therefore, to obtain a net source spectrum from PDS, the observer:
a) creates the time windows of visibility (excluding the time intervals when the source is occulted by the earth)
b) creates the time windows for each position of the rocking collimators (±OFF and ON)
c) merges the two preceding time window sets with an AND operation; merges the obtained time window sets and the time windows obtained by HK analysis (see above) with an AND operation
d) accumulates a raw PHA spectrum for the ±OFF and ON positions of the collimators for each PDS unit
e) subtracts OFF spectra from ON spectra, obtaining the net source spectra
f) equalizes the four units by passing from PHA channels to equivalent energy channels
g) if needed (to improve S/N) sums the four equalized spectra to obtain one spectrum from all four PDS units
A shell script that performs all these operations is already available. The intermediate data products are not destroyed and can be used to check the quality of data, in particular the quality of the background subtraction.

Once the net source spectrum is available, the observer can compute the PDS response matrix, for any combination of the PDS units, using *pdsmaccum*. The calculation of the response matrix is performed using extensively tables coming from Monte Carlo simulations. These simulations take into account all the materials that compose the phoswich detectors and give a very accurate estimate of the detector efficiency as a function of the energy of the incoming photons. This response matrix can be written in OGIP/FITS format and in native XAS format, depending on the setting of a XAS environment variable.[4] The spectrum, by default obtained in XAS format, is easily translated to OGIP/FITS using the XAS translation module *toogip*. This flexible approach allows the observer to analyze the resulting spectrum with the tools of his/her preference, as XSPEC or others.

2.4 In–orbit performance and SW fine tuning

PDS was first operated in flight in June 1996. Following some functional tests, a set of sources were observed to evaluate the performance of the instrument for the scientific observations. A complete list of the sources included in the so called Science Verification Phase is available on the net (*http://www.sdc.asi.it*). Here we report some preliminary results obtained during one of the observations of the Crab Nebula, the standard candle in X–ray astronomy.

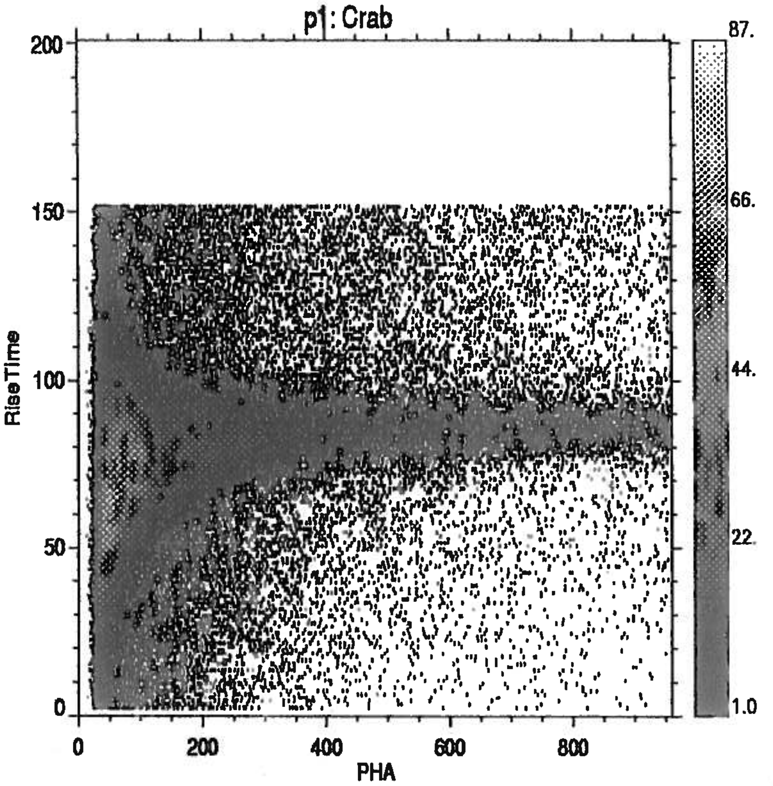

Figure 1: Pseudo–image for unit 1 accumulated during an observation of Crab. Only the first 200 PSA channels are shown.

