X-Ray Events Recognition and Caracterisation in the EPIC/MOS cameras onboard XMM

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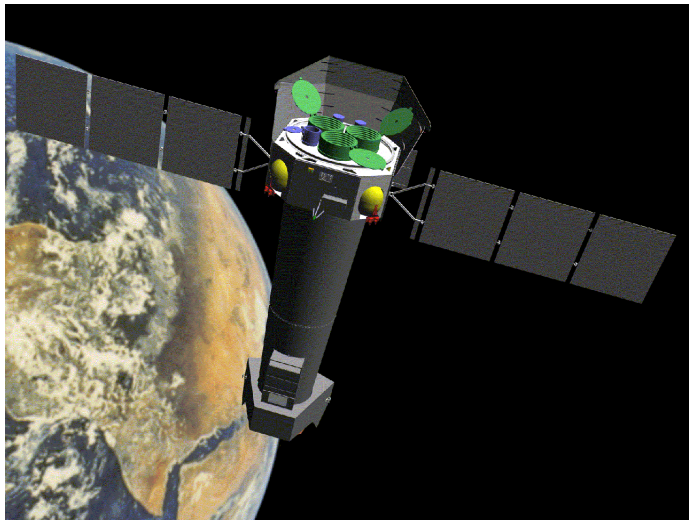
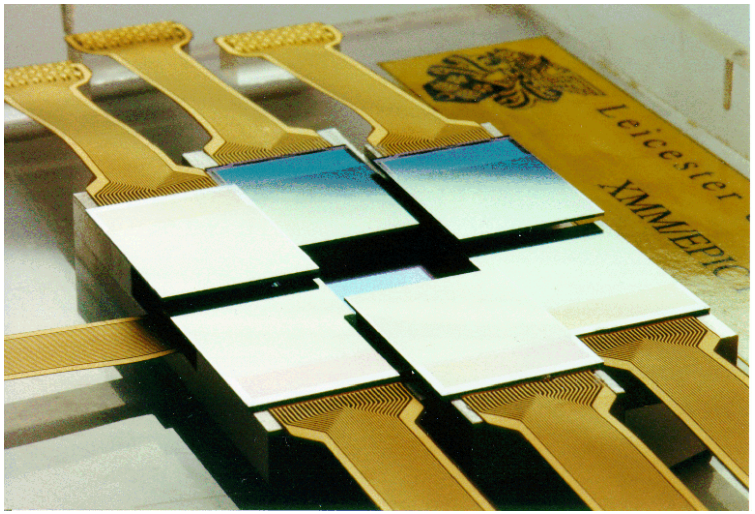




I. INTRODUCTION

The two EPIC/MOS cameras that will fly onboard XMM, to be launched in January 2000, are made of seven 600 × 600 pixels CCDs each (above picture). Each CCD will be read every ~ 3 seconds in full frame mode. Because of the telemetry constraints, a real-time onboard recognition of X-ray events present on the CCD images is necessary. The images are filtered out from cosmic-rays tracks, and only the information about the detected X-rays are transmitted to the ground. This is the role devoted to the ASIC circuits inside the Epic Mos Control Recognition unit (EMCR), designed and built by the CEA/SAp.

In this presentation we first describe the main steps followed by the recognition scheme from the raw CCD images to the transmitted X-ray events data. This processus uses a limited number of parameters, which can be set by telecommand.

Among these parameters, only the “threshold” is expected to be actually varied from one observation to the other. During the synchrotron calibration of the cameras, we have studied the variation of the detection efficiency as a function of this parameter and of the X-ray energy. The results of this study show that, except for the very low energies, the detection efficiency presents a plateau as a function of the X-ray energy.

II. X-RAY RECOGNITION SCHEME

As in all CCD detectors, X-ray events are recognised as local charge enhancements in the CCD images. To do so, each image is processed in the following way.

1. Algebraic substraction of an offset “pseudo-map”

The goal of this operation is to correct for the background level of the image. The resulting image has an average of zero.

The offset “pseudo-map” consists of two arrays of offset values, one for the lines and one for the columns. The offset value substracted to each pixel with position (C, L) in the raw image is the sum of the column offset for column C, and of the line offset for line L.

