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First qualification and selection of the eROSITA PNCCDs

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ABSTRACT

For the X-ray astronomy instrument eROSITA a framestore PNCCD was developed by the MPI Halbleiterlabor. The PNCCD has an image area of 384 × 384 pixels with a size of 75 μm × 75 μm. Each channel of the PNCCD has an own readout anode which allows parallel amplification and signal processing of the CCD signals of one row.

The first measurements for the spectroscopic characterization of the PNCCDs are made with a special measurement setup—the so-called Cold Chuck Probe Station. The Cold Chuck Probe Station allows to fully operate the CCD without mounting and bonding the chip on a PCB as the CCD is contacted only with needles. Thus all eROSITA PNCCDs can be qualified under the same measurement conditions and with an identical electronic setup. Therefore the results can be compared directly. The spectroscopic properties of the PNCCDs, like the charge transfer efficiency and the energy resolution are measured. Also pixel defects such as bright pixels or non-transferring pixels are detected.

With the Cold Chuck Probe Station a readout noise of 2.7 e^- ENC can be achieved and reliable measurement results obtained. Based on these results the best PNCCDs will be selected for eROSITA.

1. Introduction

The X-ray astronomy instrument eROSITA (extended Roentgen Survey with an Imaging Telescope Array) is one instrument on board of the Spectrum-Roentgen-Gamma satellite which will be launched in 2012. The goal of the mission is an all sky survey in the energy range from 0.3 to 11 keV to detect about 100,000 galaxy clusters. Thus it will be possible to study the large scale structure of the Universe [1]. eROSITA consists of seven Wolter-I mirror modules looking in the same direction to obtain a larger effective area. In the focal plane of each mirror module, there is a PNCCD to detect the X-ray photons [2].

These PNCCDs reach a quantum efficiency of 90% even at an energy of 11 keV as the 450 μm thick detector is fully depleted [2]. First spectroscopic measurements of the eROSITA PNCCDs achieved an energy resolution of 143 eV for all events at 5.9 keV [3]. For the parallel signal readout a special ASIC was designed, the so-called CAMEX (CMOS Amplifier and MultiplEXer) which has an own eight-fold correlated double sampling filter for each input channel [4]. As a CAMEX chip has 128 input channels, three chips are needed for each eROSITA CCD.

For the eROSITA cameras the PNCCDs with the best performance have to be selected. As mounting and bonding the CCDs is time and cost consuming, it is more efficient to test and compare the PNCCDs before the integration. For this a special measurement setup has been designed—the so-called Cold Chuck Probe Station—which will be described in detail in the next section.

2. Experimental setup

The Cold Chuck Probe Station is a measurement setup which allows to fully operate a CCD without mounting the chip on a PCB. Instead of bondwires the PNCCD is electrically contacted with needles.

Four hundred needles are needed to fully operate the PNCCD, one for each of the 384 readout channels and 16 needles to supply all necessary operating voltages. All needles except one are mounted on a PCB which is shown in Fig. 1. The remaining one touches the chip from the other side to fully deplete the detector.

For the measurements the CCD is mounted on a chuck as can be seen in Fig. 2. A vacuum exhaust keeps the chip in position. The chuck can be cooled with liquid nitrogen, so that it is possible to measure the CCD at temperatures down to −70 °C which is close to the operating temperature in space. To keep the CCD in a dry atmosphere, the dark box housing the setup is flushed with nitrogen.

For spectroscopic measurements the PNCCD is irradiated with 5.9 keV photons from an ^{55}Fe-source. Due to the setup a

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homogeneous irradiation is not possible. From the back side the CCD can only be illuminated partially as some parts are covered by the chuck. On the other hand, front side illumination is effected by the needle card which sits between the CCD and the ^{55}Fe-source and causes a shadow pattern. Therefore the chip is illuminated from both the front side and the back side to make the irradiation as homogeneous as possible.

