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Performance of new generation swept charge devices for lunar X-ray spectroscopy on Chandrayaan-2

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ABSTRACT

The Chandrayaan-2 Large Area Soft X-ray spectrometer (CLASS) is due to be launched by the Indian Space Research Organisation (ISRO) in 2014. It will map the elemental composition of the lunar surface, building on the Chandrayaan-1 X-ray spectrometer (C1XS) heritage. CLASS will use an array of e2v technologies CCD236 swept charge devices (SCD) providing an active detector area of approximately 64 cm², almost three times the active area of C1XS which used the first generation of SCD, the CCD54. The CCD236 is designed as a soft X-ray detector, 0.8 keV to 10 keV, and benefits from improvements in design to allow for increased detector area, a reduction in split X-ray events and improvements to radiation hardness. This paper describes the investigation into the performance requirements of the CCD236, focussing on an optimisation of the energy resolution of a device irradiated to the estimated worse case end of life proton fluence.

Keywords: The Chandrayaan-2 Large Area Soft-X-ray Spectrometer (CLASS), Swept Charge Device (SCD), CCD236, soft X-ray detector, X-ray fluorescence (XRF), lunar elemental mapping, Moon

1. INTRODUCTION

The Chandrayaan-2 Large Area Soft-X-ray Spectrometer (CLASS)¹, illustrated in Figure 1, is due to be launched by the Indian Space Research Organisation (ISRO) in 2014. CLASS aims to map the elemental composition of the lunar surface by measuring the X-ray fluorescence stimulated by solar X-rays. The instrument aim is to perform a global study on the diversity and distribution of lunar lithologies, providing a map of elemental abundances of the lunar crust, focusing on the major crustal provinces and mare diversity¹. Chandrayaan-2 is planned to orbit the Moon from a 200 km altitude orbit¹ for 1 year during a period of high solar activity, thus increasing its chances of encountering higher energy and frequency of solar flares interacting with the lunar surface. This may enable mapping of heavier elements such as Ti, Mg and Fe during such high-energy events, but may also result in increased proton damage to the detectors during the mission. The CLASS mission will build on the heritage of C1XS² (launched by ISRO in 2008) by producing global maps of key rock forming elements on the Moon, improving the understanding of the lunar evolution.

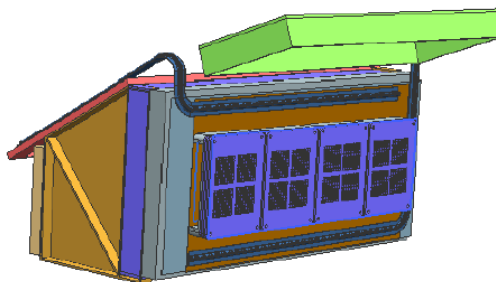


Figure 1. CLASS instrument design concept¹

The CLASS instrument will use sixteen e2v technologies CCD236 swept charge devices (SCD), illustrated in Figure 2, the largest of e2v's new generation of SCD X-ray detector³. The CCD236 is a large area (20 x 20 mm²) soft X-ray detector optimized² at 0.5 keV to 10 keV, and benefits from improvements in design to allow for increased detector area, a reduction in split X-ray events due to the 100µm x 100µm 'pixel' size and improvements towards radiation hardness. It will effectively increase the detection area from 24cm² used on C1XS to 64cm² for CLASS but with the same electronic requirements needed in C1XS [1].

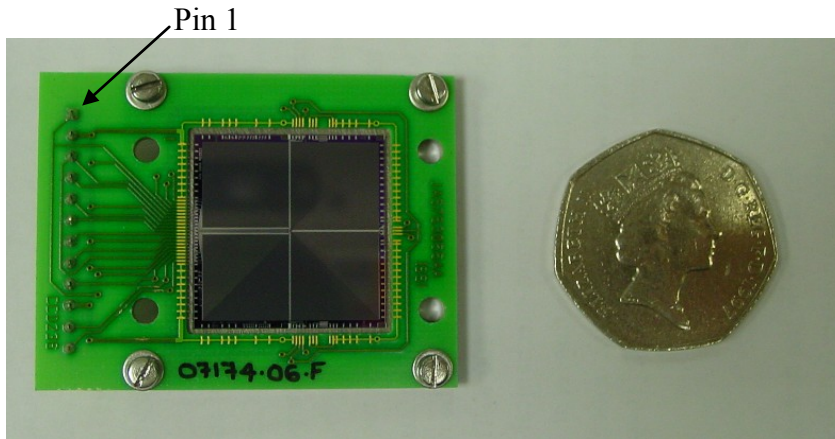


Figure 2: Photograph of a CCD236

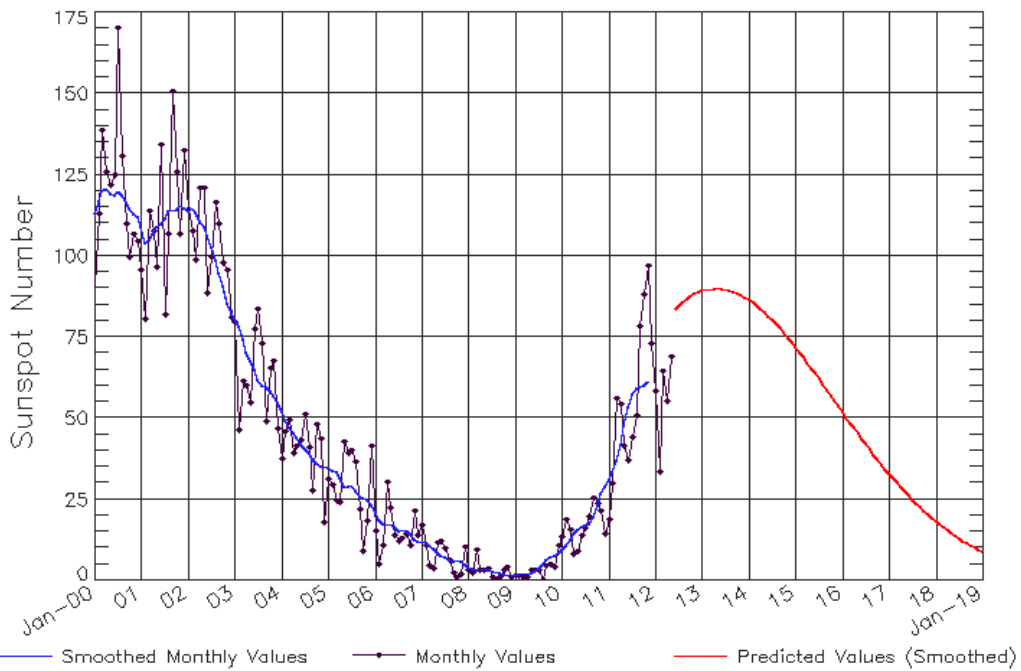
1.1 CLASS space radiation environment

The space radiation environment that will be experienced by Chandrayaan-2 can be classified into two types, the 'trapped' environment and the 'non-trapped' environment⁴. During the initial transfer from the Earth to lunar orbit the spacecraft will travel through the Van Allen belts which are formed by charged particles becoming trapped in the Earth's magnetosphere. Once the spacecraft leaves the radiation belts it will be continuously bombarded by charged particles arising from the 'non-trapped' environment', composed of cosmic rays, solar flares and solar proton events. Protons are the most numerous charged particles in the space radiation environment, and as such are the main source of damage to silicon detectors in space⁴.