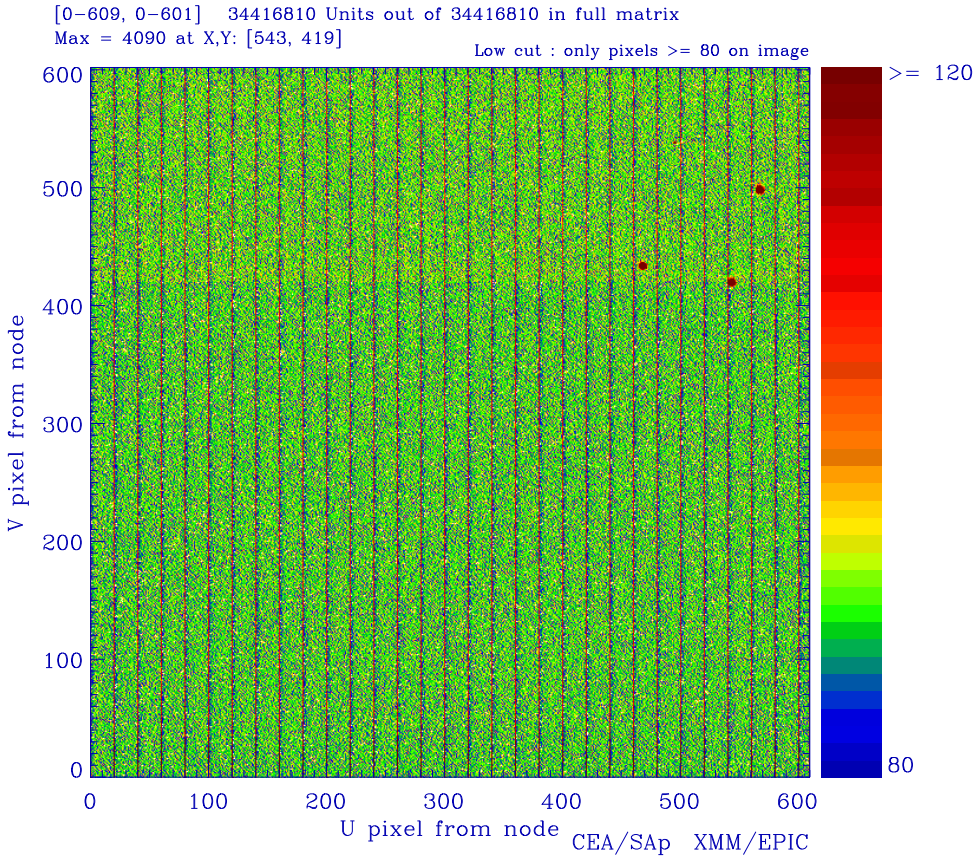
The offset pseudo-map depends on each observation, since the background level depends on the visible brightness of the observed region, as well as the setting of the camera (in particular the filter used). The offset is thus calculated at the start of each observation, following an algorithm which excludes from the calculation the zones which are very locally enhanced (as X-rays and cosmic ray tracks).

The two images below show an actual image, together with the offset pseudo-map calculated from it (note that this particular raw image was obtained with a special reading of the CCDs which generates bright columns. It has been abandonned since).