In Figure 1, we report a PDS pseudo–image. The X axis is the PHA channel, i.e. the amplitude of the signal in our detector, related to the energy of the photon that interacted with the detector. The Y axis is the PSA (or

Rise Time) channel, i.e. the duration of the detected scintillation. Higher channels correspond to longer scintillation times. The brightness of the image is linearly related to the count rate. The continuous track visible in the figure represents the events detected in the NaI(Tl) detector. The CsI(Na) events leave, if transmitted to ground, a track centered approximately at channel 290. The sharp cut at channel 150 is due to the on-board hardware threshold. All events due to CsI and most of the "mixed" events (photons that leave part of their energy in both crystals due to e.g. Compton scattering) are rejected.

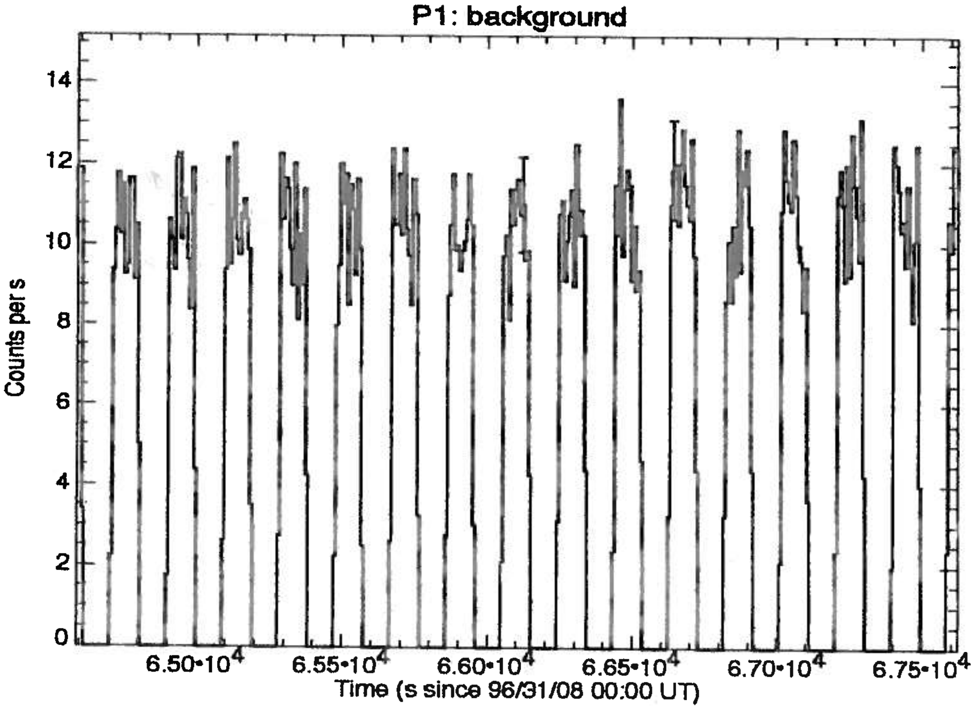

Figure 2: Count rate from background for unit 1 along one orbit during an observation of Crab; each bin is averaged on 8 seconds (see text).

In Figure 2, we report the background count rate observed with unit 1 along one orbit. The interruptions in the time series are in coincidence with the pointing of the collimator on-axis. In these intervals the average count rate per second from source is about 50 counts s^{-1}. The background count rate appears to be stable: the variation in this orbit is of the order of 10%.

