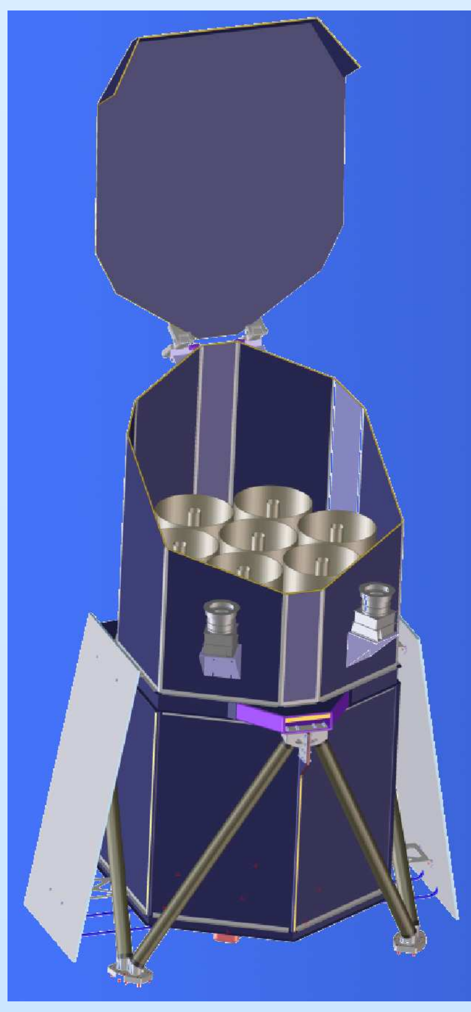
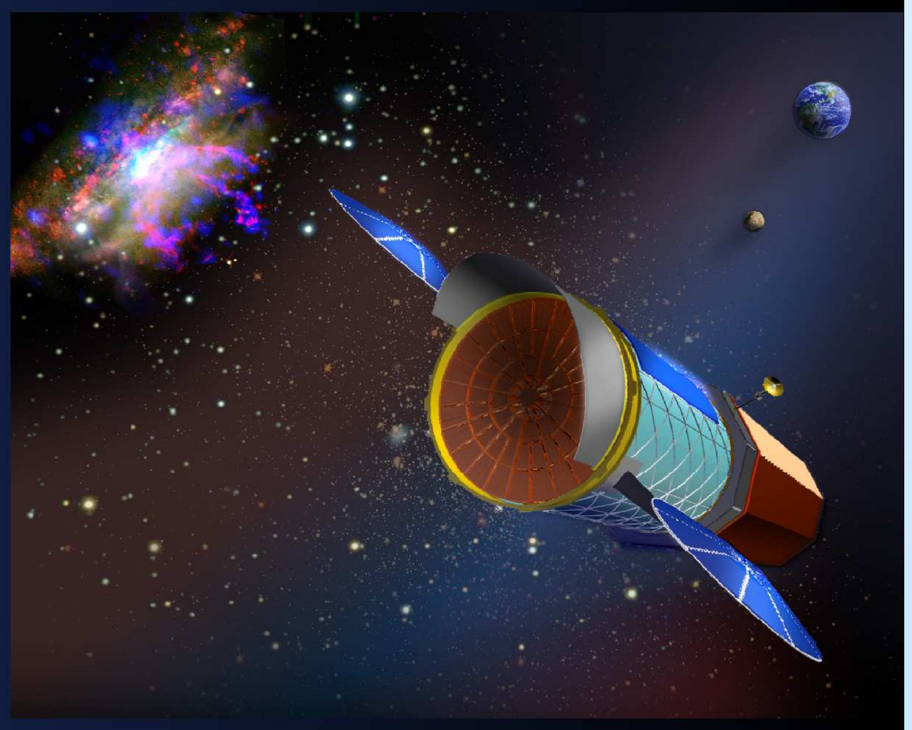


Simulations of X-Ray Telescopes for eROSITA and IXO



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Abstract

We report on the development of a generic X-ray instrument simulator to be used in simulations of future X-ray missions. Based on a Monte Carlo approach, the code generates photon events for sources in an X-ray source catalogue such as the ROSAT all sky survey or the XMM-Newton slew surveys and then models the imaging and detection process based on the available calibration files (e.g., point spread functions for the imaging). The output of the program are event lists which can be analysed using standard software such as xselect.