The flux and energy of protons incident on the detectors in CLASS is dependent on the solar cycle, the proposed launch date is during a period of high solar activity, as illustrated in Figure 3 produced by the National Oceanic and Atmospheric Administration (NOAA) Space Weather Prediction Centre (SWPC)⁵. This will allow for an increase in the probability to fluoresce higher atomic number elements such as Ti and Fe during strong solar flares¹. However the increase in solar activity also produces a higher amount of protons during this time, increasing the rate in which detector performance is reduced.

As with the CCD54 used in the C1XS instrument, it is important to ensure that the detectors will be able to provide valuable scientific data for the entire mission life-time. This can be achieved through an understanding of the space radiation environment exposure and its resulting effects on detector performance⁶. An estimated end of life proton fluence was calculated using the ESA Space Environment Information system (SPENVIS)⁷, using the same Earth Moon transfer spacecraft trajectories used during Chandrayaan-1. The radiation damage analysis performed on C1XS⁶ was also assumed for CLASS. The 2π solid angle behind the detector is shielded by 4mm of Al and 6mm Ta, based on C1XS design, and the 2π forward of the detector is 100% shielded by the moon. The prediction, shown in Figure 4 provides an estimated end of life 10 MeV equivalent proton fluence of 4.8×10^8 protons.cm⁻². This was found using the trapped proton and electron fluxes AE-8 model along with the long-term solar particle fluxes models in SPENVIS.

ISES Solar Cycle Sunspot Number Progression
Observed data through May 2012



Updated 2012 Jun 4

NOAA/SWPC Boulder, CO USA

Figure 3. Measured and predicted solar activity from the Space Weather Prediction Centre, May 2012⁵

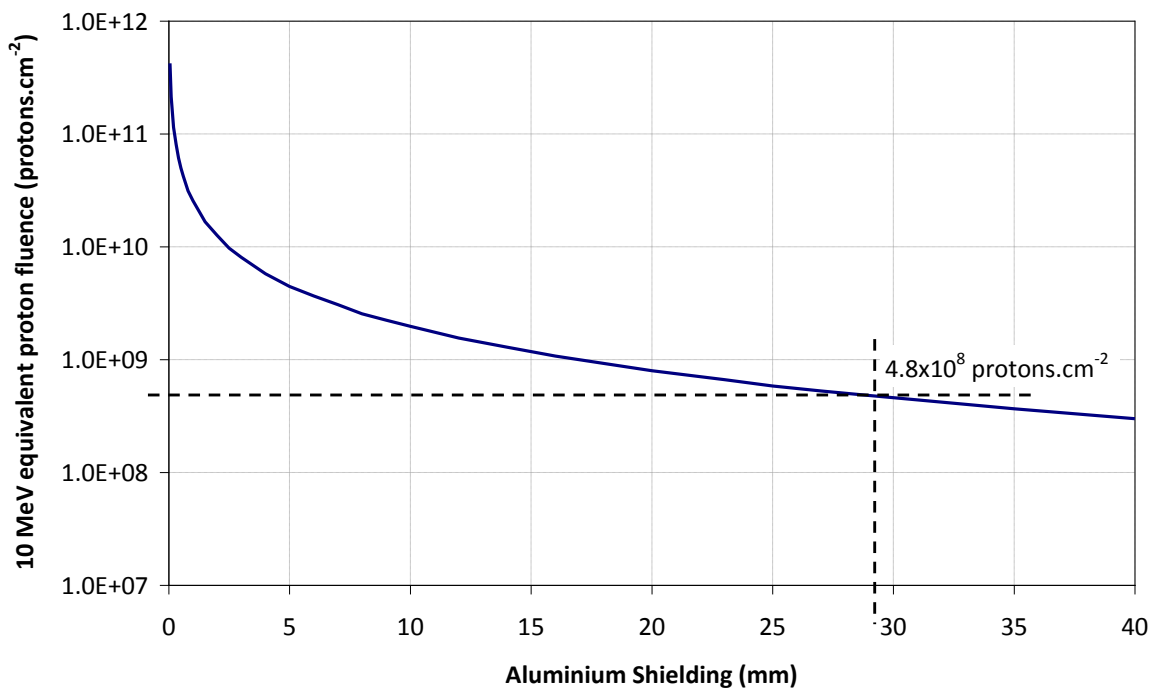


Figure 4. Predicted end of life proton fluence using SPENVIS based on Chandrayaan-1 orbital transfers and 1 year mission duration

2. EXPERIMENTAL ARRANGEMENT

Each CCD236 swept charge device (SCD) under test was housed inside a vacuum chamber, illustrated in Figure 5, with testing conducted in a class 100 environment using a lamina flow bench to ensure no contamination onto the imaging surface. The SCD was mounted onto a copper cold finger attached to a CryoTiger refrigeration system to provide cooling, the camera head assembly is illustrate in Figure 6 and photographed in Figure 7. The temperature was controlled to within ± 0.1 °C using a feedback system, comprising a Lakeshore 325 temperature controller, a heater and 1,000 Ω platinum resistance thermometers (PRT) mounted onto the copper cold finger. Due to the temperature gradient between the cold finger and the SCD silicon, typically ~ 0.5 °C the error on the temperature measurement was taken to be ± 1 °C. Clock and bias were provided using XCAM Ltd. CCD drive electronics and software, and the data were recorded onto a laptop computer. A known energy of Mn-K α 5,898 eV X-rays, provided by a ^{55}Fe source held at an adjustable distance from the SCD, was used for calibration and energy resolution measurements.