In Figure 3, we report the background spectrum of PDS. Two line blends are apparent at about 30 and at about 60 keV. These blends were also observed on ground, even if with different relative and absolute intensity. Part of the emission in these blends comes from the collimator and part from a very small fraction of untagged events from FCS. However we also expect to have an activation line, due to I^{123} at 57 keV, and other features around 30 keV in

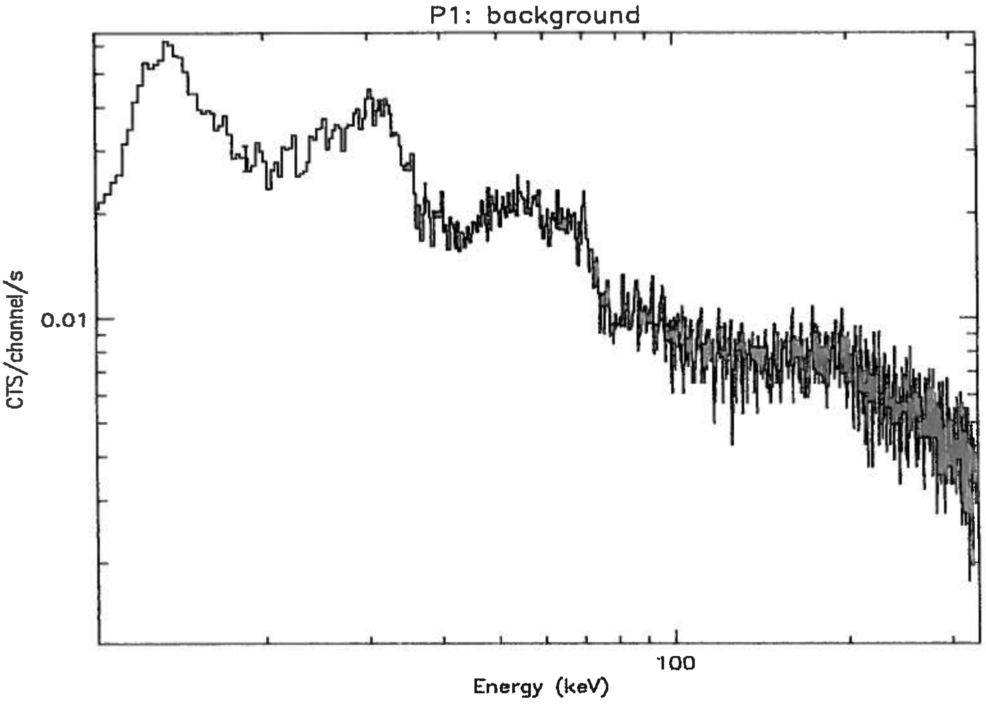

Figure 3: In–flight background for unit 1 accumulated during an observation of Crab.

addition to the ones already observed on ground. These features are due to the activation of radionuclides in the detector itself. We observe a fair stability with time.

In Figure 4 a FCS spectrum from unit 1 is shown. This spectrum is obtained accumulating the tagged events used by AGC. The two peaks in the spectrum correspond to 60 keV and to the escape for 60 keV photons. In the same figure we also report the same spectrum as measured on ground. The two spectra overlaps, this indicating that the performance of AGC is similar to that measured on ground.

Figure 5 shows a PSA spectrum of unit 1, obtained accumulating on board a histogram of all the events analyzed by PSA, without any threshold (see also Figure 1). The two peaks due to NaI (left) and CsI (right) events are well separated. We also report the same spectrum as measured on ground. The difference in the peak position is due to the difference in temperature: the decay constant has a slight dependence on the temperature of the crystals.

