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# Creation of 2–5 keV and 5–10 keV sky maps using XMM-Newton data

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Sky maps are powerful visualisation tools for quicklook analysis of extended sources. The latest sky map in soft X-rays (0.1–2.4 keV) has been created in the 1990's using ROSAT data. By analysing publically available data from XMM-Newton X-ray mission we constructed new sky maps in two energy bands – 2–5 keV and 5–10 keV, complementary to ROSAT data, covering approximately 1% of the sky, and included them in our web-based tool `http://skyview.virgoua.org`.

**Key words:** X-rays: general, virtual observatory tools

## INTRODUCTION

Usually, astronomers deal with catalogues of point sources. However, if the source is extended (i. e. its size is comparable or even bigger than the point spread function of the instrument, a more sophisticated method of scientific data visualisation is needed. The most common method of such visualisation is building sky maps — specially processed series of two-dimensional images in different energy bands. An example of such a map for X-ray astronomy is all-sky map in 0.1–2.4 keV band made by ROSAT X-ray satellite [7, 9] observations. This all-sky map also exists as an interactive web-tool[1].

Following the end of the ROSAT mission, several missions in the keV range have been in operation. These missions have covered a minor part of the sky (not more than several percent) but with a much better sensitivity and a wider energy range as compared with ROSAT. In this paper, we present the interactive maps in 2–5 and 5–10 keV range. For these maps, we use publically available observations by MOS cameras [8] of the XMM-Newton [4] X-ray mission. Special attention was paid to the handling of the most important background components, including soft proton flares and quiescent particle background, see the corresponding web-page[2] for detailed properties of XMM-Newton background. The obtained map is on the website of Virtual Roentgen and Gamma Observatory in Ukraine[3].

## METHODS

In order to construct the sky maps, we first downloaded all publically available (as of July 1, 2013) observation data files for MOS [8] cameras of the XMM-Newton X-ray observatory [4] available on the HEASARC data archive[4]. These data files were processed using `Extended Sources Analysis Software` (`ESAS`) package[5] [5] specially developed for analysis of extended sources at the NASA/GSFC XMM-Newton Guest Observer Facility[6] in cooperation with the XMM-Newton Science Operation Centre[7] and the XMM-Newton Background Working Group[8]. It is publically available as part of `XMM-Newton Science Analysis System (SAS) v.13.5.0`. The methodology of `ESAS` software is based on detailed modeling and/or subtraction of various background components (see the webpage[2] for complete list) experienced by MOS and PN cameras on-board XMM-Newton cosmic mission using the "first principles" as much as possible. To model instrumental background, `ESAS` software relies on filter-wheel-closed data and the data from the unexposed corners of archived observations, rather than "blank sky" data (contaminated to an unknown level by different variable background components) used by a number of other methods. This is essential for analysis of very faint sky regions (e. g. galaxy cluster outskirts) dominated by the background (rather

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[1]http://heasarc.gsfc.nasa.gov/cgi-bin/Tools/xraybg/xraybg.pl
[2]http://www.star.le.ac.uk/~amr30/BG/BGTable.html
[3]http://skyview.virgoua.org
[4]http://heasarc.nasa.gov
[5]http://heasarc.gsfc.nasa.gov/docs/xmm/esas/cookbook/xmm-esas.html
[6]http://heasarc.gsfc.nasa.gov/docs/xmm/xmmgof.html
[7]http://xmm.esac.esa.int
[8]http://xmm2.esac.esa.int/external/xmm_sw_cal/background

than the source) emission. The obtained data products — filtered event lists, images, lightcurves and spectra — are produced in `FITS` [2, 3] format for user-defined regions within the XMM-Newton field-of-view. Here, an "event" is a result of instantaneous positive detection in one or several adjacent CCD pixels. A single photon impacting on the CCD may produce a substantial signal in adjacent pixels causing so-called multiple (e. g. double, triple, quadruple) events. The standard selection procedure used in our analysis takes into account single, double, triple and quadruple events for MOS cameras. According to [6] the procedure based on analysis of event patterns allows to reject approximately 99% of events caused by high-energy ($\sim 100$ MeV) cosmic rays, thus significantly reducing the amount of data telemetry.