During the initial investigation into the performance, several CCD236 devices were operated at 110 kHz using the potentials given in Table 1. Each device was switched on at room temperature to assess device functionality, using sequences 236-FWHM.dex, with the initial test sampled 100 rows and 100 columns at gain A. If X-rays were detected after running for a few minutes for charge to clear, it was then cooled to begin the first set of tests. The characterisation, which included the measurements of noise and the energy resolution at Mn-K α (5,898 eV), was performed over the temperature range of 10 °C to -70 °C in 10 °C intervals. In order to remove any split events, isolated X-ray events were identified using a threshold of 5x the sigma of the Gaussian function of the noise peak and plotted as a histogram of energy MATLAB. Cosmetic profiling, where an integration time of 1ms was applied before device readout, was performed at -20 °C and -50 °C to assess the cosmetic quality of the detectors, identifying any defective pixels.

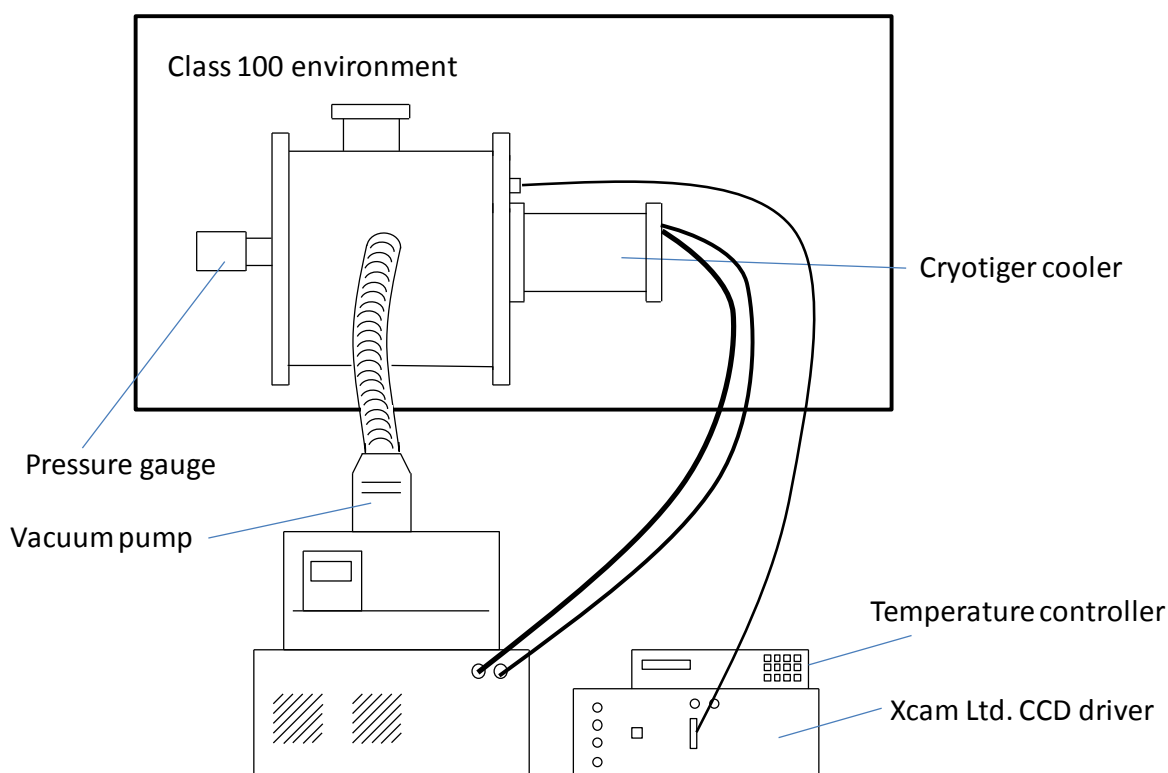


Figure 5. Illustration of experimental set up and the equipment used

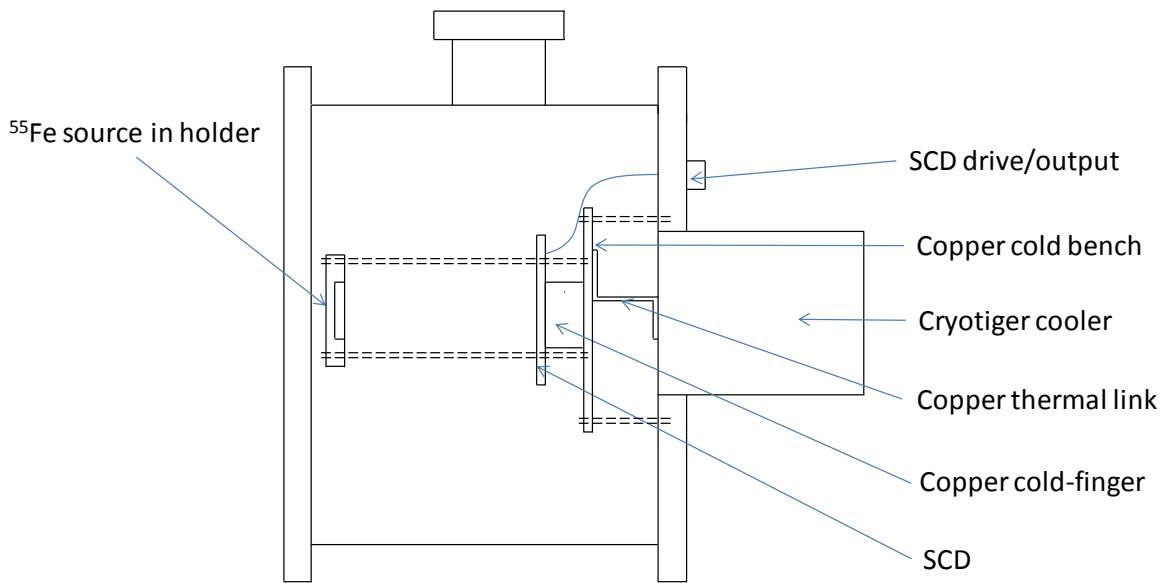


Figure 6. Schematic of the SCD inside the vacuum chamber

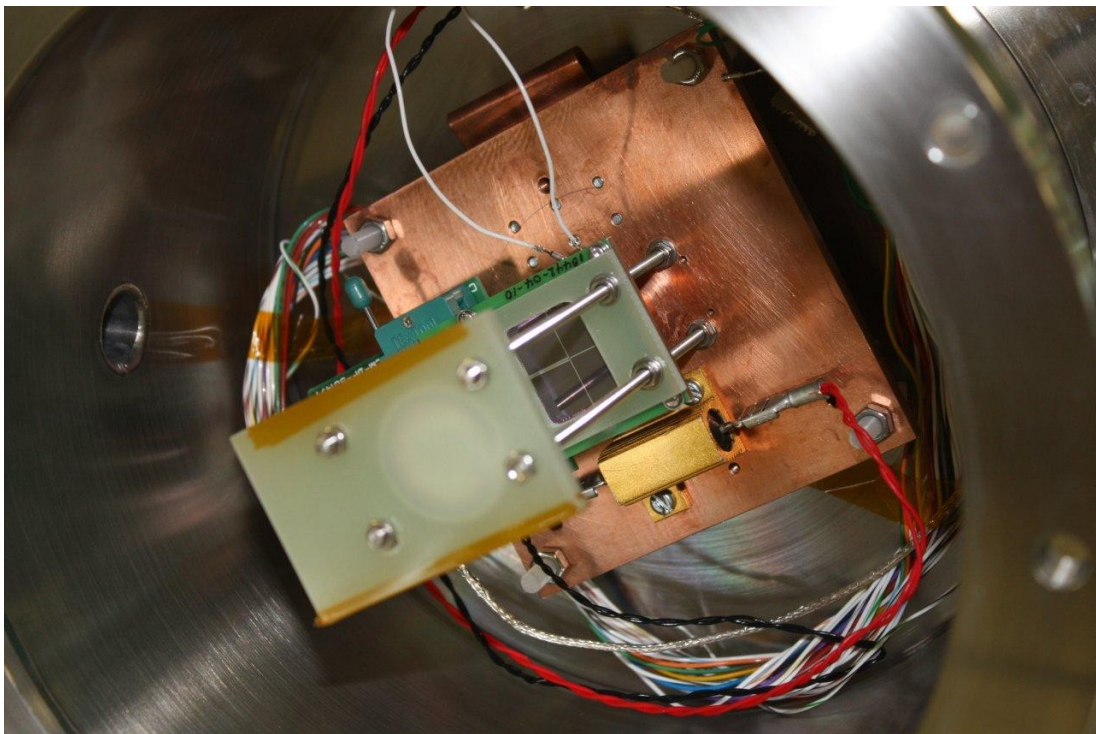


Figure 7. Photograph of the SCD mounted on the copper cold bench with the ^{55}Fe source mounted above

Table 1: Initial SCD operating voltages

Pin Number	Clock/Bias	Voltage
1	Reset 2	9.0
2	V _{SS}	9.2
3	V _{OD}	29.4
4	V _{OS}	-
5	V _{RD}	17.0
6	Reset 1	9.0
7	V _{OG}	3.5
8	V _{DOS}	-
9	V _{DD}	22.0
10	V _{SS}	9.2
11	Image clock 1	7.0
