The variability of the XMM cosmic-ray induced particle background and lessons learned for ATHENA

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Abstract

The systematic analysis of the XMM EPIC MOS2 over the full mission time-line (100 Ms of data) performed within the ESA R&D AREMBES activity has already provided a more thorough understanding of the various components of the background experienced by XMM and provided valuable lessons for Athena.

Here we further develop that study by investigating the variability of the Galactic cosmic-ray induced particle background and its variability from the 10-100 ks time-scale of a typical Athena WFI observation up to the variability at year time scales connected to the solar cycle. These results can be used to estimate the sampling strategy of the rotation of the filter wheel to the closed position of the WFI and the necessity of a particle monitor extending up to hundreds of MeVs.

1 Introduction

Achieving the ambitious scientific goals of ATHENA requires a careful work on the background that the mission will face in order to minimize its intensity and maximize its reproducibility. To this aim lessons learned from previous missions can be extremely valuable. Our team has exploited the entire XMM public data set, spanning 15 years of observations and 100 Ms of data (within the ESA R&D activity AREMBES and with the help of the FP7 EU EXTraS project). We characterized the XMM background in its various components, mainly the soft proton (protons of tens/hundreds of keVs) flaring component, focused by the mirrors and the unfocused component consisting of secondaries produced by Galactic Cosmic Rays (GCR), protons with energies greater than 100 MeV (Marelli +17, Salvetti+17, Ghizzardi+17, Gastaldello+17). These two components will also affect the ATHENA instruments and the GCR-induced component and its variability is the focus of this work. The GCR-induced background (GCR-BKG) has been measured through the analysis of the corners of the MOS2 detector not exposed to the sky where neither X-ray photons nor soft protons focused by the mirrors are collected. The key finding has been the clear correlation of this non-flaring unfocused component with proxies of the GCR rate (such as the rate of the Radiation Monitor on board XMM, when Solar Energetic Particle, SEP, events are filtered out) thus firmly establishing the connection (Gastaldello+17, see Fig.1).

