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CACTμS: A small CdTe array for a prototype balloon experiment

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Abstract

The Compact Array of Cadmium Telluride Micro Spectrometers (CACTμS) instrument was constructed as a prototype detection plane for the Coded Imager and Polarimeter for High Energy Radiation (CIPHER) telescope. The instrument, flown as a 'piggy-back' experiment on a stratospheric balloon from the Milo Italian balloon base in Sicily in July 2002, was constructed to verify the feasibility of using this kind of position sensitive detector for hard X- and soft γ-ray polarimetry and imaging. The main objective was to study the instrumental background at stratospheric balloon altitudes over the 20–1000 keV energy range. Of particular interest is the spectrum and distribution of Compton scattered events that trigger two pixel, the recognition of which is essential for providing a high sensitivity to linear polarization. The CACTμS data will be also used to evaluate the efficiency and the reliability of an off-line numerical algorithm for CdTe signal compensation, which uses the amplitudes obtained by a double shaping filter stage readout electronics. Herein we present both a description of the experiment and preliminary results from the flight data.

PACS: 07.85.Nc; 95.55.Ka; 95.85.Pw

Keywords: CdTe spectrometers; X- and γ-radiation; Stratospheric balloon; Polarimetry; Background

1. Introduction

The design concept compact telescopes suitable for hard X- and soft γ-ray astronomy based on the use of thick cadmium telluride (CdTe) position sensitive spectrometers, with their low energy threshold (10 keV) and high pixel density (a few mm^2/pixel) allows their operation both as a position sensitive spectrometer in a coded mask telescope and as a high-energy (> 100 keV) polarimeter [1]. In particular the Coded Imager and Polarimeter for High Energy Radiation (CIPHER) telescope concept has been proposed for making simultaneous polarimetric and imaging measurements in the hard X- and soft γ-ray range from 10 keV to 1 MeV [2]. The CIPHER instrument is based on a detection plane made of a large array of CdTe micro-spectrometers. It was

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The Compact Array of Cadmium Telluride Micro Spectrometers (CACTμS) instrument was constructed as a prototype of the CIPHER detector to verify the feasibility of using this kind of position-sensitive detector for X- and soft γ-ray spectroscopic imaging and polarimetry. In particular the objectives of this small experiment are: (a) to study the instrumental background at balloon altitudes over the 20–1000 keV energy range with particular respect to the spectrum and the distribution of Compton scattered events triggering two pixels (double event); (b) to evaluate the efficiency and the reliability of an off-line numerical method for signal compensation using the amplitudes obtained by an electronics with a double shaping filter stage on CdTe flight events.

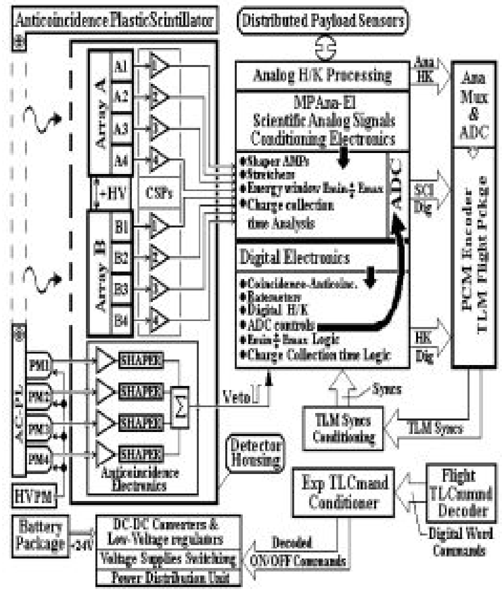

Fig. 1. CACTμS functional block diagram.

2. Instrument description

The CACTμS in-flight configuration [3] is schematically shown in the functional block diagram of Fig. 1. The main subsystem are the following: (i) *the Primary detection System Housing* [CdTe detectors]; (ii) *The Anticoincidence detector* [Plastic Scintillator: AC-PL] with four Photomultipliers tubes (PMs); (iii) *The scientific Data Handling System* [MPAna-EL with Analogue-to-Digital Conversion (ADC) and digital Control Electronics]; (iv) *The Service Electronics* (SE); (v) *The Pulse Code Modulation Unit* (PCM Enc); (vi) *The Telecommand Unit* (TLC Flight Decoder).