12	Image clock 2	7.0

To perform the radiation damage study, and allow different targets to be fluoresced, the equipment was modified to include an Oxford instruments tungsten filament X-ray tube to fluoresce targets held on a copper sheet at a 45 degree incident angle. A manganese target was used to illuminate the SCD with Mn-K α X-rays, comparable to the ⁵⁵Fe source used in previous testing, for calibration and energy resolution measurements. This arrangement enabled easy changing between target samples with the use of a target wheel, including a basalt sample was then mounted on the copper and fluoresced at 10kV. The copper was used to calibrate the spectrum. This arrangement is illustrated in Figure 8. After this an ⁵⁵Fe source was used to provide a clean source of Manganese X-rays to compare with the test results performed on the un-irradiated devices.

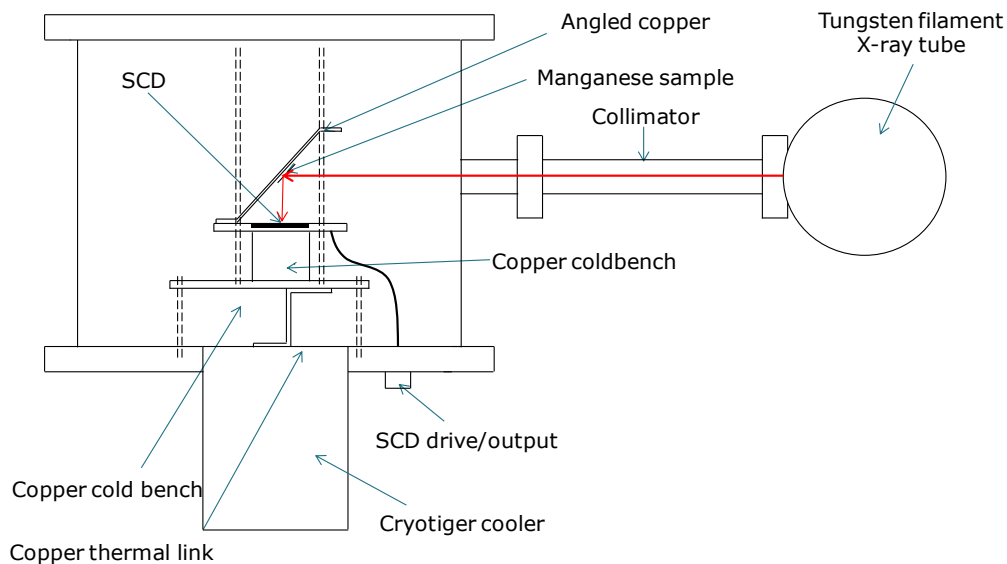


Figure 8: Illustration of SCD camera head using X-ray tube to fluoresce samples

2.1 Proton irradiation

The irradiation was performed successfully at the Kernfysisch Versneller Instituut (KVI) on 6th February 2012. The beam energy was measured to be 50 MeV at the CCD, irradiating the whole active area of the CCD236. The 10 MeV equivalent proton fluence delivered to each device was 5.0×10^8 protons.cm⁻² delivered over a period of 50 seconds. The irradiation details are given in Table 2 and the set-up shown in Figure 9. The field uniformity was measured using a LANEX (Kodak) scintillating screen, and found to be $\pm 10\%$ in dose over an area 70-80mm over 10.5 mm the beam was uniform to $\pm 3\%$.⁸

