

THE PROMPT PARTICLE BACKGROUND AND MICROMETEOROID ENVIRONMENT AT L2 AND ITS IMPLICATIONS FOR *EDDINGTON*

D. R. Smith, R. M. Ambrosi, A. D. Holland, I. B. Hutchinson, and A. Wells

University of Leicester, Space Research Centre, Dept. of Physics and Astronomy, University Road, Leicester, LE1 7RH, UK

ABSTRACT

The *Eddington* spacecraft will orbit the Sun at the L2 point during its 5 year asteroseismology and planet finding mission. The successful detection of objects of interest and the amount and accuracy of the data that is recorded will depend on the prompt particle background interacting with the detectors in the focal plane of the instrument. The sources of the particle background are both solar and galactic. *Eddington* will be operational during the next period of solar maximum and therefore consideration of the particle environment is important in deducing the shielding requirement for the *Eddington* CCD detectors and the impact the environment will have on the collected science. This paper presents measured spacecraft data and predictions of the flux and energy of the particle environment at L2. An understanding of the micrometeoroid environment at L2 is also critical to the *Eddington* mission. The impact of micrometeoroids on the *Eddington* focal plane has the potential of causing catastrophic failure of one or several detectors resulting in a large reduction in the data obtained. A review of the dust particle background and the stability of dust accumulated around the L2 point is also presented and is the subject of further study.

Key words: *Eddington*, micrometeoroid, L2, particle background, radiation damage

1. INTRODUCTION

The current baseline for the *Eddington* instrument consists of four co-aligned optical telescopes, each with a focal plane made up of 8 back illuminated frame transfer E2V Technologies custom CCDs with $13.5 \mu\text{m}^2$ pixels. An artists impression of the *Eddington* spacecraft is shown in Fig. 1 along with a diagram of the planned focal plane array for each of the four telescopes.

1.1. THE L2 PARTICLE BACKGROUND

Positioned at L2, the *Eddington* spacecraft will operate beyond the Earth's magnetosphere, and will therefore not be subjected to trapped particle radiation. The interplanetary regions of space are pervaded by a low energy flux of electrons and protons of order 10^{12} particles $\text{cm}^{-2} \text{s}^{-1}$,

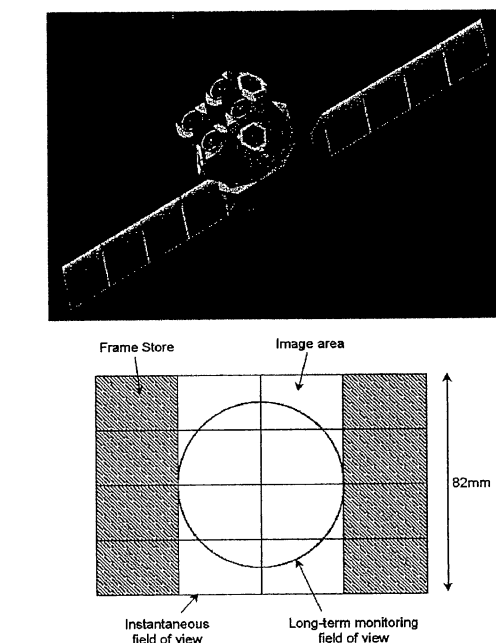


Figure 1. An artists impression of the *Eddington* spacecraft and the planned CCD focal plane array for each of the four co-aligned optical telescopes.

supplied by the solar wind. These particles have energies of less than 0.1 MeV and are absorbed by a few μm of silicon. For back illuminated CCDs, as planned for use in the *Eddington* focal plane, this radiation will not penetrate through to the electrode or readout structures of the devices and will therefore not contribute a significant amount to the total damaging radiation dose the detectors will receive over the mission lifetime. A constant background flux of particles with energies up to a few TeV also exists, with an estimated count rate of 5 particles $\text{cm}^{-2} \text{s}^{-1}$ through 1.3 mm of Al shielding.

