Simulations of X-Ray Telescopes for eROSITA and IXO

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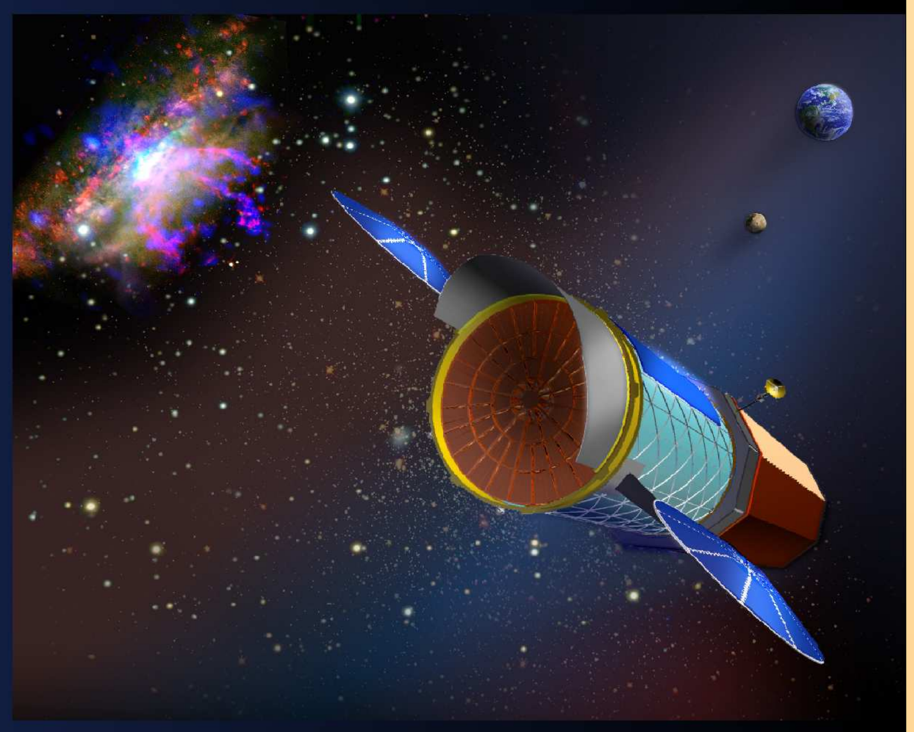

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Abstract

We present a generic X-ray instrument simulation tool developed for studies of future X-ray missions. According to the concept of Monte Carlo simulations the software generates a sample of photons for different X-ray sources based either on several catalogs like the ROSAT all-sky survey or on images of light cones from cosmological hydrodynamical simulations. The imaging in a Wolter telescope and the detection process are modelled by means of standard calibration files like a point spread function and the detector response. The resulting event files have FITS format and can be analysed with standard tools.

Using this software we performed simulations of parts of the eROSITA all-sky survey for several fields of galaxy clusters, and we studied the detector-specific pile-up behaviour of the High Time Resolution Spectrometer and the Wide Field Imager on the International X-ray Observatory in order to estimate the bright source performance of these instruments.

General Features of the Simulation

In order to analyse the properties of future X-ray telescopes we are developing a simulation software package containing models for different detector concepts. The simulation is based on individual photons generated for either point-like or extended X-ray sources with realistic spectra and time variability provided in several catalogs. In order to model the imaging process in the mirror shells of a Wolter telescope, we use the corresponding Point Spread Function to obtain impact positions on the detector for the individual photons. The simulation of the detection process itself is mainly based on the detector-specific response file. Additionally we consider the particular read-out mode of the different kinds of detectors and take pile-up and split events into account.

Currently the software package contains models for the eROSITA pn-CCD framestore detector and for several instruments on IXO. According to its modular concept common parts of the simulation like the PSF model for Wolter telescopes or the implementation of detector-specific effects in the respective response files can be used for the different types of X-ray telescopes, such that the software package can be extended easily.

The simulation software is written in ANSI C and implements standard interfaces like the CFITSIO and the Parameter Interface Library (PIL). It is compatible with standard software and the generated event data can be evaluated with common tools.

