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Memorie della

The Simbol-X focal plane

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Abstract. The Simbol-X focal plane is designed to detect photons focused by the mirror in the 0.5 to 100 keV energy band. Composed of two detectors, it will measure the position, energy, and arrival time of each incoming X-ray. On top of it will be a collimator to shield all photons not coming from the mirror field of view. The whole system is surrounded by an active and passive shielding in order to ensure the required very low background.

Key words. Simbol-X

1. Introduction

The Simbol-X detector payload is composed of two separate systems: the X-ray photon camera, called the Focal Plane Assembly or FPA, which is described in part 2, and the collimator, which shields the light not coming from the field of view. The geometry and composition of this collimator is given in part 3. In part 4, we detail the on-board data storage and telemetry rates.

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2. The focal plane assembly

The focal plane is composed of two imaging detectors on top of each other, the Low Energy Detector (LED) and the High Energy Detector (HED), described below, and shown in Figure 1. The LED and the HED measure the position in focal plane coordinates, the energy, and the onboard arrival time of each incoming X-ray.

Each imaging plane is made of 128×128 pixels, with a pixel size of 625×625 μm^2. This, in conjonction with a mirror with a 15 arcsec Half Energy Width angular resolution (Pareschi et al. 2007) at 20 meters away, provides an oversampling of the Point Spread Function by a factor 2.3.

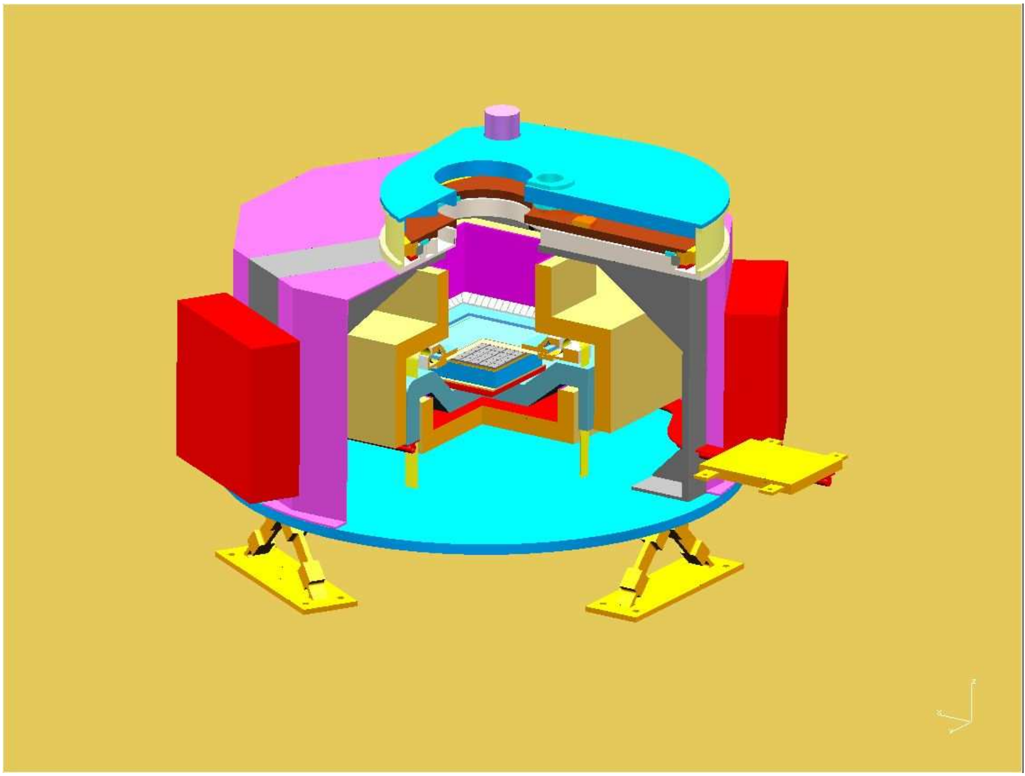

Fig. 1. cut view of the focal plane assembly. The active shielding, in orange, is in two parts to surround the imaging detectors. On top is the calibration wheel.

The two imaging detectors are placed as close as possible, to be well within the focal depth range (a few cm), taking also into account the relative motion of the two satellites. In addition, in order to avoid any electrical interferences, a aluminum conducting foil is placed between the two detectors. This foil is the only matter between the X-ray detecting materials of the two planes.

In order to reduce the background to the required level (Ferrando et al. 2007), the two imaging planes are surrounded by an active and passive shielding (anticoincidence) which encloses them completely, except for the telescope field of view.

Lastly, on top of the focal plane assembly, is located a calibration wheel which hold the calibration sources (^{60}Fe and ^{241}Am). This wheel has also an open position, for observations, and a close position for protection of the detectors during times of high radiation and study of the internal background.