The most critical component to the total damaging radiation dose is caused by transient particles from solar events. These particles range in energy from a few keV for protons, to GeV for heavier ions. During solar maximum

the average flux of these particles is predicted to be 10^5 particles $\text{cm}^{-2} \text{s}^{-1}$ through 1.3 mm of Al shielding (Kim & Wilson 2000).

Eddington is scheduled to be launched in 2008 and will therefore be operational during the next period of solar maximum. The particle fluence from the sun is strongly dependent on the 11 year solar cycle. Figure 2 shows the projection of sunspot activity for 1.5 solar cycles indicating the next cycle will peak 2010. The *Eddington* timeline is also shown in the figure. From 2009 the prompt particle rates in the CCDs are expected to exceed 10 , 10^2 , 10^3 and 10^4 particles $\text{cm}^{-2} \text{s}^{-1}$ for respectively 24%, 9%, 4% and 1% of the time, as modelled for 16 μm thick back illuminated CCDs (Ambrosi et al. 2003).

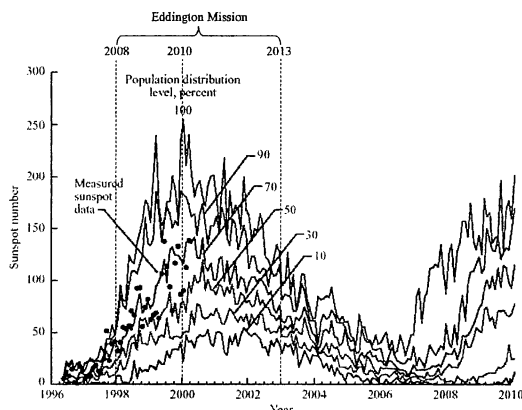


Figure 2. Projection of sunspot activity for solar cycle 23 and part of cycle 24 indicating that the next cycle will peak between 2009 and 2011. Measured sunspot data is presented along with modelled data that show statistically how likely a given sunspot number will occur at a given time in the solar cycle. The relationship of the planned *Eddington* timeline to the sunspot activity is also shown.

1.2. THE L2 MICROMETEOROID ENVIRONMENT

Figure 3 shows the modelled interplanetary micrometeoroid flux for different particle sizes, indicating that the smaller the particles, the higher the flux rate (Lindsey 1998). On average, interplanetary particle velocities are of the order $20\text{--}70 \text{ km s}^{-1}$.

In addition to the interplanetary high velocity component, there is an additional low velocity micrometeoroid component as a result of the transient stability of the L2 Earth-Moon system with respect to dust concentration. This velocity component is of the same order as the low Earth orbit micrometeoroid velocity regime and ranges from a few km s^{-1} to 10 km s^{-1} . In terms of flux and

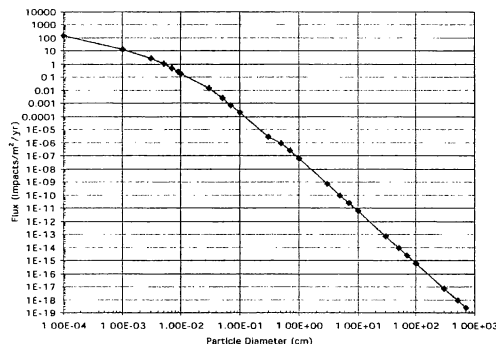


Figure 3. Modelled interplanetary micrometeoroid flux vs. particle size.

particle size, it is similar to the interplanetary component (Moeed 2003).

Both the micrometeoroid and radiation environment at L2 need to be considered when finalising the shielding regime to be used around the CCD detectors.

2. MEASURED SPACECRAFT DATA

The average fluxes of protons above 1 MeV and 30 MeV over a 14 year period as measured by the GOES spacecraft are shown in Fig. 4 (SPIDR 2003). The regions of high flux are correlated with the 11 year cycle of sunspot activity. Figure 5 shows the solar proton flux detected by the *XMM-Newton* radiation monitor while the spacecraft was outside the Earth's radiation belts (Altieri 2001). This data was recorded during the April 2001 period of high solar activity. The dark line indicates particles above 12 MeV, the lighter line those above 2 MeV. One orbit of *XMM-Newton* is 48 hours in duration indicating that the increase in activity after a solar event is rapid, but the decay period may span several days.