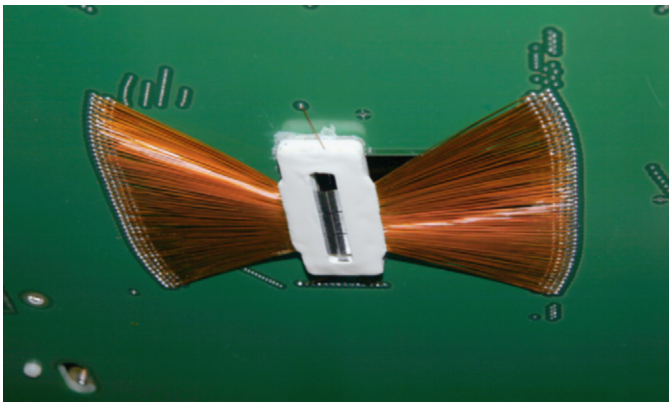

Fig. 1. The probe card with the needles mounted on it. Through the needle contacts all operating voltages are supplied and the CCD signals are read out.

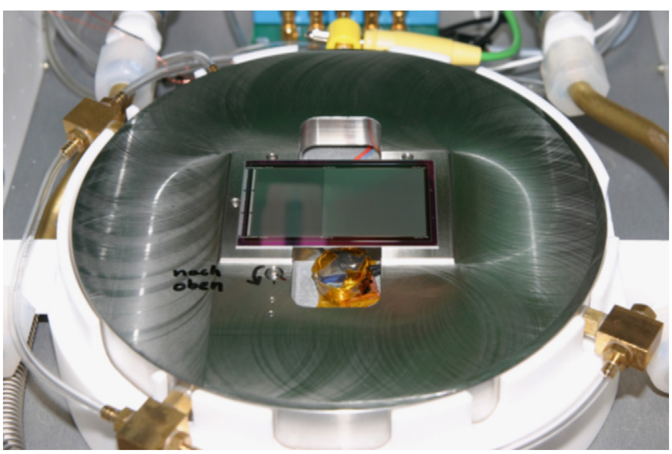

Fig. 2. An eROSITA-PNCCD mounted on the chuck which can be cooled with liquid nitrogen. Underneath the CCD one of the ^{55}Fe-sources for back side illumination can be seen.

Measurements are done both in full frame and frame store mode. The frame store mode measurements are important as this is the normal operation mode on the satellite. In addition the full frame mode is necessary to investigate possible pixel defects of