2.1. The low energy detector

The heart of the low energy detector is a monolithic macro pixel detector array. The readout scheme of the pixel detector is that of an active pixel sensor, that is a Silicon drift detector with an integrated DEPFET. The Silicon thickness is 450 μm. An aluminum optical blocking filter, 100 nm thick, is deposited directly onto the surface of the LED. The LED mechanical design is shown on Figure 2.

The LED quantum efficiency is given in Figure 3, taking into account the 450 μm depletion depth for the bare LED chip (without optical window), and the 100 nm Al filter deposited on the LED.

Fig. 2. LED mechanical design

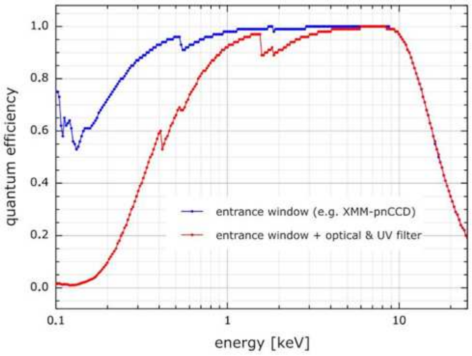

Fig. 3. Quantum efficiency of the bare LED chip (blue curve) and with the nominal optical filter (red).

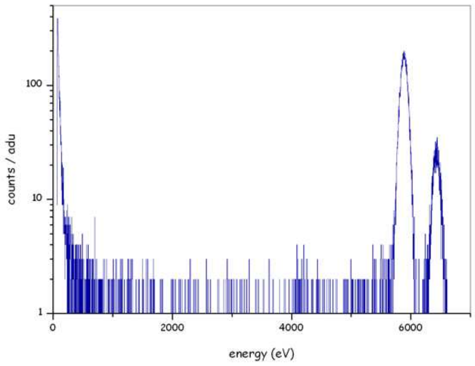

Fig. 4. Example of spectrum measured on a 64×64 pixels device, with a pixel size of 64 μm. The energy resolution is around 130 eV at 6 keV. The operating temperature is ≈ −40 C.

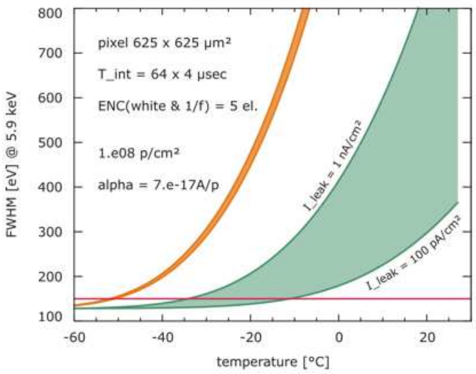

Fig. 5. expected energy resolution of the LED, as a function of detector temperature. The best to worst leakage current cases are indicated. The green area is before any radiation damage. The orange area is for an irradiation of 10^8 protons/cm^2 (10 MeV equivalent) considered at this stage as an upper limit for 2 years of solar maximum for the orbit of Simbol-X. The red line is the requirement.

the LED design allows an excellent energy resolution for relatively high temperatures. An example of what has been achieved on a 64×64 pixels device, with a pixel size of 64 μm is shown on Figure 4. The energy resolution is around 130 eV at 6 keV, for an operating temperature of ≈ −40 C.

The energy resolution of the LED is dominated by leakage current. The leakage current strongly depends on temperature, on the detector material, the pixel volume and on the integration time. This resolution will degrade with irradiation of the detector. On figure 5 is shown the expected energy resolution for an irradiation by 10^8 protons/cm^2 (10 MeV equivalent), expected after five years of operation in space. The required 150 eV resolution (Ferrando et al. 2007), obtained at the beginning of the mission with an operating temperature of ≈ −30 C, can be also achieved at the end of the mission cooling the LED down to ≈ −45 C.

The LED detector is logically and functionally divided into four quadrants of 64 × 64 pixels each, which can be read in parallel. The read out scheme proceeds row by row, and can be flexible. The read-out time of one row is 4 μs in the baseline design, with a CAMEX (Charge Amplifier MutliplEXer) chip. With an upgrade of the read-out electronics, which is under study, the read-out time can be diminished to 2 μs per row.

Two main imaging modes are presently considered :

i) the full frame mode, in which all the 64 rows of the quadrants are read, giving a 128 $\times$ 128 pixels frame. The baseline readout time is 256 μs. The upgraded readout time is 128 μs.

ii) a window mode, in which only a predefined numbers of rows are read for each quadrant.