The CACTμS detector is based on two small CdTe detector arrays operating at room temperature. Each detection array consists of a single CdTe crystal electrically divided into four independent channels by means of a segmented electrode deposited on one face (collecting electrodes), while on the opposite one there is a common electrode connected to ground. The pitch between the strip centres is 2 mm (1.8 mm wide metallic strip plus a 0.2 mm gap). Each strip, which is positively biased at +120 V, collects independently the charge released by an X-ray event in the CdTe crystal. Since any electrode is separately read by a hybrid Charge Sensitive Preamplifier (CSP), each CdTe crystal unit is equivalent to an array of 4 pixels of $2 \times 2\,\mathrm{mm}^2$ with a thickness of 10 mm. The detection assembly is housed in a light-tight container (Fig. 2) together with the front-end electronics (CSPs), the high voltage supply (HV), the low voltage supplies, the temperature sensors, the analogue processor for the PM anticoincidence signals and the voltage monitoring signals. The primary detection system is actively shielded by an anticoincidence (AC) plastic scintillator. The AC shield is separately housed in a light-tight container surrounding the CdTe housing and is made of 3-cm-thick Plastic scintillator shaped as a cylinder with a central hole. Four half-inch diameter PMs optically coupled to the scintillator collect the light delivered by an event. The PM's analogue signals conceived as a balloon borne payload primarily intended to perform measurements of the polar- ization level of strong astrophysical sources (the target of the first flight being the Crab pulsar) and thereby to assess the performance of such an instrument in the context of a small/medium size satellite high-energy survey mission.

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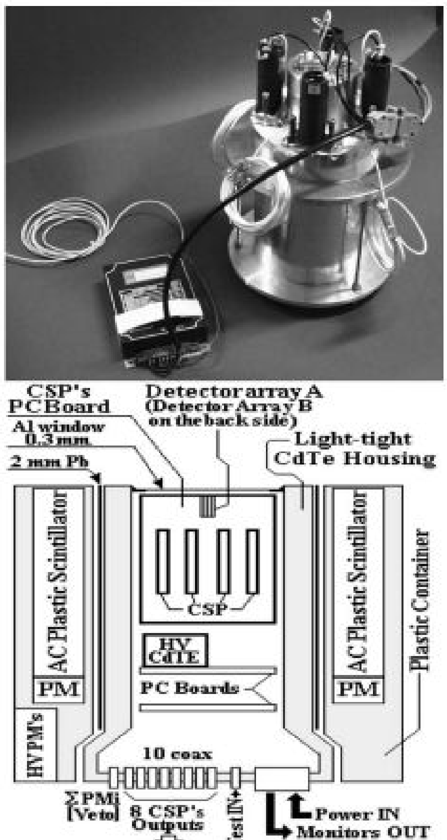

Fig. 2. The CACTμS detection system. (Top) A picture showing the CdTe detector housing surrounded by the A/C plastic shield coupled to 4 PMs; (Bottom) Schematic cross-sectional view of the CACTμS detection equipment.

are summed inside the CdTe housing to provide the "veto" command to the Digital Control Electronics. An additional passive shield (2-mm-thick Pb layer) is inserted between the AC shield and the CdTe detector.

The Scientific Data Handling System, based on a custom multi-parametric electronics (MPAna-El), conditions the signals from the CdTe channels and includes the digital Control Electronics, and the A-to-D converter. The signal from any detector CSP is fed to the MPAna-El to be first amplified to match to the ADC converter range and then shaped by two parallel active filters. The first filter (0.35 μs shaping time) is used to extract information on the electron charge collection ("fast" signal component) while the second, (3 μs shaping time), gives information on the total charge (electrons and holes) collected ("slow" signal component). The "slow" component represents the integrated charge collected at the electrode which is proportional to the total energy of the X-ray event, while the "fast" accounts for the position of the event with respect to the collecting electrode; the off-line analysis of both components could permit the recovery of information on the charge loss in the detector and should allow a reconstruction of the energy of the primary photon [4]. Both offset and gain drifts of each analogue amplification chain are automatically corrected by test pulses that are periodically generated on board.

The Digital Electronics controls the functions specified in Fig. 1 and also codes and formats the data for their correct loading in the PCM encoder.

The Service Electronics includes all the active devices to properly bias the experiment subsystems, the DC–DC converters power supplies, the Telecommands (TLC) conditioner connected to the flight TLC decoder, the analogue housekeeping module which mainly monitors the temperatures and the operating voltage supplies, and the Sync electronics which regulates the data transfer timing to the PCM encoder.

The Telemetry (TLM) format is generated by a programmable 760 Metraplex PCM Encoder. The operative bit rate used in the CACTμS flight was 8192 bps with a basic word length of 8 bits. Scientific data were super-commutated in the TLM format (256 byte) while both Analogue HK and Digital HK were sub-commutated. The Digital HK includes the integrated counts accumulated in the CdTe detector and the anticoincidence detector on a time base of ~65 ms. During the flight the serial output code generated by the PCM Encoder was transmitted to ground through the IRIG sub-carrier "G" channel.

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3. Preliminary flight results

CACTμS was flown as a 'piggy-back' experiment on a stratospheric balloon platform dedicated to the BABY experiment as part of the summer 2002 trans-Mediterranean flight campaign from the Italian Space Agency balloon facility in Milo (Sicily). The balloon was launched on the 10th July 2002 at 23.08 local time. The payload arrived safely in Spain after a flight of about 12 h. The average float altitude was about 39 km.