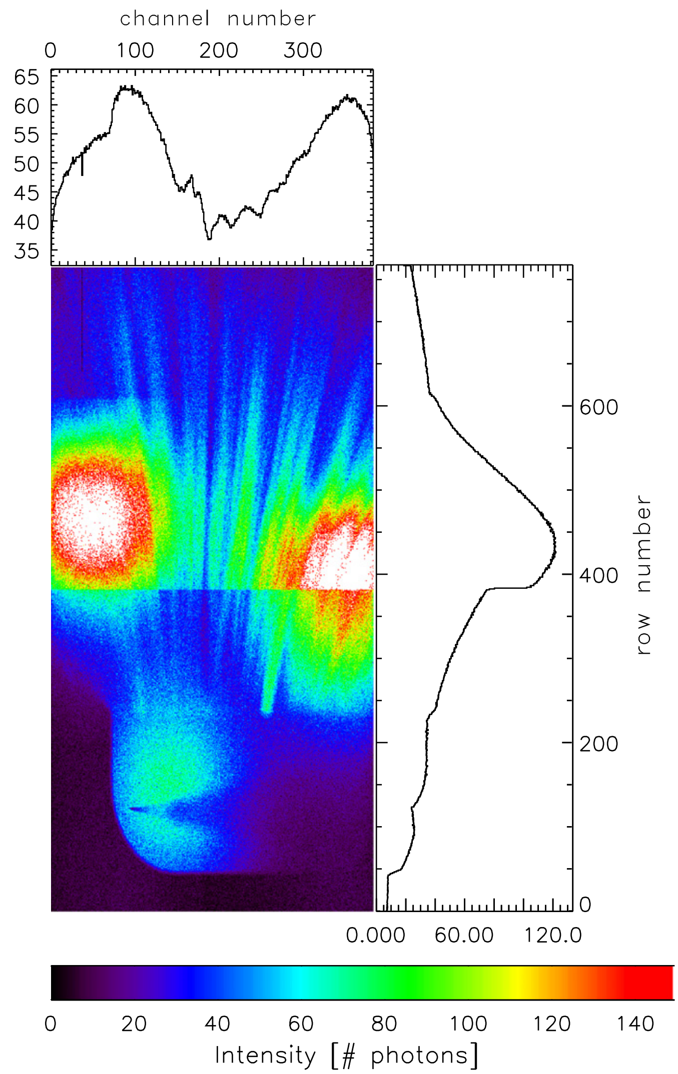

Fig. 4. Intensity map of a Cold Chuck Probe Station measurement showing the inhomogeneous illumination caused by the needles.

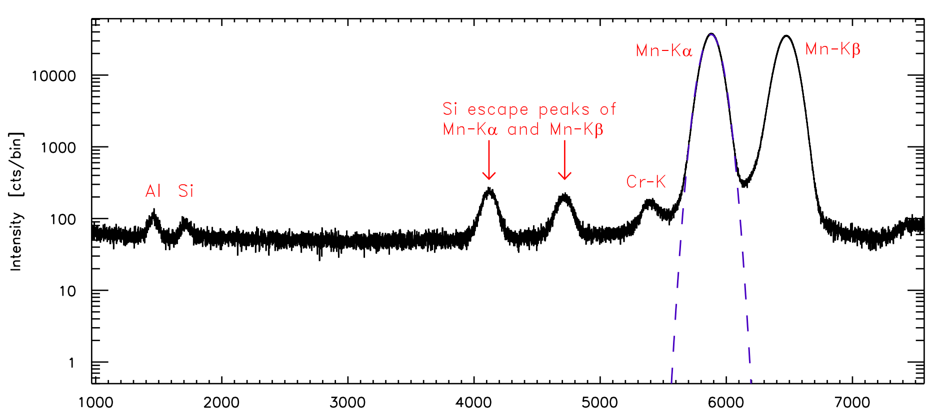

Fig. 3. This plot shows an ^{55}Fe-spectrum measured with a PNCCD at $-70\,^{\circ}$C in the Cold Chuck Probe Station. The FWHM at 5.9 keV is 157 eV. In addition to the Mn-Kα and Mn-Kβ peaks, both Si escape peaks can be seen. The Al, Si and Cr-K lines are due to the setup. X-rays enter the CCD from the front and the back side in this setup resulting in an increased fraction of partial events.