2.2. The high energy detector

The High Energy Detector is a hard X-ray camera made of arrays of "Caliste" modules of 1 cm^2 arranged in a 8×8 square in order to cover the mirror field of view. The reference configuration is to have 8 sectors of 2×4 modules each, as illustrated in Figure 6.

The detector material is a 2 mm thick CdTe (or CdZnTe) crystal which provide the stopping power necessary to detect the focussed photons.

A Caliste module is made of a pixellated CdTe crystal mounted on its associated front end electronics. All electrical contacts are routed below, so that the module is four-side buttable; a demonstrator module is shown in Figure 7.

Segmented electrodes are defined on each monolithic crystal, by a photolithography process, to define an array in 16 $\times$ 16 pixels. A guard ring, of 50 μm width, is also implemented on the edge of the crystal for spectral resolution and stability reasons. Due to the dead area on the edge, the Caliste filling factor is 96%.

During phase A, a number of CdTe and Cd(Zn)Te crystals, of different thickness and contact types, have been systematically characterized in a dedicated test chamber. Spectroscopic measurements have been performed on 64 pixels crystals read-out by the

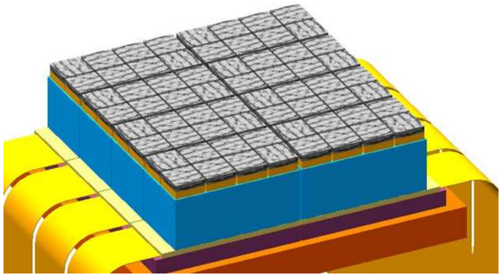

Fig. 6. assembly of the 64 Caliste modules, into 8 sectors of 8 modules each

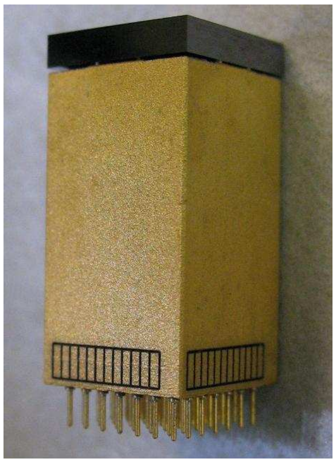

Fig. 7. demonstrator of the Caliste module (CEA - 3Dplus - CNES).

IDeF-X V1.0 chip, which is an intermediate development version of the specific Simbol-X chip. The Figure 8 shows the sum spectrum over 64 pixels of a 2 mm thick CdTe Schottky detector operated at - 37C. An excellent spectral response is obtained, with a 0.78 keV resolution at 60 keV, fulfilling the Simbol-X mission requirements. A similar result is obtained for CdZnTe crystals (0.93 keV).

The HED is a self-triggered detector, so there is no concept of frame time as for the LED. The read-out of each Caliste module is also independent of the read-out of the other modules. The module read-out time is less than 50 μs, the accuracy of the time tag is better than 300 ns.

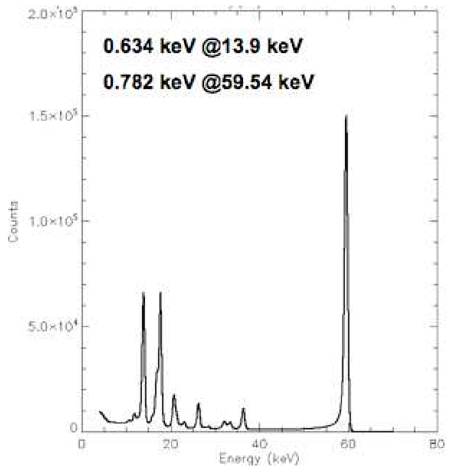

Fig. 8. measured spectrum of a ^{241}Am source with a CdTe Schottky, 2 mm thick, 64 pixels detector. The operating temperature is −37 C, with an applied bias of 600 V.

2.3. The background reduction system

The background reduction system is made of two principal parts.

The first part is an active shielding, which gives a fast signal when it is traversed by a charged particle. As this charged particle could generate background signals in the HED or LED (directly, by going also through the imaging detector, or indirectly by generating photons through interactions with the surrounding matter), this fast signal is used as a veto signal for the acquisition of imaging detectors data.

The second part is the a passive shielding against photons, coming from all the sky direction except the field of view and which could also induce background events in the detectors.

The phase A study has led to a design completely hermetic to particle straight line trajectories. The active part is made of plastic scintillators, coupled to optic fibers. These optic fibers are read by multi-anode phototubes fixed on the Focal Plane Assembly protective enclosure. The time tag accuracy of each anticoincidence event is better than 50 ns.

