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Evaluation of the performance of the CCD236 swept charge devices in lunar orbit using in-flight data

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Abstract: India’s Chandrayaan-2 Large Area Soft X-ray Spectrometer (CLASS) employs 16 CCD236 Swept Charge Devices (SCDs) similar in structure to Charge Coupled Device (CCD) image sensors. The CCD236 permits X-ray detection over a large surface area, intended to improve low flux performance, with simplified control interfaces and improved warm temperature performance. These devices were the subject of ground testing and performance evaluation before flight. Data that was recently made available by the Indian Space Research Organisation (ISRO) has permitted the analysis of the performance of the CLASS SCDs after over a year of operations around the Moon. Of particular interest is the change in device performance and behaviour during transit and in lunar orbit. Preliminary analysis has indicated that device FWHM, representing the aggregate of different noise sources, has increased in line with predictions based on ground irradiation and testing.

Keywords: Radiation damage to detector materials (solid state); Space instrumentation; X-ray detectors

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1 Introduction

The CLASS instrument aboard Chandrayaan-2 [1] uses 16 CCD236 swept charge devices (SCDs) to monitor X-ray fluorescence of the surface of the Moon to map its elemental composition [2]. The Centre for Electronic Imaging (CEI) completed a set of ground irradiations of the CCD236 in order to demonstrate its suitability for the instrument [3–6], and identified a linear trend of fluorescence peak FWHM for proton irradiation fluence [7]. In-flight data has been made available by the CLASS calibration team, including from Pillai et al. [2], and in the PRADAN public repository [8]. These have enabled the identification of the actual effects of radiation on CCD236 performance.

2 Irradiation and data

2.1 Expected irradiation

The orbit parameters of Chandrayaan-2 during its transfer and arrival at the Moon, and the shielding model used in [4], were input to the Space Environment Information System (SPENVIS) [9]. This generated a predicted irradiation dose of $5.4 \times 10^7$ 10 MeV proton equivalent fluence (cm$^{-2}$) during transit to the Moon, and negligible further irradiation once there, up to February 2021. This dose is much less than previous prediction of $4.8 \times 10^8$ 10 MeV proton equivalent fluence (cm$^{-2}$) [4], primarily because solar activity was very low during this period.

2.2 Data and extraction of noise values

Data has been made available in the two forms shown in figure 1: calibration results using a known X-ray source to record FWHM values over a wide range of temperatures (shown in figure 1(a)) collected before flight and after arrival at the Moon; and raw event data from the instrument accompanied by basic housekeeping information which was used to generate spectra, such as that shown in figure 1(b). The calibration X-ray sources (55Fe) were unavailable once science operation commenced.
Figure 1. Example presentation of the data from CLASS available to this investigation: (a) calibration curves of peak FWHM generated using calibration sources (the FWHM during flight is larger due to the extra device noise caused by radiation damage) and (b) in flight data from the instrument, here presented as a spectrum.

Fluorescence from the instrument collimator due to incoming solar radiation generated Al Kα (1.487 eV) and Cu Kα (8.047 eV) peaks that were found across the dataset. Due to solar inactivity these peaks were faint, requiring the aggregation of data collected by the instrument over the course of tens of minutes to provide enough of a peak profile to be fitted reliably. During periods of higher solar activity (for which data has not been available for this study) such peaks will be measurable after only 8 seconds. Assuming the peaks are Gaussian, peak FWHM may be converted to an e− rms noise value using equation (2.1), where \( \omega \) is the energy required to produce electron hole pairs.

\[
\eta_{e^{-}, \text{r.m.s.}} = \frac{\text{FWHM}}{2.355 \omega}.
\]  

(2.1)

When comparing the noise values calculated from peaks of different energies, the Fano noise component was removed using equation (2.2), where \( F \) is the Fano factor in silicon, and \( E \) is the peak energy, in eV.

\[
\eta_{e^{-}, \text{r.m.s.}} = \sqrt{n_{e^{-}, \text{rms,tot}}^2 - \frac{F.E}{\omega}}.
\]  

(2.2)

3 Results

The ground testing described in [7] indicated that, following transit to the Moon, the devices should exhibit an increase in 8.7 e− rms at –30 °C. This increase was calculated from the difference, in quadrature, of the noise before and after irradiation, because the additional noise was not expected to be correlated to prior noise sources (figure 2).
Figure 2. Noise observed at −30 °C after transit to the Moon (blue) compared to previous predictions based on Gow et al. [5] (red). The $0.57 \times 10^8$ 10 MeV proton equivalent fluence (cm$^{-2}$) value has been interpolated from the unirradiated and $3 \times 10^8$ cm$^{-2}$ experimental values from [5].

No such increase was expected after arrival up to early 2021, which matched overall observations of noise difference, shown in figure 3. Comparisons over this period have suffered due to the aforementioned data aggregation, which introduces longer period device variations smearing fluorescence peaks unpredictably.

Figure 3. Difference in noise between 2019 and 2021. Devices with stray light have been removed. The error bars shown are the single sigma errors propagated from estimated error in the measurement of 2019 and 2021 in flight fluorescence peak FWHM.

4 Conclusions

The noise exhibited by the CCD236 devices aboard CLASS has shown good agreement with predictions. This work has only probed the total noise properties of the devices; further work may be able to identify the contributions of individual noise sources, for example dark current or optical light leakage.
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References