Due to its modular concept the simulation can be easily adapted to different concepts of imaging detectors. As examples for the potential use of the simulation we present results of simulations of an observation of galaxy clusters with eROSITA and of the detector performance for the High Time Resolution Spectrometer and the Wide Field Imager on the International X-ray Observatory.

General features of the simulation

We are developing a generic simulation software package for different kinds of X-ray detectors. The program simulates the generation of X-ray photons for sources with arbitrary spectra and time variability. The X-ray sources are given in several input catalogues for point sources and extended sources. The imaging of the individual photons in a Wolter telescope is performed with a randomization process based on a given PSF. Finally the software package contains models for the eROSITA pn-CCD framestore detector and several of the different instruments on IXO.

These models implement the particular read-out modes of the respective detectors and enable the simulation of split events and photon pile-up.

According to its modular concept common parts of the simulation can be used for the different types of X-ray telescopes and can be extended easily. The software is written in ANSI C according to the HEAdas standards and therefore provides common interfaces like the CFITSIO and the Parameter Interface Library (PIL).

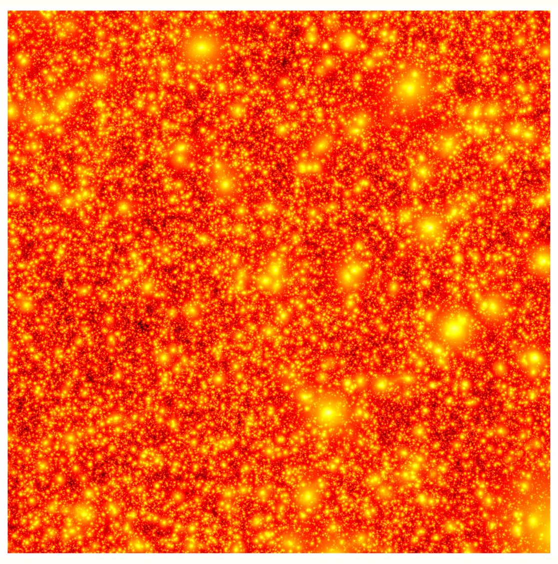
Simulations for eROSITA

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 also be used in the standard data analysis for eROSITA. These test data are an essential part of the ongoing software verification.

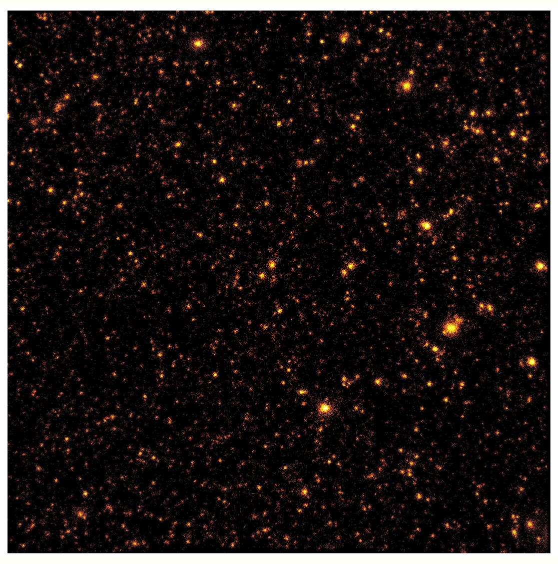
Apart from testing, the generated data can also be used to study the impact of different telescope properties on the scientific output of the mission. E.g., the quality of the mirrors is highly relevant for the detection of galaxy clusters at high z, which is a main objective of the eROSITA mission.

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.

Realistic distributions of galaxy clusters 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 simulated measurements for different survey scenarios.



Input image of a light cone ($3.78\,\mathrm{deg} \times 3.78\,\mathrm{deg}$) of galaxy clusters (Roncarelli et al., 2006) with logarithmic brightness scale.



Simulated image for the left-hand light cone located at a polar field after a scanning survey of half a year.