Example of a raw image, and of the offset pseudo-map deduced from it

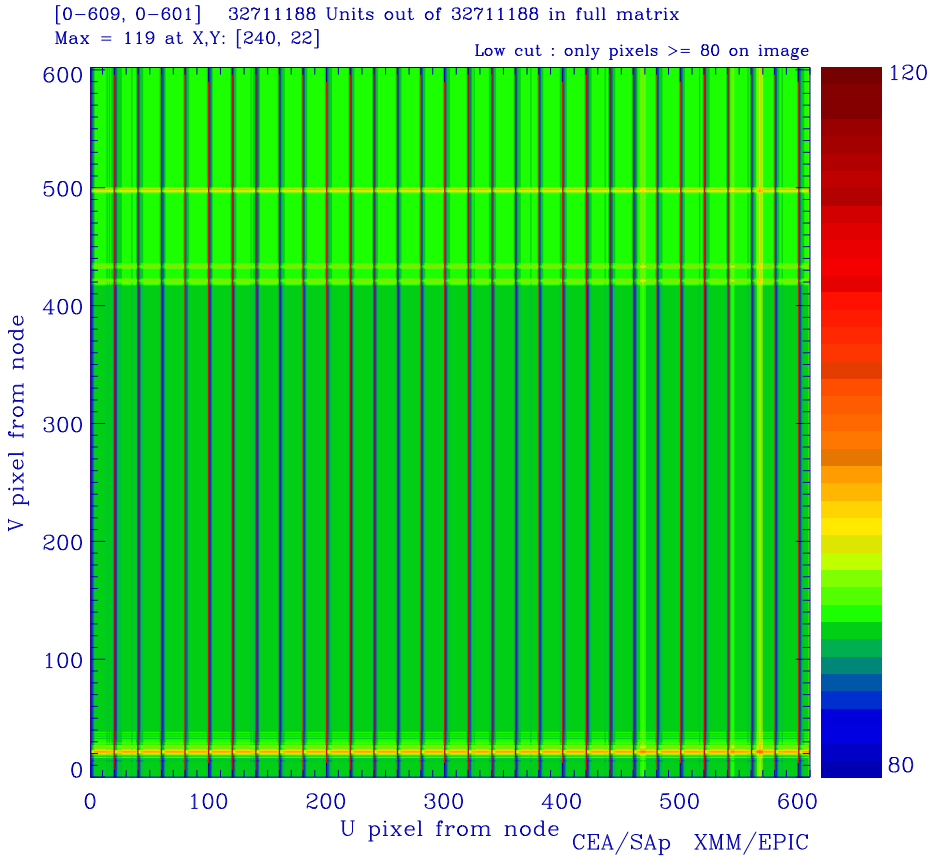
Raw image

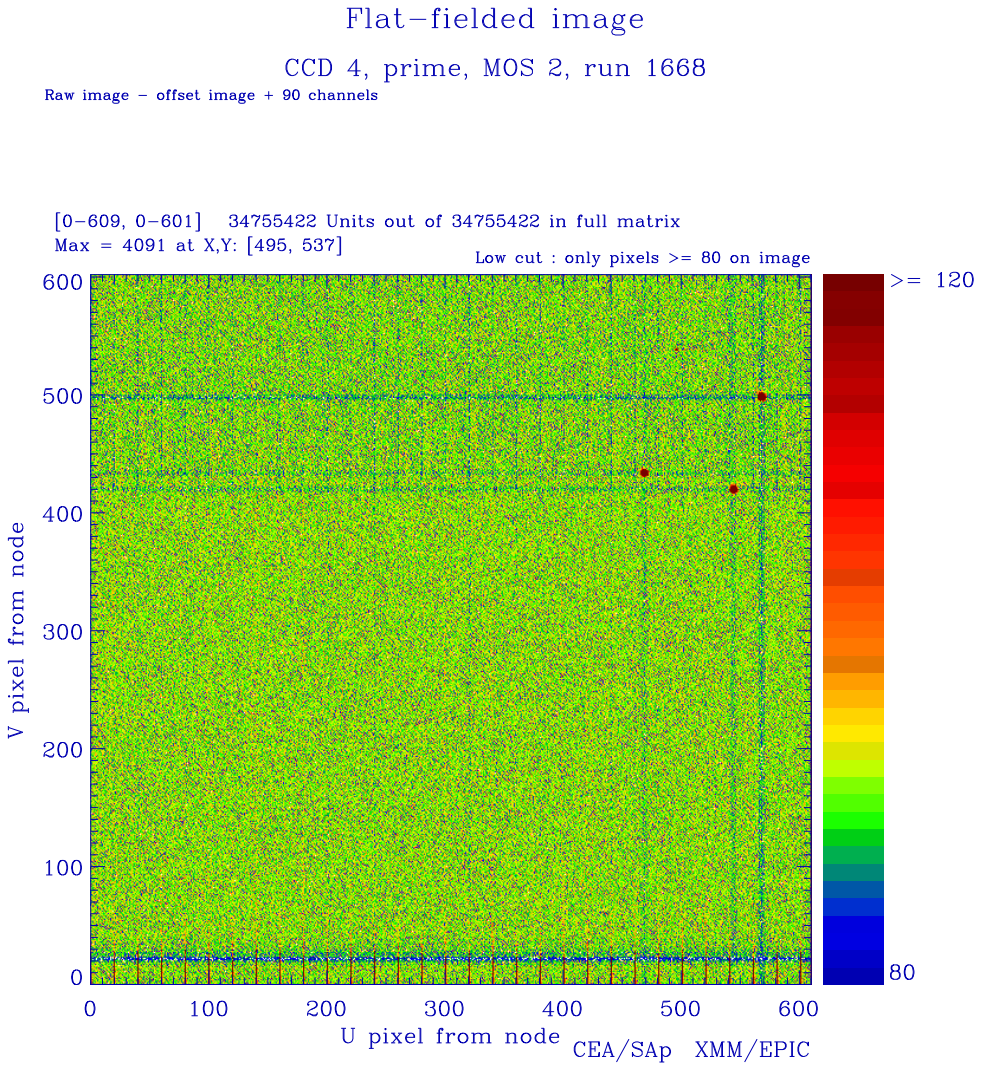
CCD 4, prime, MOS 2, run 1668



Offset pseudo-map

CCD 4, prime, MOS 2, run 1668





The image on the left shows the result of the substraction of the offset pseudo-map to the raw data (shifted by 90 channels here).

As expected, the three cosmic-rays have been rejected from the offset calculation, and are thus appearing on this image. But, whereas the systematic bright columns have been indeed flat-fielded, this is not the case for all of the image.

This clearly illustrates the fact that the offset pseudo-map is the sum of two 1-D arrays, and not a true 2-D image. The offset pseudo-map can thus correct for smooth variation of the background over the CCD, but not for very localised strong variations as the one induced by a bright star.

Besides the two offset vectors, the calculation gives the variance of the offset corrected image, which is an input for the setting of the “threshold” parameter used for the X-ray detection.

2. X-ray event recognition

The event recognition scheme looks for a local enhancement of signal in the flat-fielded image. This enhancement is searched in a sub-image of 5×5 pixels which sytematically scans the full image, and is defined with respect to a threshold value, constant for the full CCD frame, set by telecommand for each observation.