3. RADIATION DAMAGE

The major type of radiation damage for a CCD space mission placed above the radiation belts is atomic displacement caused by solar protons. CCD are extremely sensitive to displacement damage because small charge packets are moved slowly through centimetres of silicon, suffering Charge Transfer Inefficiency (CTI). Figure 6 shows the growth in CTI on-orbit of CCDs 1 and 2 in the EPIC-MOS1 camera of *XMM-Newton* (Bennie 2001).

Low energy protons can be a particular problem when their penetration depth is correlated with the buried channel position within the CCD. Figure 7 shows the amount of energy deposited into the buried channel volume of a CCD for a given incident proton energy, emphasising the damaging power of low energy protons (Ambrosi et al.

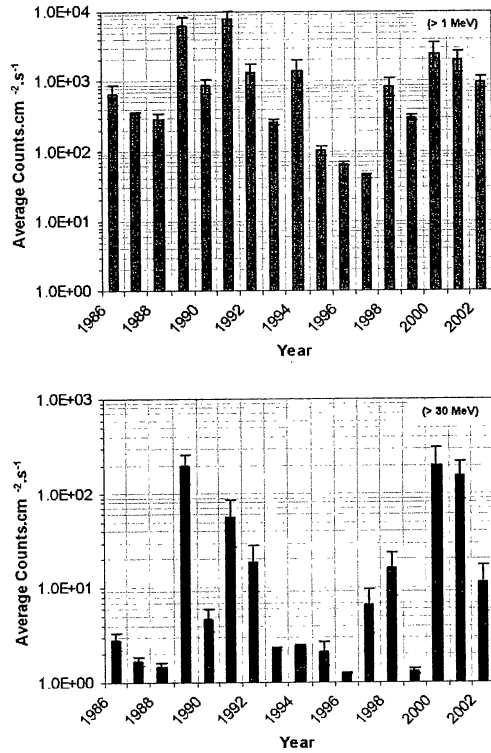


Figure 4. The average flux of protons above 1 MeV and 30 MeV over a 14 year period as measured by the GOES spacecraft.

2002). Further study of the measured *XMM-Newton* radiation damage is needed to determine the relevance of the EPIC-MOS results to *Eddington*.

Dark current increases with radiation damage but is not just a white noise source. Bright pixels and columns also result from radiation damage. Some bright pixels are observed to flicker like the one shown in Fig. 8, but these are generally only a significant problem at temperatures > 190 K (Smith et al. 2002).

3.1. EVENT MORPHOLOGY

Figure 9 is a CCD image frame showing ^{60}Co gamma ray events interacting with a back illuminated CCD with 20 μm depletion depth (Ambrosi et al. 2003). The morphology of particle events is important for distinguishing objects of interest from the particle background. Objects of interest will have an event shape determined by the optics of the telescope. The different event types are highlighted in the numbered panels, panel 1 showing the relative intensity of the background noise. The shape of events does

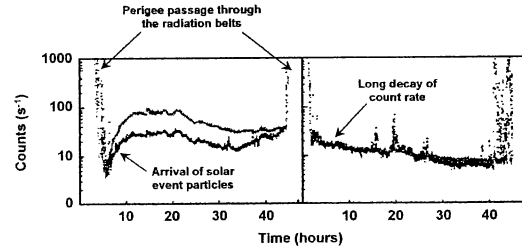


Figure 5. The particle rates detected by the XMM-Newton Radiation Monitor. The data presented is from revolutions 239 and 240, recorded during the April 2001 period of high solar activity. The dark line refers to particle energies above 12 MeV, the lighter line to those above 2 MeV.

