**TITLE**
ASP Conference Series, Vol. **VOLUME**, **PUBLICATION YEAR**
**EDITORS**

# Evaluations of Domestic X-Ray CCDs with XIS Analog Electronics

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**Abstract.**
We performed the evaluation of domestic X-ray CCDs and compared with XIS, onboard Chandra and ASTRO-E II. We evaluate them with analog electronics made for XIS. After fine tuning of gain, we found that the energy resolution of the CCD is about 135eV at 5.9 keV (FWHM) and read out noise about 6 electron. This result reveals that domestic X-ray CCDs are as good as XIS except for the read out noise.

## 1. Introduction

X-ray CCDs are now main contributors for X-ray astronomy, because of their fine imaging and spectroscopic performances, We are developing domestic X-ray CCDs in collaboration with Kyoto University, Osaka University, Ehime University, and Hamamatsu Photonics. Our goal is X-ray Imaging Spectrometer (XIS) onboard Chandra and ASTRO-E II, which has good energy resolution of 130 eV at 5.9 keV (FWHM), deep depletion layer of 70 $\mu$m, and read out noise of 3 electron. Since studies of analog electronics for these CCDs are now processing, we evaluate them with analog electronics made for XIS (XIS AE). Using same analog electronics also enable us to do direct comparison of performance of domestic CCDs and XIS.

## 2. Experiment

We construct the noise evaluation system of domestic CCDs with XIS AE. Because the gain of the domestic CCD is 6 times smaller than that of XIS, we insert an amplifier between the readout point of the CCD and XIS AE. The clock pattern to drive a CCD is constructed of a repetition of exposure, 1 vertical transfer, and horizontal transfers. For noise evaluation, the number of read

out are set more than that of pixels. As a result, a reconstructed image has not only real image (imaging region) but also imaginary region so called, over clock region. The over clock regions undergo the noise only in transferring, compared with the imaging region undergoes the noise both in exposuring and transferring. We evaluate the noise of the CCD using the difference of including noise of each region.

## 3. Noise Evaluation

We succeed to drive a domestic CCD called CREST Deep 1 and the energy resolution of the CCD is found to be 135 eV@5.9 keV, which value is as good as that of XIS.

We separate the origins of noise to the dark current, the spurious charges, and charge transfer inefficiency (CTI), and the read out noise. The dark current caused by the thermal electrons in a CCD and become lower as the CCD is colder. We find that the dark current of the CCD become $< 0.01$ electron $\mathrm{sec}^{-1}$ $\mathrm{pixel}^{-1}$ and the noise by the dark current $< 0.2$ electron on $-100$°C. Holes trapped in an electrodes of a CCD run out to the depletion layer when a transfer begins. Electrons kicked out by them are called spurious charges. The spurious charge of the domestic CCD is estimated to be 0.4 electron and the noise by it to be 0.6 electron. A part of signal electrons are lost in transferring. CTI presents the probability of the electron loss. We evaluate the CTI to be $8.4 \times 10^{-7}$ for vertical transfer and $1.3 \times 10^{-6}$ for horizontal transfer (the unit of CTI is probability of loss/1 transfer). Considered the number of transfer, the noise by CTI is evaluated to be 2.8 electron. The read out noise includes the noise from the FET and the capacitance in a CCD, dark current in horizontal transferring, and the noise from analog electronics. We find that the read out noise of the CCD is 6.4 electron@5.9 keV, worse than that of XIS.

We compare these noise of the domestic CCD with that of XIS. Table 1 shows that the domestic CCD has as good character as XIS, except for the read out noise. The possible causes of bad read out noise are thought as (1) the noise by static electricity around the CCD (we did not make any cover for it), (2) the noise from the amplifier we made, and (3) the noise from cables between the CCD and the amplifier (they may be amplified by our amplifier). Improved of them, the domestic CCDs will show as good performance as XIS.

Table 1. Comparison of the noises between domestic CCD and XIS.

| Noise (electron) | domestic CCD | XIS |
|---|---|---|
| Dark Current..... | $< 0.2$ | $0.66^{\dagger}$ |
| Spurious Charge... | 0.6 | - |
| CTI..... | 2.8 | $\sim 3$ |
| Read Out Noise ... | 6.4 | 3 |

$^{\dagger}$: Including the noise by the spurious charges.