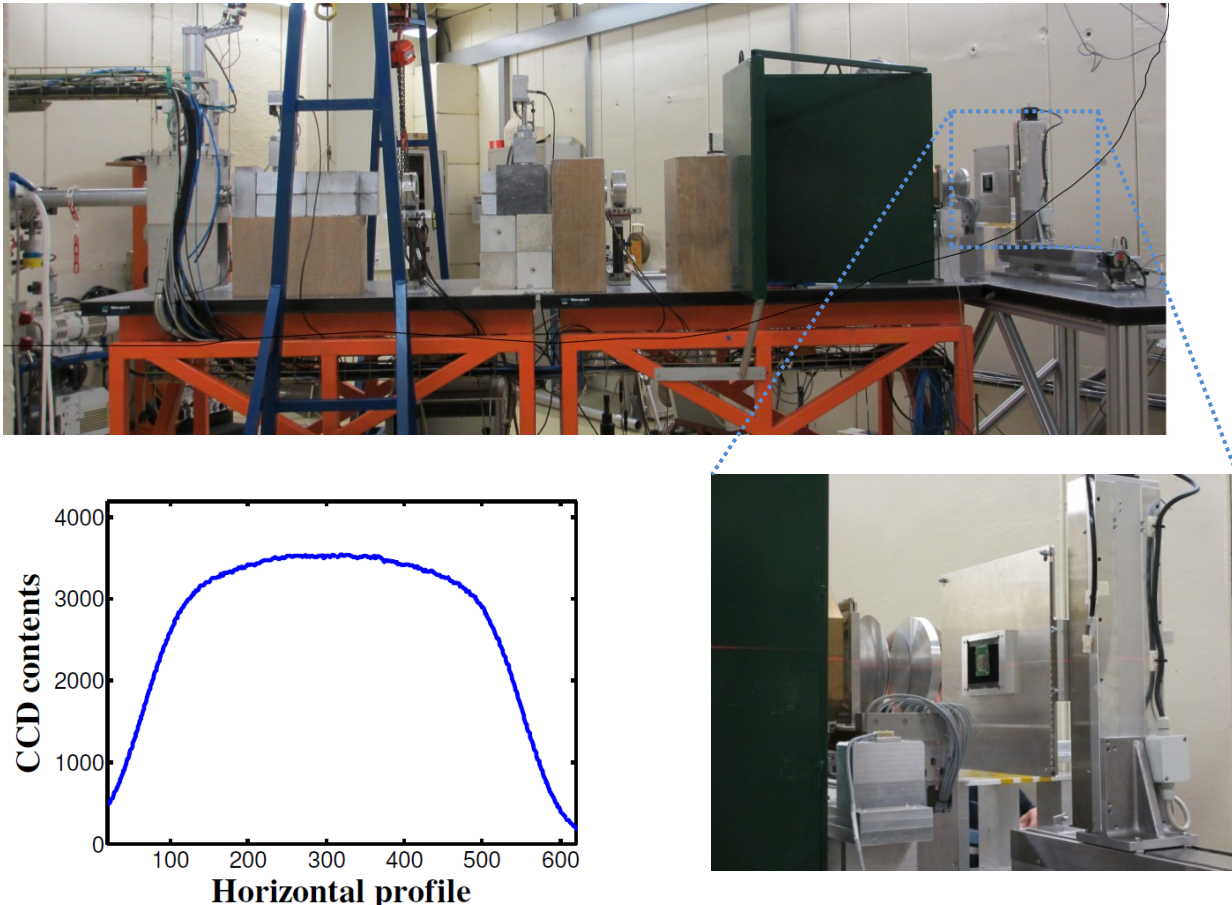


Figure 9: Photograph of the KVI beam line with enhanced region showing SCD mounting. The Horizontal profile shows the beam uniformity in mm

Table 2: Irradiation details

<i>Parameter</i>	<i>Value</i>
Beam Energy	50 MeV
Beam Fluence	1×10^9 p.cm ⁻²
Beam Flux	2.0×10^7 p.cm ⁻² .s ⁻¹
Exposure Time	50 s
Equivalent 10 MeV Fluence	5.0×10^8 p.cm⁻²
Beam diameter	8 cm
Beam uniformity	10% over $\phi 8$ cm 3% over central $\phi 1$ cm

3. RESULTS AND DISCUSSIONS

3.1 Cosmetic quality

The dark current and bright defects (cosmetic quality) of each device were assessed by obtaining line profile pseudo images as shown in Figure 10, by using Sequencer 235-COSM.dex. at $-50\text{ }^{\circ}\text{C}$ and 236-COS2.dex at $-20\text{ }^{\circ}\text{C}$. The SCD requires 120 clock cycles to read out the entire device. 150 clock signals were used in the measurement to ensure the entire device was read out. Any bright/dark pixels in the line profile of each device are shown on the cosmetic line profile. For n rows dark current integrated for 1 ms and readout as a single row with over scan and displayed as a pseudo image. Each element averaged over n times which are then plotted in a line profile. Due to the readout nature of the SCD, and as with previous cosmetic quality analysis of the CCD54⁵, defects are visible by bright/dark columns.