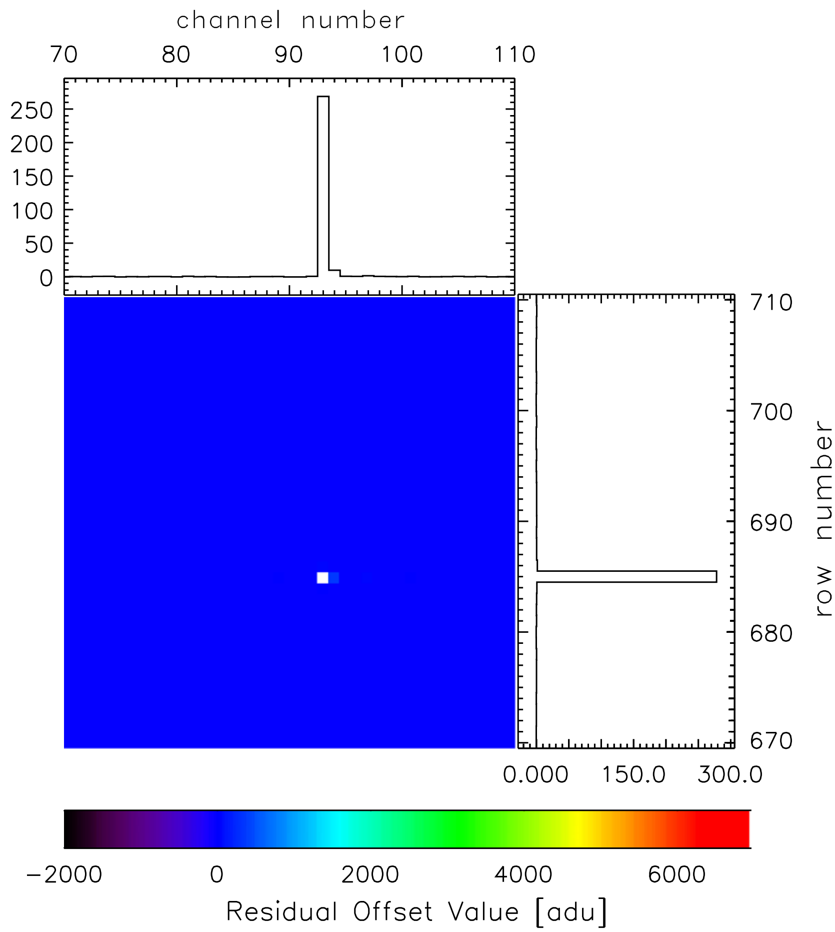

Fig. 5. This residual offset map shows a bright pixel in channel 93 and row 685.

the whole CCD. The CCD is operated with a cycle time of about 200 ms which is four times longer than the cycle time planned for the eROSITA mission. This is necessary to keep the number of "out of time" events, which are caused by photons entering the CCD during the readout, at an acceptable level of roughly 10% as about 20 ms are needed for the readout.

With these measurements it is possible to determine CCD properties like gain, charge transfer efficiency and energy resolution. First results are given in Section 4.

3. Selection of the flight CCDs

The measurement results of different PNCCDs can be compared directly, as all chips are measured under the same conditions—including an identical readout electronics. So the seven PNCCDs with the best performance can be choosen for the eROSITA flight instrument. Most important of all performance parameters is the energy resolution as the CCD is used for spectroscopic measurements. To obtain a good energy resolution the charge transfer inefficiency has to be small. Additionally the CCD should have no pixel defects, like bright or non-transferring pixels. Also a low noise and normal operating parameters (e.g. no extreme voltages) are required.

4. Measurement results

The first measurements of eROSITA CCDs with the Cold Chuck Probe Station were done successfully. In spite of the long wires between the CCD and the amplification chip a noise of 2.7 e^- ENC was achieved.

On the plot in Fig. 3 an ^{55}Fe-spectrum measured at $-70\,^{\circ}$C is shown. Beside the Mn-Kα and Mn-Kβ peaks, both Si escape peaks can be seen. As the intensity of all sources is reduced with a 150 to 250 μm thick Al foil, the intensities of the Mn-Kα and Mn-Kβ peaks are nearly equal. This shielding also causes the peak at 1.5 keV which is an Al fluorescence line. Another fluorescence line due to the setup is the Cr-K line at 5.4 keV. The chuck is made of stainless steel which contains a certain amount of Cr. The Si peak (1.7 keV) is caused by the detector material itself.

For the PNCCDs measured with the Cold Chuck Probe Station so far the FWHM of Mn-Kα at $-70\,^{\circ}$C varies between 146 and 190 eV. Nearly 50% of the CCDs have an FWHM better than 160 eV. In the example spectrum in Fig. 3 the FWHM of the Mn-Kα peak for all events is 157 eV. Compared to the results obtained with eROSITA CCDs mounted on a PCB, the energy resolution obtained with the Cold Chuck Probe Station is worse. The reason for this is an insufficient correction for the charge transfer inefficiency (CTI) in the data analysis which does not apply for an inhomogeneous illumination. This can be improved using a correct model for the CTI which is currently under development. The inhomogeneous illumination can be seen in the intensity map in Fig. 4. The shadow pattern caused by the contact needles is clearly visible.