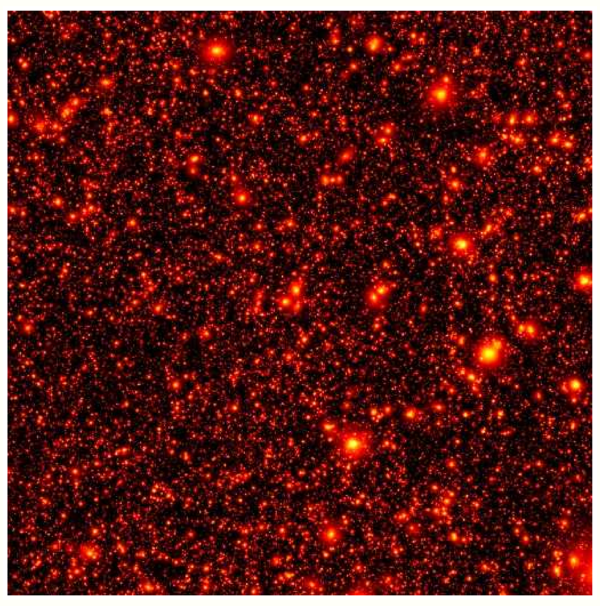
Simulations for eROSITA

For the development of the data analysis pipelines of the eROSITA (Predehl et al., 2006, 2007) Near Real Time data Analysis (NRTA) software our simulation is used to generate realistic event files. The simulation can produce event data in the same binary format that will be used in the standard data analysis for eROSITA. These test data are an essential part of the ongoing software verification, as we can simulate particular observation scenarios like transient X-ray sources or detector failures in order to check the detection algorithms of the NRTA for such events.

Apart from testing, the generated data can also be used to study the impact of different telescope properties on the scientific output of the mission. The quality of the mirrors, e.g., is highly relevant for the detection of galaxy clusters at high z, which is a main objective of the eROSITA mission. The motion of the telescope axis over the sky during the scanning survey produces different effects of the PSF in regions close to the scan equator and at the survey poles respectively. These features have to be analysed in detail to obtain accurate scientific results from the future measurements.

eROSITA Simulations for Galaxy Clusters

In order to simulate observations of galaxy clusters realistic distributions have been obtained from a cosmological hydrodynamical simulation (Borgani et al., 2004). Based on light cones from this simulation (Roncarelli et al., 2006) we have analysed different survey scenarios. If the light cone is located close to the equator of the eROSITA all-sky survey, the average exposure is much lower as for fields close to the survey poles. We study the impact on the detection probability with standard galaxy cluster detection algorithms, e.g., from the XMM-Newton SAS.



Input image of a light cone ($3.78\,\mathrm{deg} \times 3.78\,\mathrm{deg}$) of galaxy clusters (Roncarelli et al., 2006) obtained from a cosmological hydrodynamical simulation (Borgani et al., 2006) with logarithmic scale. The number of photons is equivalent to a 10 ks on-axis pointed observation with the effective area of the 7 eROSITA telescopes.

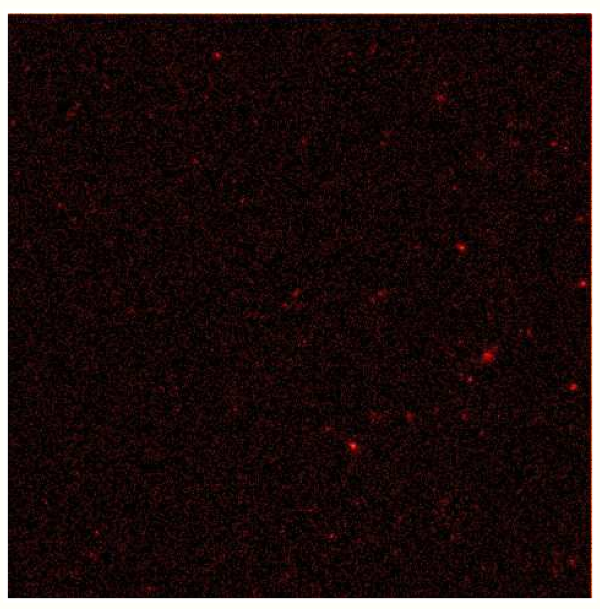


Image of the light cone obtained in a simulated half-year survey for a location at the *survey equator*. The telescope's Field of View slews approximately three to four times over each point in the field, resulting in an average exposure of 142 s.

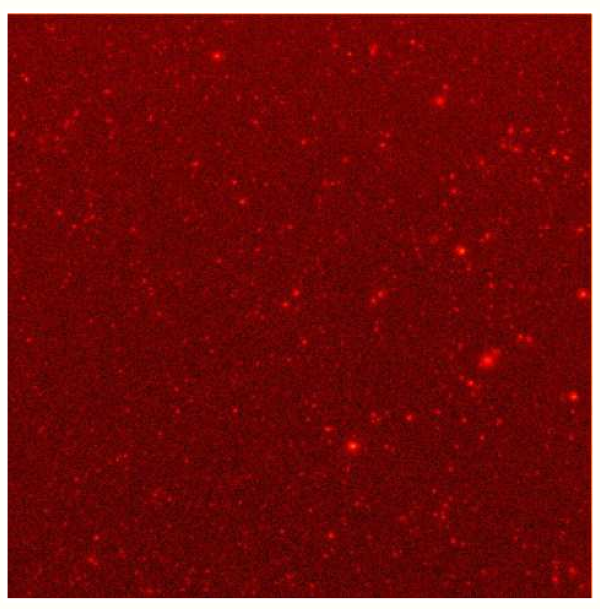


Image of the light cone obtained in a simulated half-year survey for a location at one of the *survey poles*. Due to the higher exposure of on average 2600 s fainter objects are visible and the cluster structures can be observed more clearly. Of course, there are also more background events than for the equatorial field.