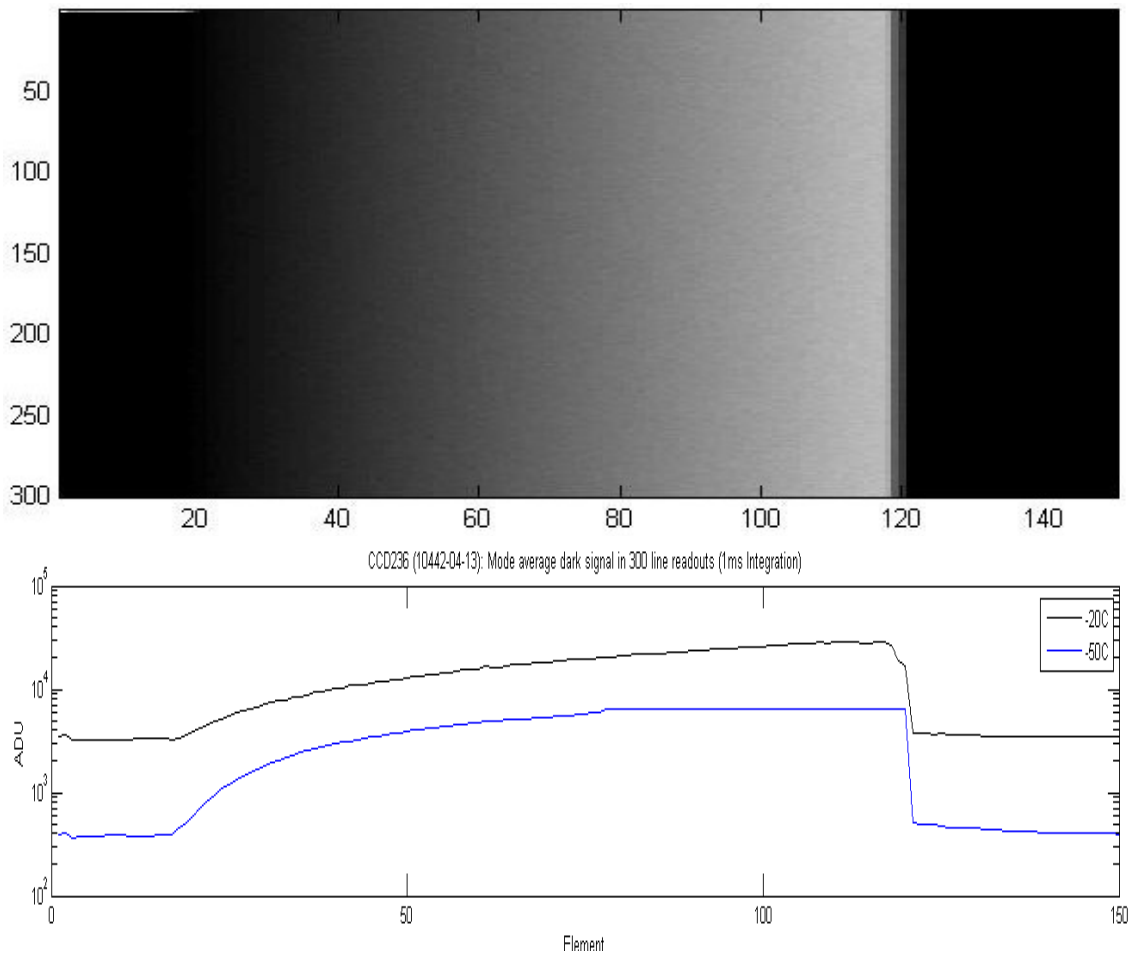


Figure 10. Pseudo image of cosmetic profile for CCD236 (top) and line plot of average reading per column (bottom)

3.2 Energy resolution and noise measurements

Sequencer 236.FWHM.dex was used to determine the calibration of each device using Mn-K α X-ray events. An example X-ray spectrum is given in Figure 11, plotting an integration time of 152.5 seconds at $-20\text{ }^{\circ}\text{C}$. This plot shows the Mn-k α and Mn-k β peak, as well as the Si escape peak from the detector and potentially pile-up events. The energy resolution given by the full width half maximum (FWHM) of the Mn-K α X-ray peak, measured using isolated X-ray events, as a function of temperature for three un-irradiated CCD236s is illustrated in Figure 12. The shaded region indicates the CLASS proposed operating temperature. Three images, a combined total of 457.5 seconds live time, for each

temperature were recorded and averaged. The predicted performance calculated from the Fano limit is also included in Figure 12 for reference.