In addition to the spectroscopic performance, individual pixel defects like bright and non-transferring pixels can be detected. A bright pixel can be detected easily by the so-called residual offset map. This map is calculated by subtracting the median values of the respective row and column from the offset of

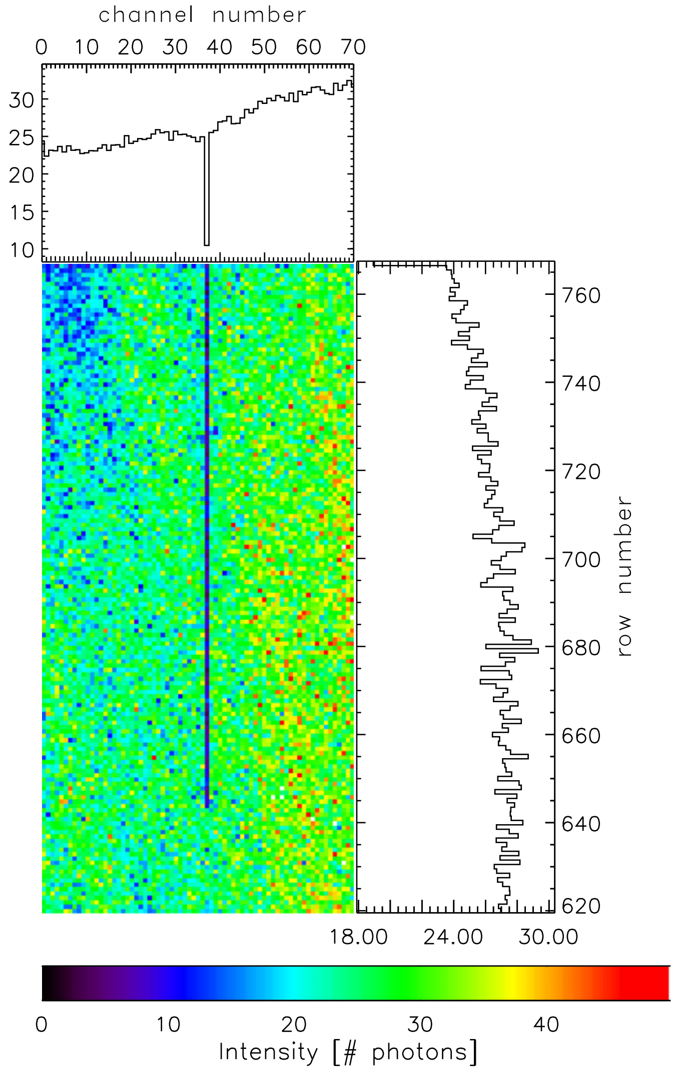

Fig. 6. Part of an intensity image showing a non-transferring-pixel. Behind the non-transferring-pixel the intensity is nearly zero.

each pixel. A bright pixel can be seen as its offset value deviates clearly from the median. Approximately every second eROSITA PNCCD shows no bright pixels. Two-thirds of the CCDs with bright pixels show clusters of more than ten bright pixels. Whereas the remaining third has only single bright pixels. In Fig. 5 such an example of a single bright pixel is shown.

About one-third of the measured CCDs have so-called non-transferring pixels. Mostly only one single non-transferring pixel is observed, but also small clusters of up to six pixels were measured. An effect of a non-transferring pixel can be seen in Fig. 6. There a part of an intensity image of a PNCCD measured with the Cold Chuck Probe Station is shown. One can see clearly that the pixel in channel number 37 and row number 644 is a non-transferring pixel as there are nearly no photons counted in this channel behind this pixel. The few events which can be seen in the channel behind the non-transferring pixel are "out of time" events.

5. Conclusion

With the Cold Chuck Probe Station it is possible to fully operate and characterise the PNCCDs only contacted by needles. The first measurements have shown that the spectroscopic performance as well as pixel defects can be determined. All eROSITA PNCCDs can thus be characterised with identical measurement parameters, so that the results are directly comparable. This allows to select the seven best PNCCDs for the seven cameras of the satellite mission.

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