3.1. House-keeping analysis

All the voltage supplies, including the two high voltages biasing the CdTe detector and the Plastic PMs, were continuously monitored during the flight with data transmission in the TLM format. During the entire flight no voltage monitor deviated from its nominal value by more than twice the quantization uncertainty (± 40 mV), thus confirming the reliable operation of all the CACTμS subsystems.

The in-flight monitored temperatures deviated from their value at ground due to the thermal gradients with respect to the external environment. Fig. 3 shows both the maximum temperature (Power Electronics) and the minimum temperature (CdTe detector) recorded during the flight: any other CACTμS subsystems' temperature showed a trend similar to those shown in Fig. 3. The detector temperature drift from $+28°$C down to about $-6°$C should not have produced any influence on the overall detection apparatus since in-flight automatic gain and offset correction are continuously performed inside the analogue processing electronics.

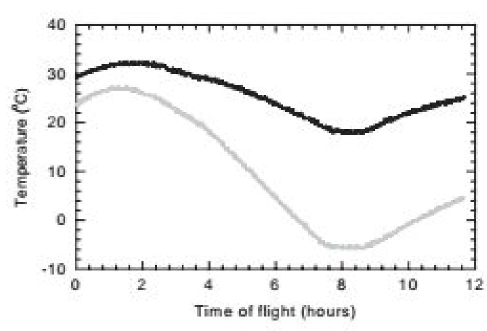

Fig. 3. Detector and electronics monitored temperatures as a function of time from the launch.

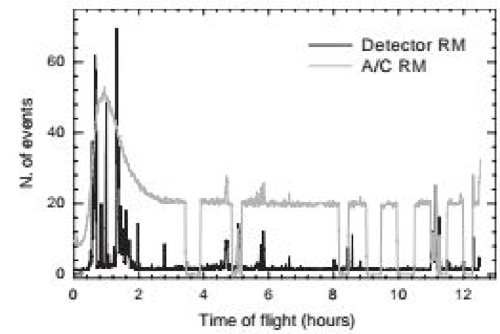

Fig. 4. Two digital house-keepings (detector and AC counter) during the flight. These counters represent the detector good-events and the plastic counts integrated over the operational energy range and in a time interval depending on the actual TLM bit-rate.

During the flight, at regular intervals, we continuously sent two tele-commands to switch-on and switch-off the anti-coincidence system in order to evaluate the efficiency of the Veto system to reduce the instrumental background. Fig. 4 shows the count rates of the detector and anticoincidence during the entire flight. During the ascending phase (~ 2 h) strong spikes are detected in the CdTe units, probably due to atmospheric shower events. At plafond, both the detector and AC count rates are quite constant (~ 1.5 for the CdTe and ~ 20 for the Scintillator). Other visible features are still under investigation as well as the effect of the AC on–off cycles on the detector count rate.

3.2. Scientific data analysis

The scientific data analysis is just started and as a first step we have concentrated on the analysis of single events (events that hit only one CdTe pixel) by integrating the energy spectrum over each pixel during different phases of the flight. The data have shown a good uniformity in the spectroscopic response of each pixel spectrum allowing us to obtain a summed energy spectrum for the entire

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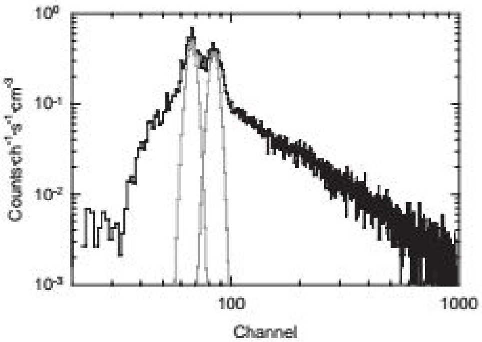

Fig. 5. The counts spectrum of single events at float integrated over ~5 h. The two visible spectral features are compatible with the K-edge lines from Pb.

detector. In Fig. 5 the raw energy spectrum at float altitude is shown. This spectrum of single events is obtained by accumulating about 5 h of data (from 2:54:30 to 7:46:22 UT). Using the energy channel conversion obtained during the ground calibrations we have the effective low energy threshold at ~30 keV. The two visible spectral features are compatible with the Pb K-edge lines which would be expected to originate in the 2 mm thick lead cylinder surrounding the CdTe array. The count rate integrated over the full operational energy range is of $22 \pm 5\, c/\mathrm{s}/\mathrm{cm}^3$ and is compatible with the results form other balloon experiments [5].

4. Conclusion

The preliminary analysis of both the CACTμS house-keeping and scientific data have shown the correct behaviour of the instruments during the flight. For the next step we will concentrate on a deeper analysis of the detected energy spectrum (for all event types) and in particular on the effect of the veto system as well as on the possibility to use the bi-parametric information (*fast* and *slow* amplitudes) of each event to improve both photopeak efficiency and spectroscopic performance of the CdTe array.

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