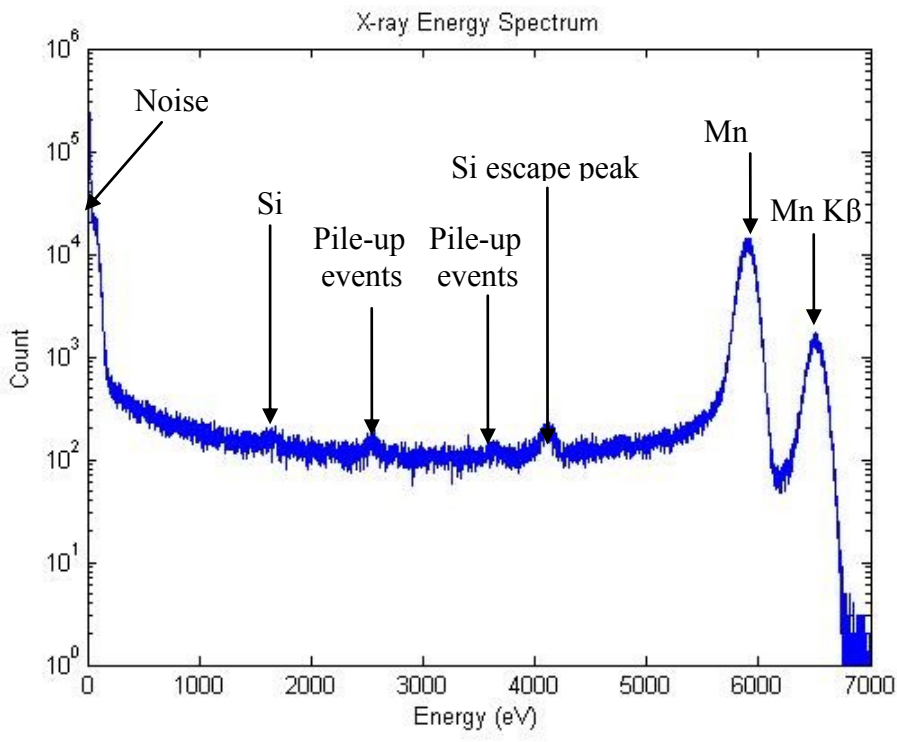


Figure 11. Single event energy spectra of 3×10^6 samples at -20°C

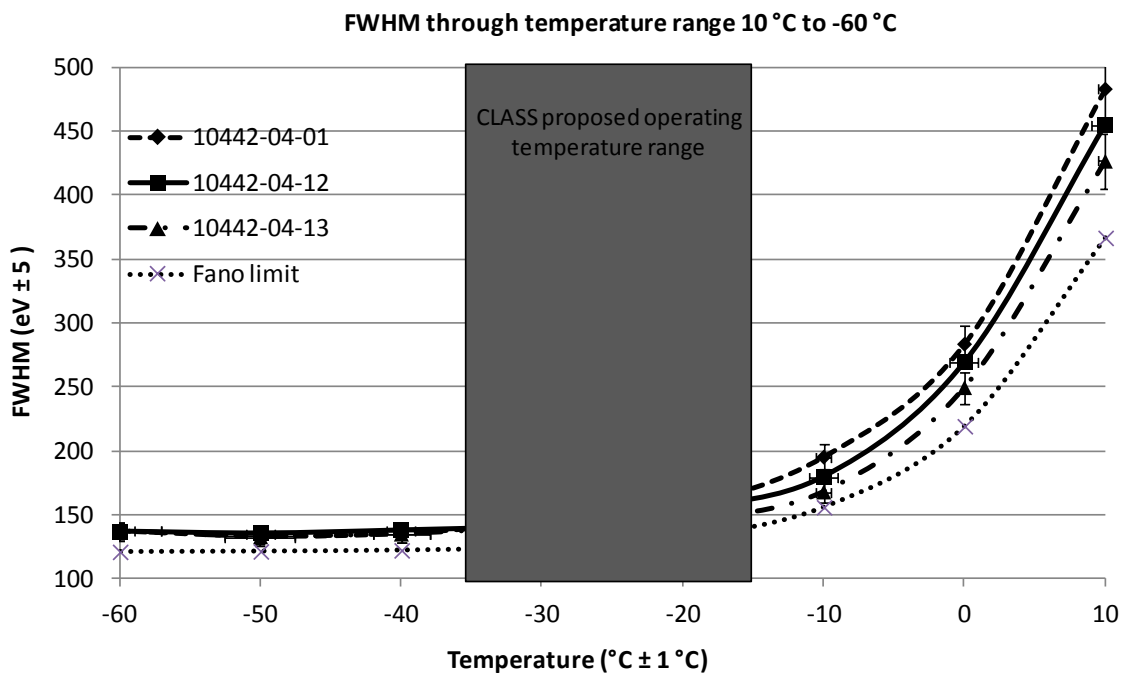


Figure 12. Energy resolution FWHM of three swept charge devices and the Fano limited predicted performance measured as a function of temperature

3.3 Pre and Post irradiation optimisation of the SCD236 investigation

Pre and post irradiation of the CCD236 under test was operated over the temperature range of -40°C to 10°C in 10°C increments, with 5°C increments through the CLASS proposed operating temperature range of -35°C to -15°C . Each device used the initial voltages and 110Hz clocking speed. The FWHM at Mn- $\text{K}\alpha$ (5,898 eV) was measured and the energy resolution is plotted as a function of temperature in Figure 14. The energy resolution improves as the temperature decreases due to the reduction in thermally generated dark current within the device.

The aim of the radiation damage study, of which this paper describes the initial investigation, was to achieve at least an energy resolution of 250 eV at Mn- $\text{K}\alpha$ throughout the mission lifetime, comparable to the aim set out for the C1XS characterisation⁵. It is evident from Figure 13 that with the SCD operated at 110 kHz the radiation induced dark current is sufficient to cause the energy resolution to increase above 250 eV.

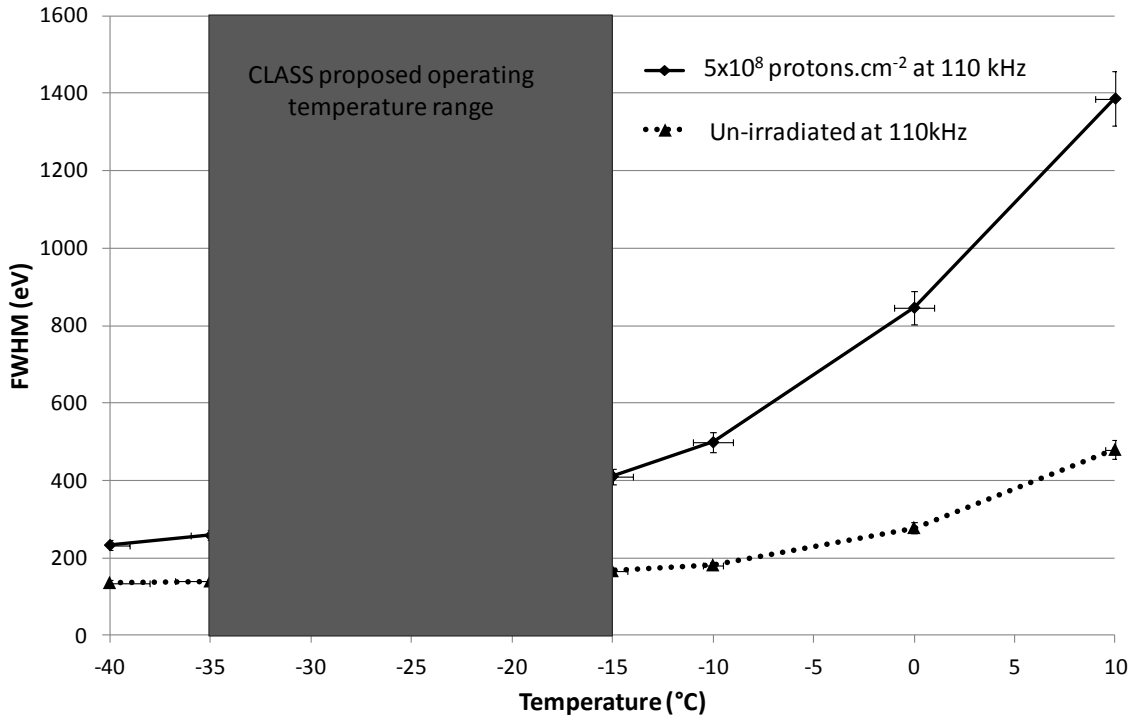


Figure 13. Energy resolution FWHM of a pre and post irradiated SCD through the CLASS proposed operating temperature range

An investigation into the optimum voltages and clocking speeds was carried out with the aim to improve the energy resolution over the proposed CLASS operational temperature range. The optimum voltages for this investigation were found to be those listed in Table 3. The optimal clocking speed was 175kHz, the results of this investigation are plotted in Figure 14.