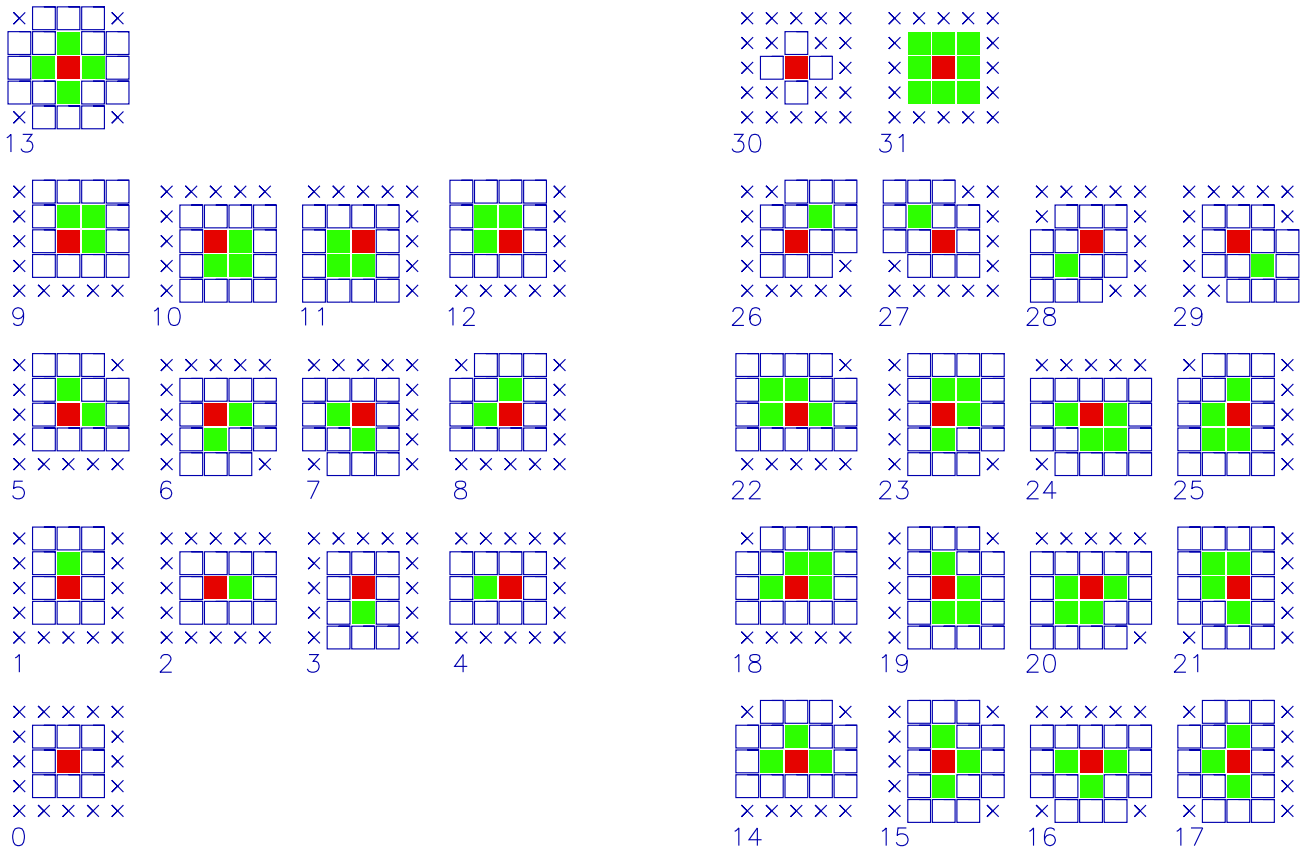
An event is found if, in the 5×5 matrix, the figure formed by the pixels above threshold corresponds at a predefined pattern. There are 32 patterns which are searched for, forming the "pattern table". Although the pattern table is not expected to be changed in flight, since it comprises the majority of patterns resulting from X-rays, it is a programmable parameter which can be uploaded by telecommand. The following figure shows the pattern table which has been used for the calibration of the cameras.

All patterns correspond to an isolated event (zone above threshold completely encircled by pixels below threshold), except the two following patterns :

- pattern 30 which can be connected to a pixel above threshold on the diagonals of the center pixel,
- pattern 31 which can have any of the border pixels above threshold.

These two patterns are designed to quantify the cosmic-rays extended tracks.

Imaging pattern table used in calibration



Coding of the table

- center pixel, above threshold, and with the largest signal in the 3 × 3 inner matrix
- pixel above threshold,
- pixel below threshold,
- × pixel not considered.

The calibration data show that X-rays are generating patterns from number 0 to 12, corresponding to a compact region of energy deposition in the CCD. High energy X-rays also generate pattern 31 events (20 % of the patterns at 6 keV, 50 % at 9 keV), due to an energy deposition below the depleted zone.

The cosmic-rays leave tracks on the CCD which do not generate events corresponding to the requested patterns, except a few patterns 31. This onboard pattern analysis scheme provides a very high efficiency for the rejection of cosmic-ray events, which would saturate the telemetry if a simple thresholding was applied to the data.

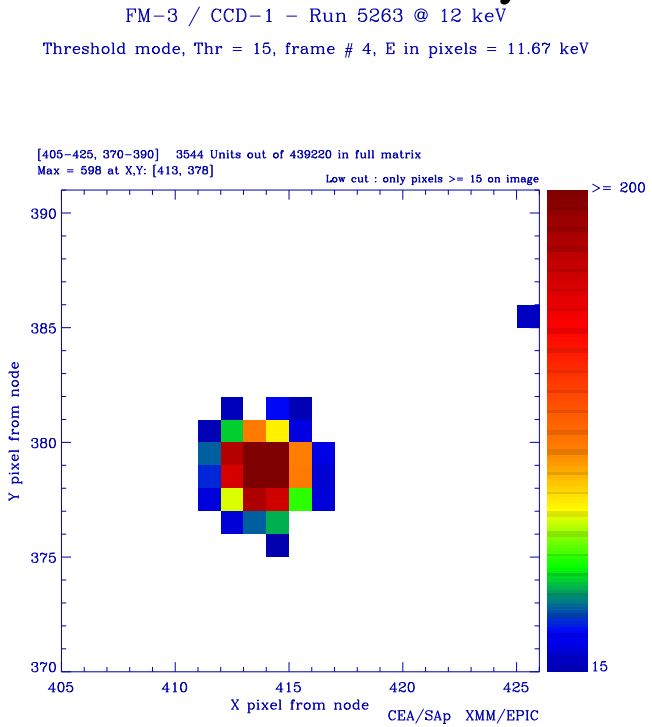
Finally, for each detected event, the following information is transmitted :