Simulations for IXO

The IXO (White et al., 2009a, 2009b) mission submitted to the U.S. Decadal Survey committee and to ESA's Cosmic Vision process, will consist of several different kinds of X-ray detectors to enable observations of different phenomena. In order to study the capabilities of these instruments various simulations are required.

Our software package is implemented to answer the following issues:

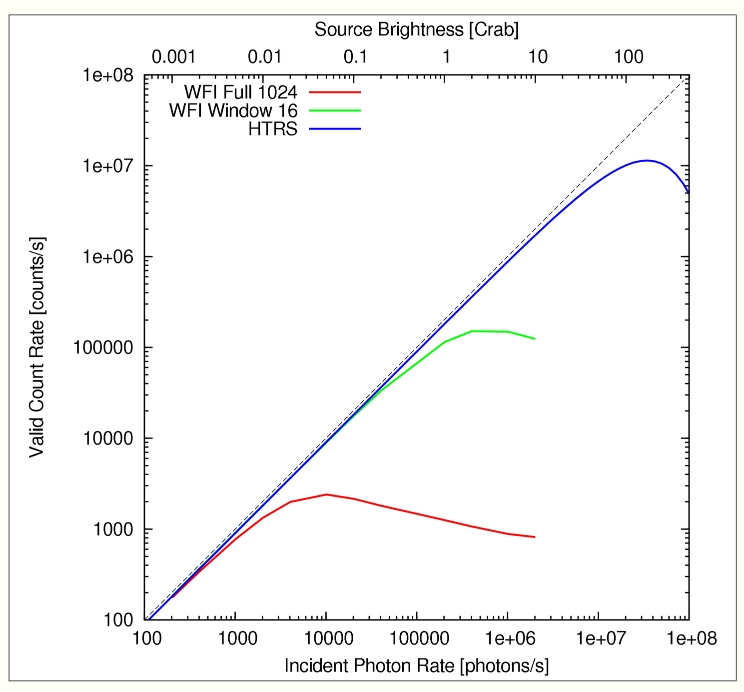
- **Wide Field Imager (WFI) (Strüder et al., 2004):** This Active Pixel Sensor (APS) detector is designed for observations with a large Field of View. In order to avoid pile-up for large photon fluxes different read-out modes are considered. With our simulation we study the performance of these modes and analyse the impact of split events and their recombination.
- **High Time Resolution Spectrometer (HTRS) (Barret et al., 2008):** This detector is aimed at the observation of very bright X-ray sources. Simulations reveal its advantages in this field in comparison to other instrument concepts. Due to limited telemetry it will be impossible to transfer the data obtained at high count rates in a single-event format to the ground. Therefore we analyse alternative data formats like spectral modes in order to reduce the transfer rate. The appropriate telemetry mode depends on source characteristics like the spectrum and especially the time variability, which can be simulated with our software.
- **X-ray Microcalorimeter Spectrometer (XMS) (Kelley et al., 2009):** This Transition Edge Sensor (TES) Spectrometer has an excellent energy resolution. As simulations have confirmed, bright source defocusing optics (Willingale, 2009) or other flux-reducing techniques have to be applied to avoid degradations due to pile-up.
- **X-ray Grating Spectrometer (XGS) (Heilmann et al., 2009):** This instrument provides high energy resolution for low and intermediate photon energies. Simulations will be performed to study the bright source performance.

According to the modular concept of the software package, the simulations for the different instruments share a common photon generation and imaging algorithm. The data from these simulations can be used to predict the capabilities of the IXO instruments at early development stages. Currently the models for the WFI and the HTRS have achieved a development stage, where realistic data can be produced.

Another purpose of the software package is the development of a generic X-ray simulation implementing a web interface that can be used by scientists for a quick analysis of specific measurement scenarios.

Bright Source Performance

We have performed simulations of the WFI with full frame and window read-out modes and of the HTRS for sources of different brightness in order to study the impact of the particular detector read-out process on energy and pattern pile-up depending on the incident photon rate.



Bright Source Performance of the WFI and the HTRS: The graph displays the count rate of valid event patterns vs. the incident photon rate. For higher source fluxes more and more pile-up occurs and creates invalid split patterns for the WFI. However the HTRS is able to observe even very bright sources due to its different detector concept and the approximately uniform distribution of the incident photons among 31 pixels. As our simulations show, these two instruments are complementary to each other.

References

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