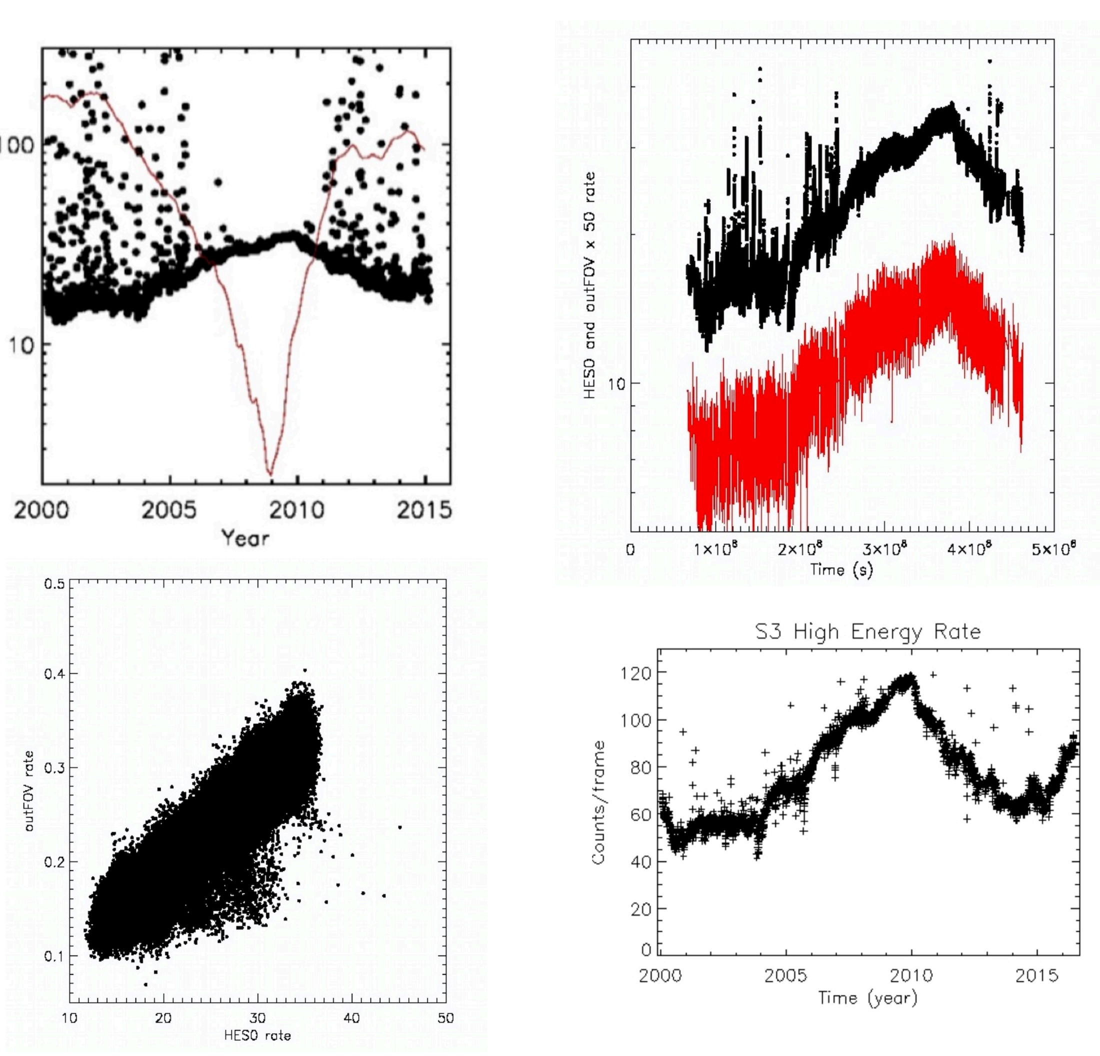

Fig.1 *(Top left panel). Median count rate of the EPIC Radiation Monitor (ERM) HE0 channel (sensitive to protons in the 8-20 MeV energy range) as a function of time. Overplotted in red arbitrary units the number of sun spots as a proxy for the solar cycle. There is a clear anti-correlation as expected given that most of time the 8-20 MeV proton rate reflects the GCR rate, with the exception of SEP events, present only during high solar activity.*

(Right top panel) ERM HE0 (black) and MOS2 outFOV rate (red) as a function of time with SEP events filtered out

(Left Bottom panel) The clear correlation between ERM HEO rate and MOS2 outFOV rate, when SEP events are filtered out

(Right Bottom panel) Chandra ACIS S3 threshold rate (Ford & Grant 2012), a proxy for the unfocused component in Chandra. The striking similarity reinforces the idea of the common GCR origin for this background component of CCDs in similar orbits.

2 GCR-BKG variability at long time scales

We further develop our study by making a quantitative correlation of the MOS2 outFOV rate with the Chandra S3 threshold rate (Ford & Grant 02): once obvious outliers are removed, the linear relationship connecting the two rates has a 1σ intrinsic scatter of 2%, see Fig.2 left panel. To access directly the relevant energy range of GCRs instead of approximate proxy given by the XMM ERM we used the data of Kuehl+16. The authors extended the available energy range of the EPHIN detector on board SOHO to cover the energy range 100 MeV – 1 GeV making available a large data set in terms of energy and time coverage, comparable to the XMM dataset. The correlation between the MOS2 outFOV rate and the 900 MeV proton flux (monthly averaged) is extremely good with an intrinsic scatter less than few %, see Fig. 2 right panel.

These correlations highlight the fact that precise measurements of the GCR protons with an High Energy Particle Monitor on board ATHENA can predict with high precision this background component.