- the position of the central pixel in the image (■ above),
- the signal in this central pixel (E1),
- the sum (E2) of the signals of all external pixels in the 3 × 3 inner matrix (■ pixels above),
- the sum of the signals of all pixels below threshold in the 3 × 3 inner matrix (E3),
- the sum of the signals of all pixels below threshold in the corona of the 5 × 5 matrix (E4), and the number of these pixels.

By using the information carried by the "background" energies E3 and E4, one can calculate the real offset around each detected X-ray. This provides a mean, on ground, to check the validity of the offset pseudo-map, and even correct for features that the offset pseudo-map cannot cope with.

III. DETECTION EFFICIENCY AS A FUNCTION OF THRESHOLD

The value of the threshold plays an obvious role at low energy, for which X-rays give rise to single isolated pixels (pattern 0), since a threshold equivalent at an energy E will obviously select X-rays with energies greater than E only. But it also plays a role at high X-ray energy, for which the deposited energy is spread on several adjacent pixels, as illustrated by the figure below for a 12 keV X-ray. Depending on the threshold, the event will or will not be detected onboard as a valid X-ray.

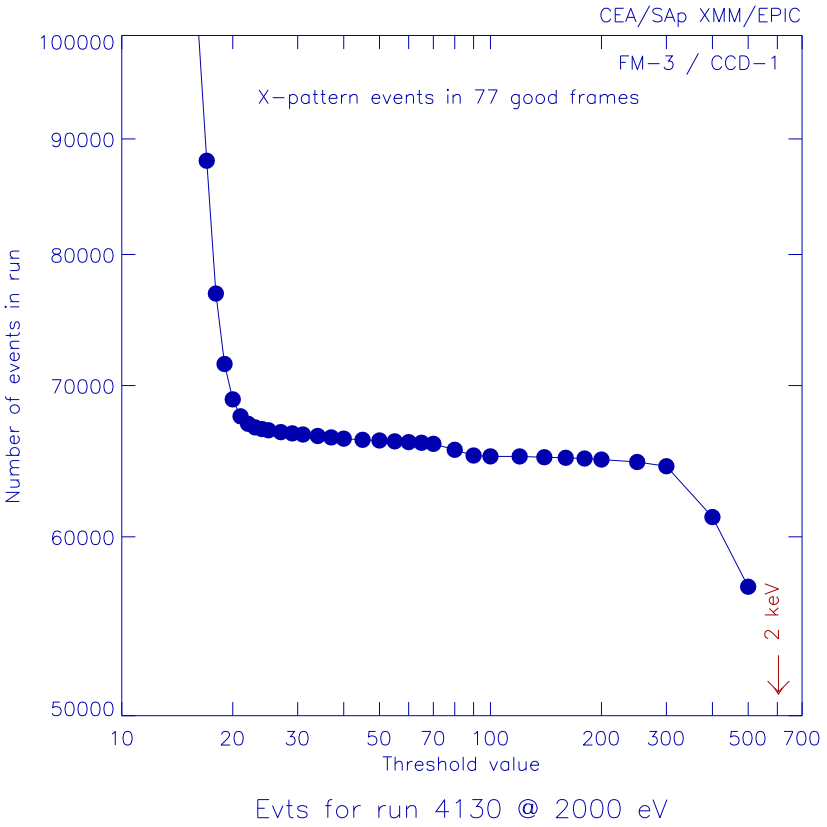


In that example, all pixels with energy above 50 eV (threshold of 15) have been represented. With such a low threshold, the event will not be recognised as valid onboard. However, by setting a higher threshold, the pattern formed by the pixels above threshold will belong to the onboard pattern table, and the event will be recognised and transmitted to the ground.