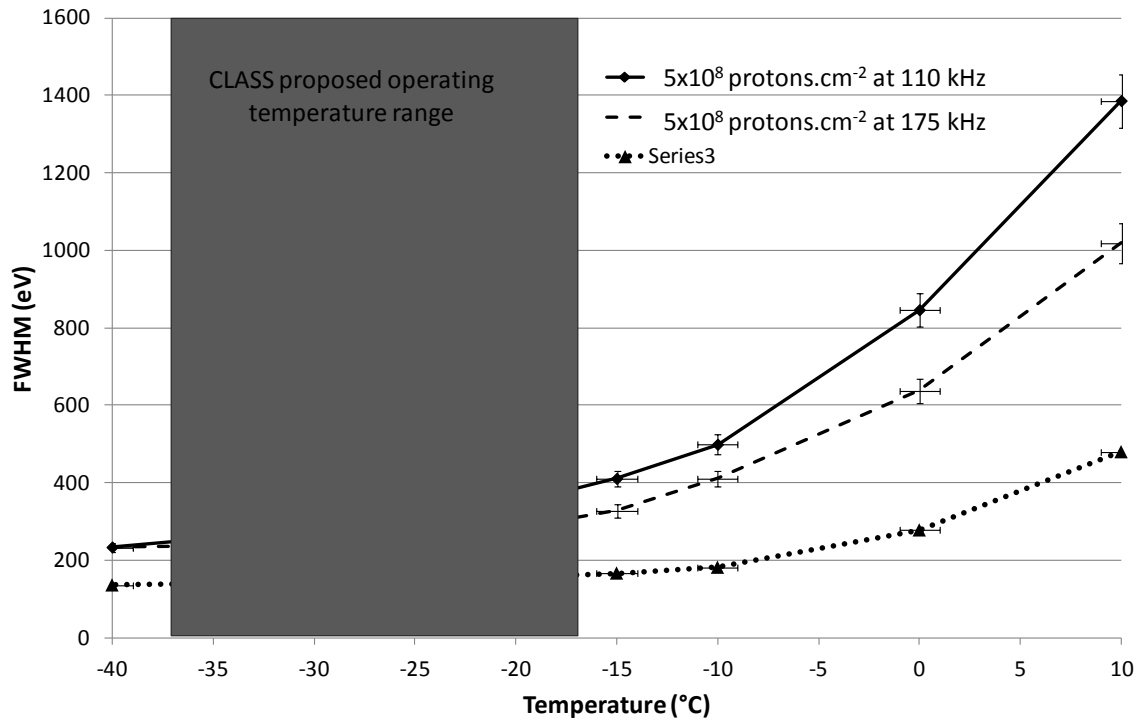


Figure 14. Energy resolution FWHM pre-irradiation SCD, and post-irradiated to 5×10^8 protons/cm² at the operating clock speed of 110kHz and 175kHz

Table 3: Optimum voltages for this investigation

Pin Number	Clock/Bias	Voltage
1	Reset 2	9.0
2	V _{SS}	9.0
3	V _{OD}	31.5
4	V _{OS}	-
5	V _{RD}	16.5
6	Reset 1	9.0
7	V _{OG}	3.0
8	V _{DOS}	-
9	V _{DD}	22.0
10	V _{SS}	9.2
11	Image clock 1	6.0
12	Image clock 2	6.0

CONCLUSIONS AND FUTURE WORK

The Chandrayaan-2 launch date of 2014 will allow the CLASS instrument to benefit from a high flux of solar X-rays, providing an excellent opportunity to detect the resulting fluorescence from the lunar surface, particularly the chance of Ti, Mg and Fe during such high-energy events. The flux of protons incident on the CLASS detectors is also increased during the period of solar maximum, especially when compared to the flux experienced by the detectors in C1XS. Although the mission duration is only 1 year the initial estimate of the CLASS end of life 10 MeV proton fluence, of 4.8×10^8 protons.cm⁻², is around almost 70% of the end of life prediction for the two year C1XS 10 MeV proton fluence⁹. Therefore, it is important to understand the physical effects on the detector as a result of radiation throughout the mission, and through investigations into device behaviour identify methods of operation and instrument design, i.e. shielding and drive electronics that will allow the instrument to provide valuable scientific information throughout the mission.

The performance of the CCD236 for the CLASS instrument has demonstrated that with the CCD operated at 175 kHz, the limit of 250eV FWHM as defined by the CEI, can be achieved up to -25 °C after the device has experienced a proton fluence of 5×10^8 protons.cm². Repeating the SPENVIS analysis using mission parameters for Chandrayaan-2 will allow an improved estimation for the end of life proton fluence. Further investigation into a previously irradiated device to a 10 MeV proton fluence, of 3×10^8 protons.cm⁻² will enable a model of the SCD performance throughout the mission lifetime to be predicted while it encounters proton radiation over time. This optimisation study allows the quad modules, containing an array of 4 CCD236 detectors as shown in Figure 15 to be investigated.

Further work will involve running un-irradiated devices at 175kHz and investigating methods to minimise radiation induced CTI, and adjusting the detector electronics with the aim to decrease noise performance from >10e-r.m.s to at least 6 e-r.m.s at -25°C. Headboard modifications to use the differential amplifier and the radiation damage effect on the central column will also be investigated

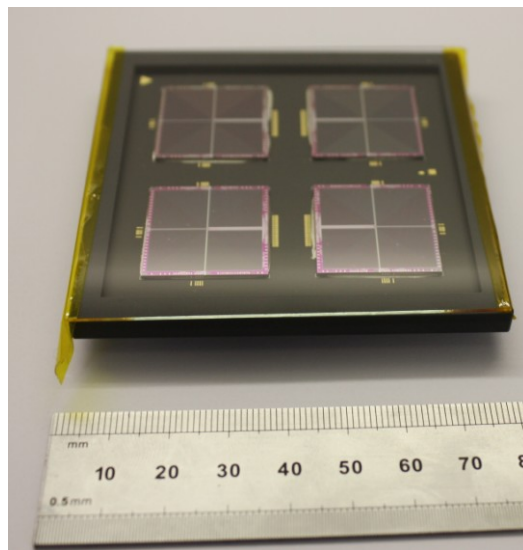


Figure 15: Photograph of a CCD236 quad pack

REFERENCES

- [1] V. Radhakrishna et al., "The Chandrayaan-2 Large Area Soft X-ray Spectrometer (CLASS)", 42nd Lunar and Planetary Science Conference, p.1708, (2011).
- [2] M. Grande et al., "The C1XS X-ray Spectrometer on Chandrayaan-1", Elsevier, Planetary and Space Science vol.57, pp.717-724, (2009).
- [3] A. Holland P. Pool "A new family of swept charge devices (SCDs) for x-ray spectroscopy applications", High Energy, Optical and Infrared Detectors for Astronomy III Proc. SPIE 7021, (2008).
- [4] E. Stassinopoulos and J. Raymond, "The Space Radiation Environment for Electronics", Proc IEEE vol.47, pp.2451-2459, (1988).
- [5] Space Weather Prediction Centre, (May 2012). <http://www.swpc.noaa.gov/SolarCycle/>
- [6] D. Smith et al., "Proton irradiation of swept-charge devices for the Chandrayaan-1 X-ray Spectrometer (C1XS)", Nuclear Instruments and Methods in Physics Research Section A, vol.583 pp.270-277, (2007).
- [7] D. Heynderickx, B. Quaghebeur, E. Speelman, E. J. Daly, "ESA's Space ENVironment Information System (SPENVIS): A WWW Interface to Models of the Space Environment and its Effects", Proc. AIAA, vol.0371, (2000).
- [8] R. Ostendorf, "Flux calibration for the irradiation for cei on February 6, 2012", KVI, 22nd February (2012).
- [9] J. Gow et al., "Radiation Study of Swept-Charge Devices for the Chandrayaan-1 X-ray Spectrometer (C1XS) instrument", Proc. SPIE, vol. 7021, (2008).