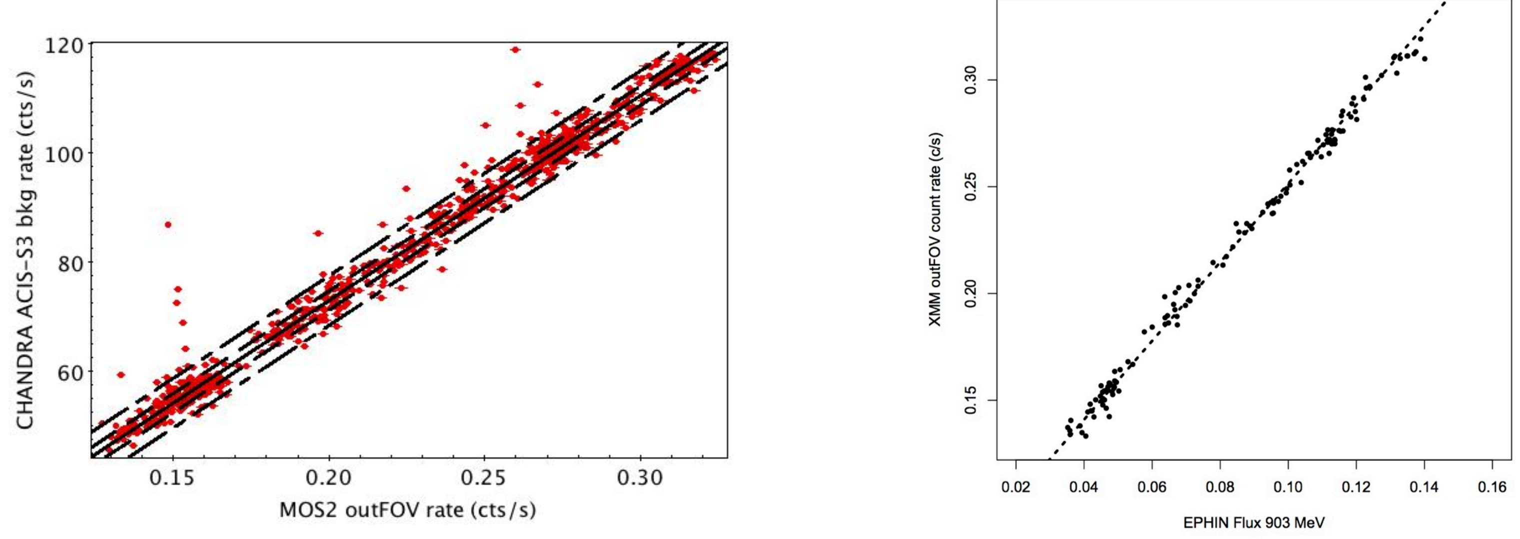

Fig.2 *Correlation of the XMM MOS2 outFOV rate with the Chandra S3 threshold rate on the left panel and with the SOHO EPHIN proton flux at 903 MeV on the right panel (errors on the SOHO flux data are omitted for clarity).*

3 WFI background sampling technique

We investigated the time variability of the GCR-BKG at scales ranging from 15-20ks to 100ks (the typical background sensitive WFI observation). We analyzed 105 outFOV light curves of observations lasting an entire revolution (about 120ks) to avoid aliasing, representative of XMM observations. Using the excess variance technique (Nandra+97) we have found no evidence for variability, after excluding few bins at the end of the orbit.Upper limits at 3σ have been computed for different choices of the time binsize (see Fig.3, left panel as an example). We can exclude with high confidence variability larger than 5%-8% on time scales shorter than 100ks.

Contrary to the MOS, the background monitoring strategy in the WFI will not involve shielding permanently the corners of the detectors but sampling the GCR-BKG by rotating the filter wheel (FW) to the closed position (for background sensitive observations). Using the XMM results we estimated that sampling the WFI background for 1ks every 10ks will allow a high accuracy estimate of this component for the WFI (see Fig.3, right panel), requiring 20k FW rotations over a 10 years mission's lifetime (von Kienlin+18).

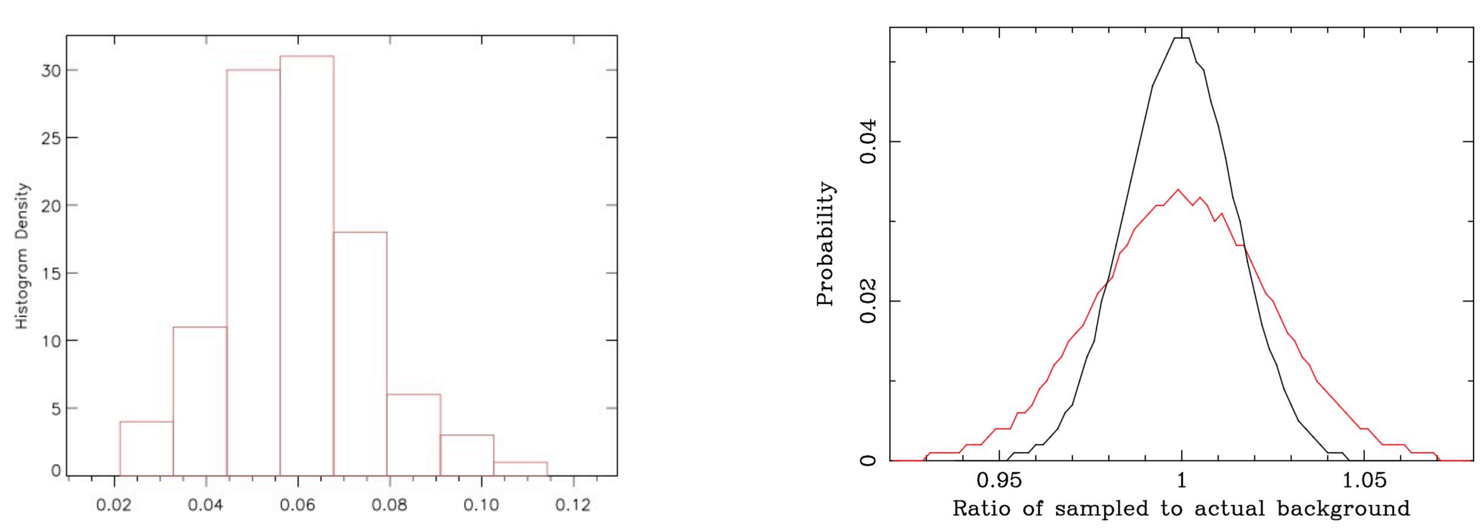

Fig.3 *(Left Panel): Distribution of 3σ upper limits on fractional variance of the 105 outFOV light curves in our sample for a time binsize of 2.5ks. (Right panel): Distribution of the ratio of sampled to actual background for 1.e5 realizations of a 100 ks WFI observation. Variability has been injected in the form of normally distributed fluctuations of 5%, black curve, and 8%, red curve, on a timescale of 1 ks.*

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