In this particular example, a threshold of 170 (0.56 keV) gives raise to a pattern 23 event, a threshold of 500 (1.7 keV) to a pattern 2 (bi-pixel) event.

In order to quantify the dependence of the detection efficiency with the threshold, we have taken data, during the calibration of the camera, in a special mode for which all pixels above

threshold are transmitted. We have then applied to these data the same recognition scheme as the one used onboard for the imaging mode, and determined how many events are detected in this mode as a function of the threshold applied. We present below the results of this study for X-ray energies of 150 eV, 2 keV and 12 keV, as curves of number of events versus threshold.



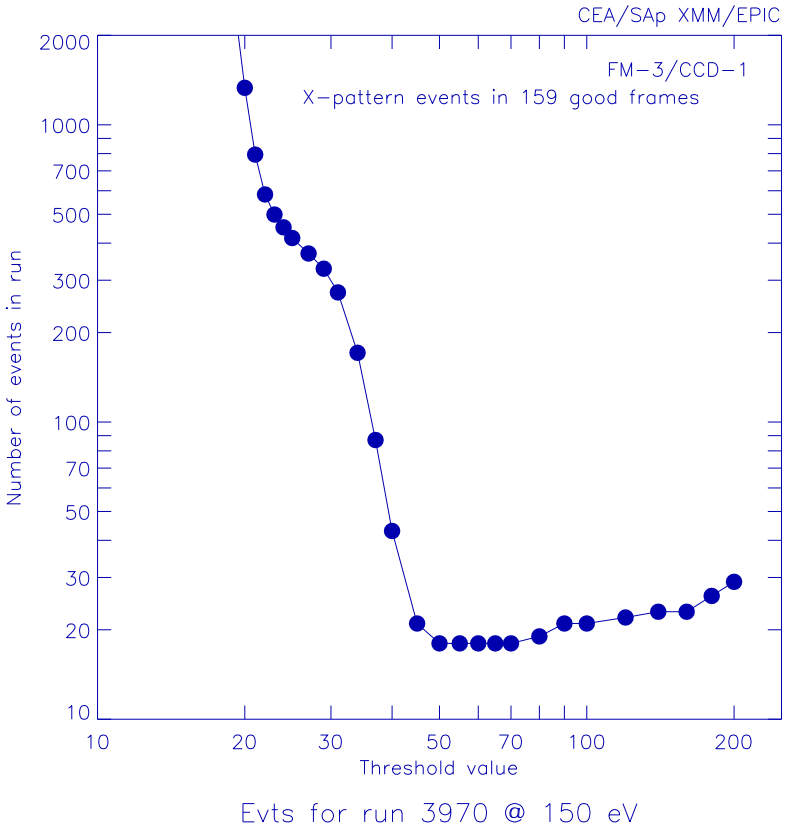
Evts for run 4130 @ 2000 eV

These curves, all calculated by considering only pattern 0 to 12 events (X-patterns), can directly be read as the detection efficiency dependence with threshold.

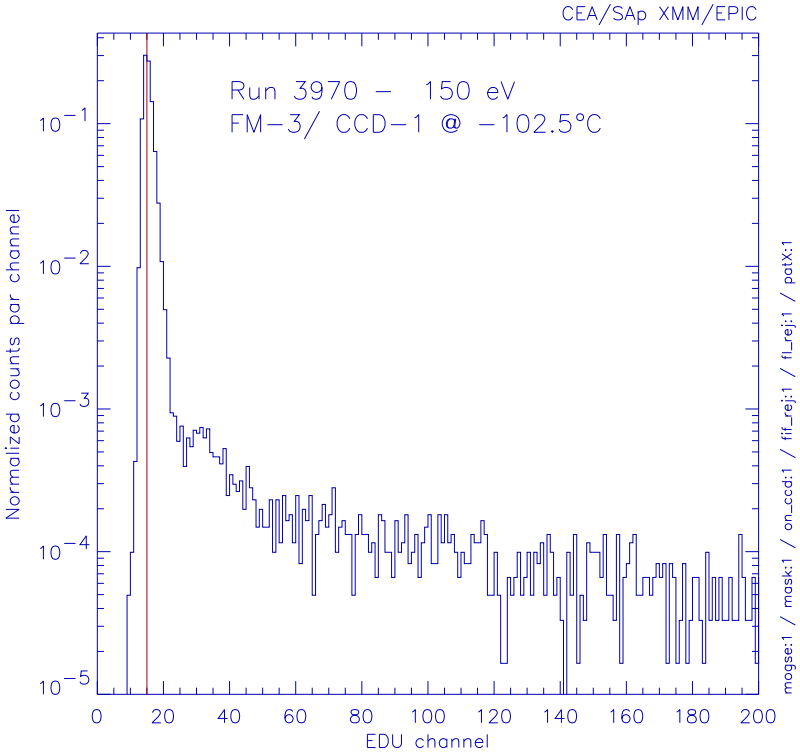
In this first example at 2 keV, the curve is reasonably flat for threshold values between 25 and 300. This gives a very weak dependence of the detection efficiency with threshold.