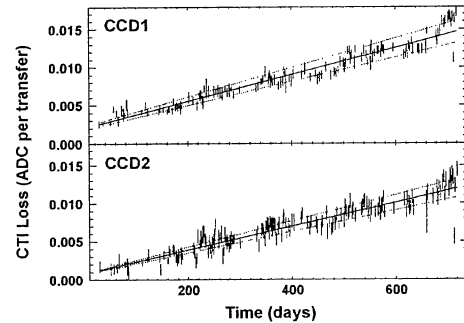


Figure 6. The on-orbit change in CTI observed by EPIC-MOS1 CCDs 1 and 2 of XMM-Newton.

not include the *Eddington* PSF. This distinction can be used to remove background particle events from the data. For comparison, the ring shape of the current baseline *Eddington* PSF is shown in Fig. 10.

4. CONCLUSIONS

This paper has described the main components of the L2 environment that will have a marked affect on the *Eddington* CCDs. The work presented is being used to develop a radiation and particle effects simulation package that can be used with simulated *Eddington* data to model the effects of the L2 environment on the CCD images and mission science. The *Eddington* spacecraft needs to be designed such that the CCDs receive an acceptable level of radiation damage over the duration of the mission. The lower energy, < 30 MeV particle flux, can be attenuated by ~ 5 mm of Al or equivalent shielding, as modelled using SRIM (Ziegler et al. 1985). Prompt particle events with energies > 30 MeV will however pass through this shielding and cause ionisation and displacement damage in the CCDs resulting in a gradual CTI change over the

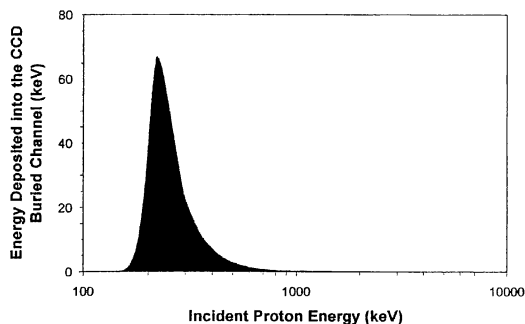


Figure 7. Energy deposited into the buried channel volume of a CCD as a function of incident proton energy.

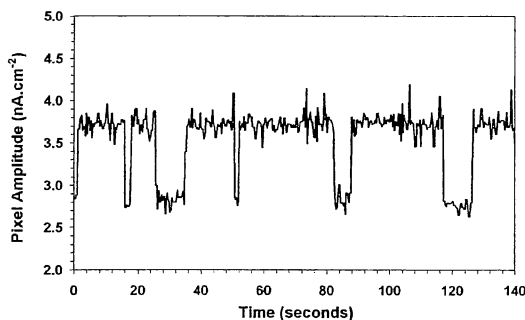


Figure 8. The variation in amplitude over time of a 'flickering' CCD pixel.

mission duration, and the generation of bright pixels and columns. A radiation monitor and suitable use of the telescope shutter will reduce the amount of damaging flux reaching the CCDs. The data analysis software will be required to differentiate objects of interest from background events.

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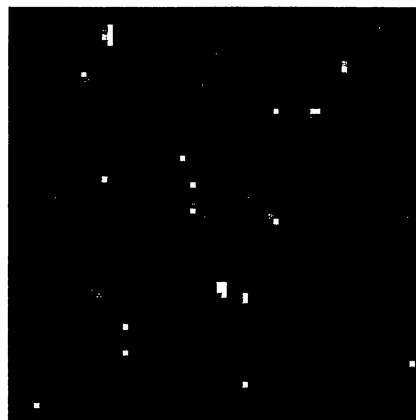


Figure 9. An 80×80 pixel CCD image frame showing ^{60}Co gamma ray events interacting with a back illuminated CCD57 from E2V Technologies, approximately $20 \mu\text{m}$ thick. The event types and shapes are highlighted in the numbered panels.

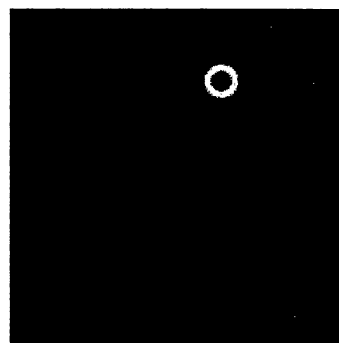


Figure 10. A simulated CCD observation of a star field showing the ring shape of the baseline Eddington PSF.

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