Table 1: General properties of MOS observations used in our analysis.

| Camera | MOS1 | MOS2 |
|---|---|---|
| No. of observations | 3942 | 4022 |
| No. of data files | 4029 | 4104 |
| Cleaned exposure, Ms | 77.9 | 81.5 |

Our data reduction is started from production of filtered event lists using `ESAS` script `mos-filter`. This script effectively removes time intervals affected by highly variable background components — soft proton flares, see [5] and the web-page[2]. We used the standard filters and cuts provided by `ESAS` software. For example, we selected single, double, triple and quadruple events (described by event `PATTERN` $<= 12$) of highest quality (described by `FLAG` $== 0$). Such a selection based on `FLAG` keyword excludes events out of instrument FoV, near CCD corners and "hot pixels" etc. It is generally recommended[9,10] to select `FLAG == 0` for high-quality spectral analysis. The main parameters for obtained event lists are shown in Table 1. The leftover MOS event lists were processed by `ESAS` scripts `mos-spectra` and `mos_back`, resulting in observed and modelled quiscent particle background spectra, exposure maps, count images for selected energy ranges, and modelled particle background count images. The resulting images and exposure maps of individual observations are then combined by `ESAS` scripts `merge_comp_xmm` and `bin_image_merge` into count-rate images of sky regions with size $22^\circ \times 22^\circ$ and minimal pixel size $2.5'' \times 2.5''$. Point sources are not excluded, although very bright point sources observed with timing mode (such as BY Cam, see Fig. 2) have not been processed by `ESAS` and therefore do not appear on the map. For the sky map, we chose two energy ranges — 2–5 keV and 5–10 keV — motivated by:

- Their negligible contamination by remaining Solar Wind Charge Exchange background component, see [5] the web-page[2] for details; and
- The complementarity to existing ROSAT all-sky map[1] in 0.1–2.4 keV.

For sky map visualisation, we used the standard NASA `skyview.jar` tool[11]. This tool selects appropriate images overlapping with a given sky region and samples them to the given pixel size. The Sutherland-Hodgman clipping algorithm was used to resample images. This method treats the output pixel grid as a window over the input images grid and integrates the flux within each output pixel exactly. The output image can be produced at the given sky coordinates and projection. The obtained images in `FITS` [2, 3] format are available for a quick look and can be directly downloaded from the web-page[3].

## RESULTS

We constructed sky maps in 2–5 keV and 5–10 keV bands using $\sim$4000 publically available observations of MOS cameras on-board the XMM-Newton X-ray cosmic mission. Positions of given observations and their basic properties are shown in Fig. 1 and Table 1, respectively. The produced maps are cleaned from variable soft proton component and instrumental background with the help of standard analysis for extended sources — `ESAS` software[5] — and added to the web-interface of Virtual Roentgen and Gamma-Ray Observatory in Ukraine[3], see Figs 3 and 4 as examples. The obtained maps cover approximately 1% of all sky, see Fig. 1 for details. They are complementary to existing ROSAT all-sky map in soft X-rays (0.1–2.4 keV) as well as usual X-ray catalogues of point sources.

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[10] http://xmm.esac.esa.int/external/xmm_user_support/documentation/uhb
[11] `http://skyview.gsfc.nasa.gov/current/jar/skyviewinajar.html`

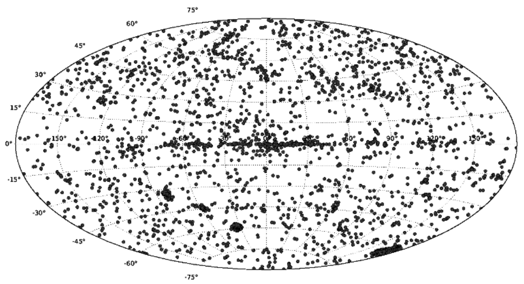

Fig. 1: Positions (in galactic coordinates) of XMM-Newton observations used in our analysis. The field-of-views of XMM-Newton observations are given in natural values, so one can easily recognize the zones observed by XMM-Newton covering about 1% of all sky.