The passive part is made of a graded shield of similar composition than for the collimator (see 3), and same thickness except for the Tantalum. Indeed, it was found necessary, by Monte-Carlo simulations (Chipaux et al. 2007), to increase its thickness to 3 mm in order to efficiently reduce the background due to hard X-ray photons.

3. The collimator and sky shield

The function of the system made of the collimator on the detector spacecraft, and the sky shield on the mirror spacecraft, is to prevent out of the field of view photons to reach the focal plane. The collimator should also never screen the field of view.

The dimensions of these systems are calculated to fullfill these two constraints, taking into account possible misalignments (lateral and in tilt) as well as movements in all directions due to the formation flight. For mass optimization the collimator is made of three tubes with increasing diametre and decreasing thickness, from the detector end to the mirror end.

The shielding of the collimator is composed of successive layers (from outside to inside) of Ta/Sn/Cu/Al/C. The C layer is the inner tube itself. The thickness of the layers are calculated, for each tube, in order to have less than 0.01% of transmission of X-ray photons up to 100 keV, arriving from the sky onto the detectors.

As the sky-shield, on the mirror satellite, is covering a very small solid-angle, its opacity to X-rays does not need to be as large as for the collimator. Calculations show that a single layer of Ta is sufficient for ensuring the necessary screening.

4. Data storage and telemetry

The three detectors generate events with the following size :

- 146 bits for the HED
- 32 + 32 (time tag header, one per line) bits for the LED
- 29 bits for the ACD

The HED and LED data are stored in an on-board mass memory, after treatment in the Event Processing Electronic (EPE). It is not

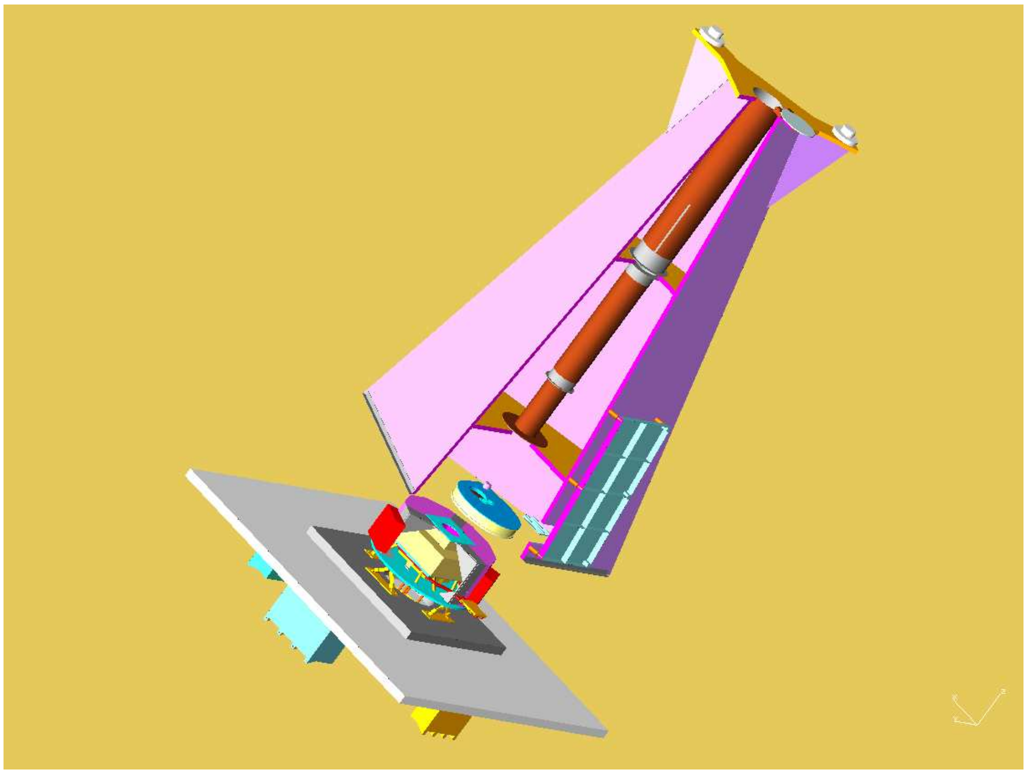

Fig. 9. implementation of the collimator above the focal plane assembly. The collimator tube is inside a tower structure which also supports the radio-frequency antennas for the formation flight, and the radiator for the cooling of the imaging detectors.

anticipated to download anticoincidence data during normal operations. The interfaces between the detectors electronics and the EPE allows a bit rate of at least 20 Mbits/s, which is not a limiting factor for all astrophysical observations. The mass memory is of at least 32 Gbits.

The phase A telemetry capabilities have been sized to ensure :

– a scientific data download capability of 9 Gbits per orbit (with margin).
– a scientific quicklook capability of 50 Mbits per contact with the ground.

References

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