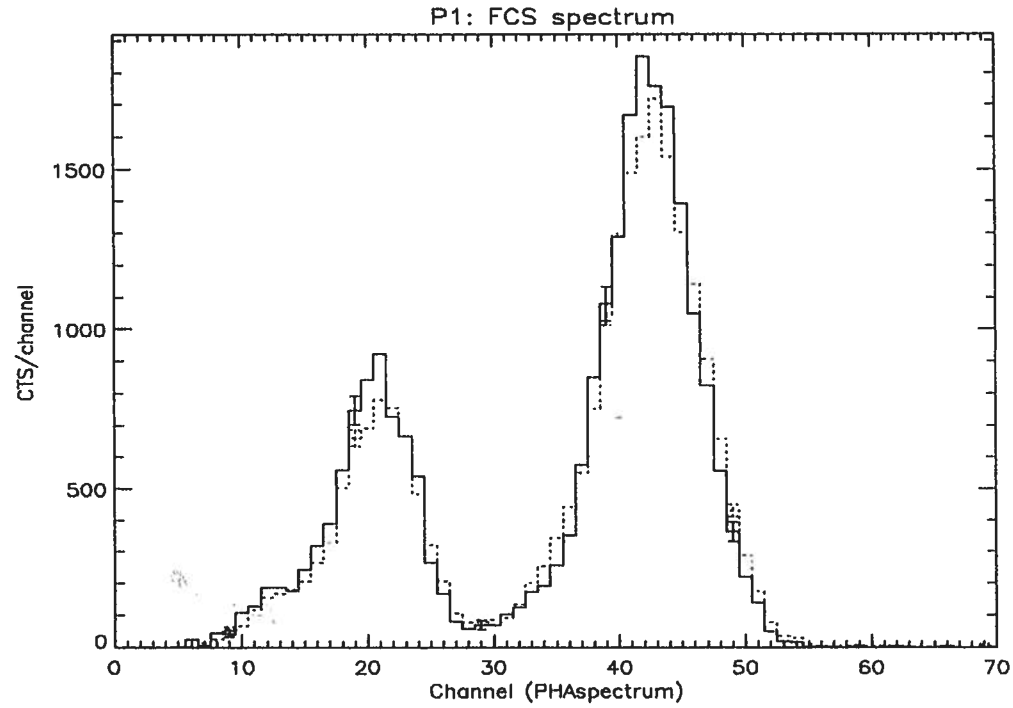

Figure 4: In–flight and on–ground FCS spectrum for unit 1. Continuous line: on ground. Dotted line: in flight.

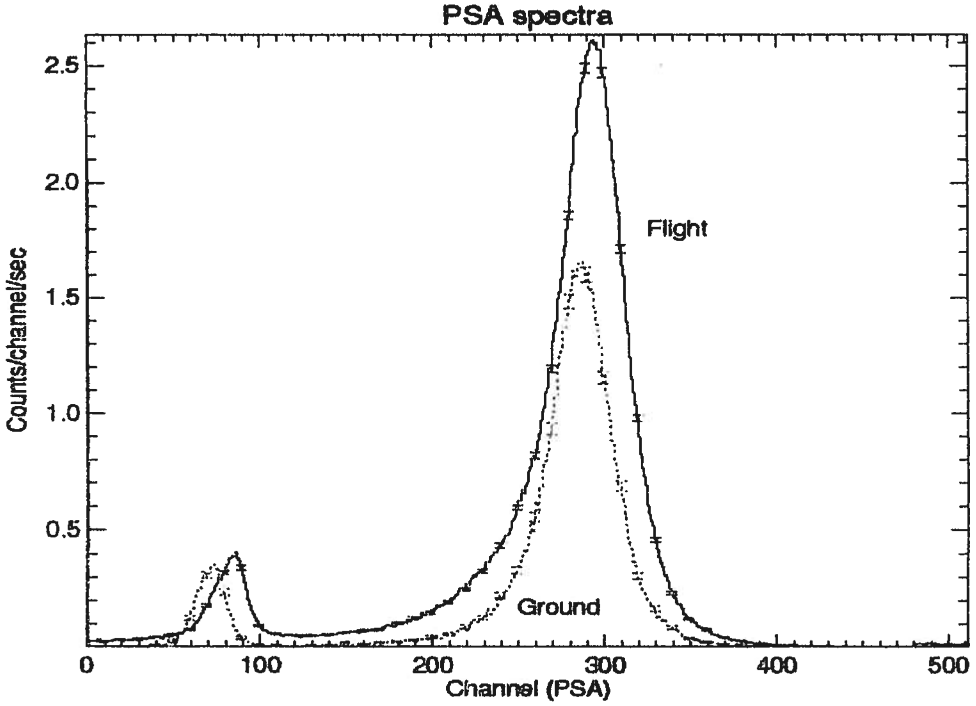

Figure 5: In–flight and on–ground PSA spectrum for unit 1.

3 Conclusions

The good in–flight performances of PDS simplify the design of the SW to analyze data. The layered and modular development of the SW guarantees that refinements can easily be added, as soon as more detailed calibrations become available.

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