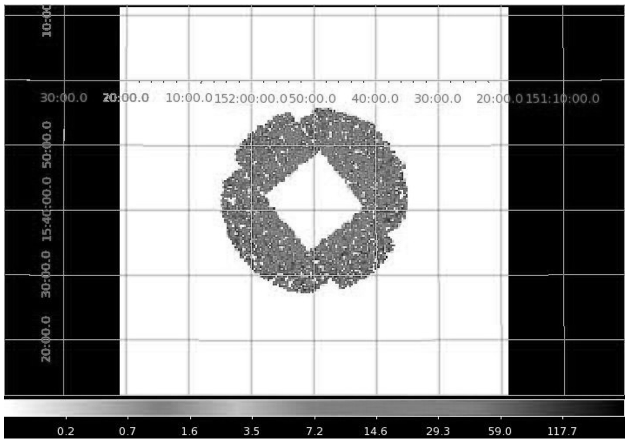


Fig. 2: An example of very bright point source observation — polar BY Cam in 2–5 keV. The units are in cts/s/deg$^2$. The position of BY Cam coincides with central CCD of MOS instruments. Because this point source is very bright ($\gtrsim$ 1 mCrab [1]), it was not observed in usual imaging mode and therefore appears as a "gap" in the sky map.

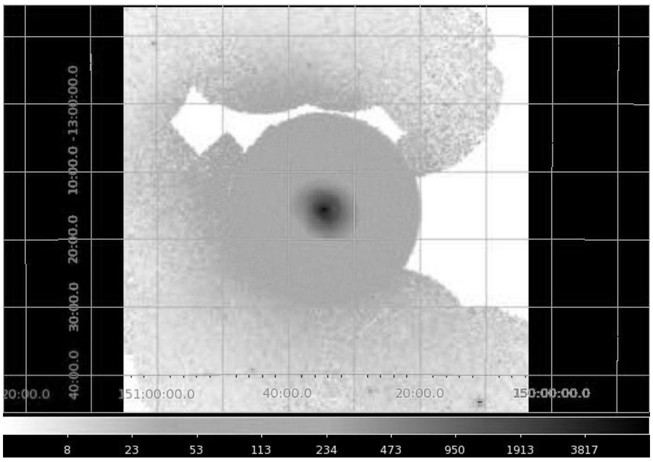


Fig. 3: A 2–5 keV image of 1 square degree around Perseus cluster of galaxies. The units are in cts/s/deg$^2$.

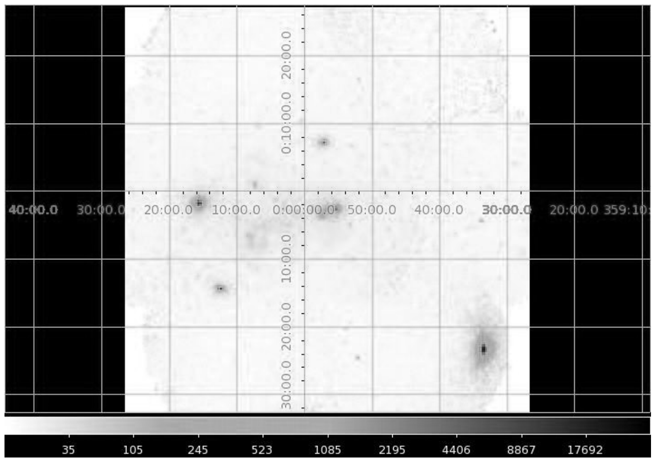


Fig. 4: The same as in Figure 3 but for Milky Way centre in 5–10 keV range.

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