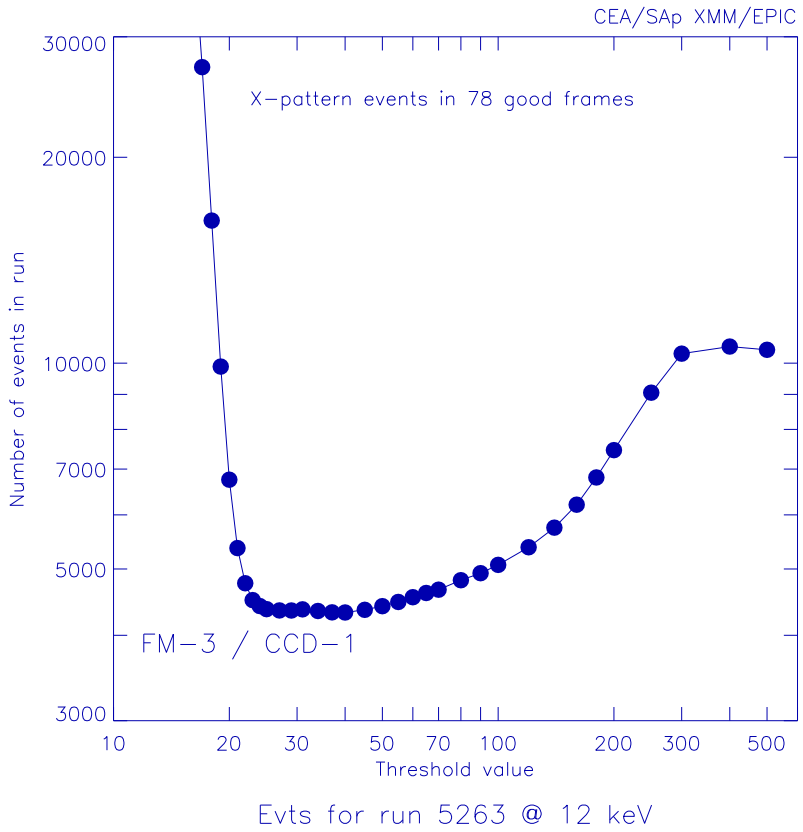
The rise on the left side is due to the noise spectrum, while the decrease on the right side corresponds to the threshold value entering into the signal peak.

This second example is at 150 eV. The detection efficiency curve is strongly threshold dependent. This is readily explained by the peak response of the CCD at this energy being not separated from the noise, as can be seen from the spectrum on the right.



Evts for run 3970 @ 150 eV





This final example at 12 keV also shows a plateau region for thresholds between 25 and 50, a much more limited range than at 2 keV, but still comprising the values expected to be used in flight (between 25 and 35).

The rise on the high energy side is due to the effect examplified above, which allows large spread events to “enter” the pattern table.

IV. CONCLUSIONS : We have shown that, except at low energy where it was expected, the exact value of the threshold is not critical for the X-ray detection, provided it stays between ~ 25 and 50 channels (80 to 160 eV).

Note : the event recognition scheme described here is for the imaging mode of the camera; a similar scheme is used in timing mode, although with strong differences in the pattern table.