Simulations for IXO

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

Our software package is implemented to answer the following issues:

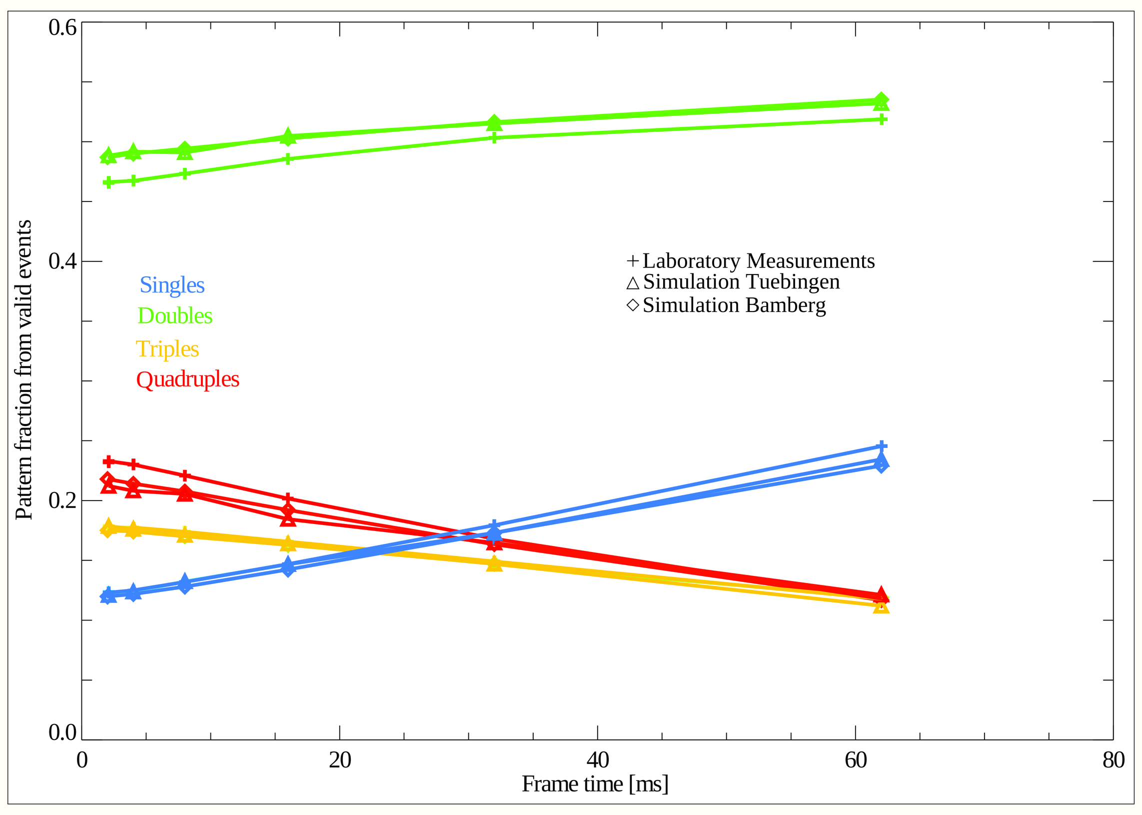
- **Wide Field Imager (WFI) (Strueder et al., 2004):** This instrument is an Active Pixel Sensor (APS) and can be operated with different read-out modes. Currently a full mode with 1024×1024 pixels and 16×16 window mode are considered. The simulation can be used to study the performance of these modes for bright X-ray sources and to analyse the generated split events and their recombination. It provides an estimate for the resulting data volume in the telemetry stream.
- **High Time Resolution Spectrometer (HTRS) (Barret et al., 2008):** This detector is aimed to the observation of very bright X-ray sources. Simulations reveal its advantages in this field in comparison to other instrument concepts. As the high count rates result in a large data volume, an adequate data format has to be determined based on estimates provided by simulated measurements.
- **X-ray Microcalorimeter Spectrometer (XMS) (Kelley et al., 2009):** This Transition Edge Sensor (TES) Spectrometer has an excellent energy resolution. As simulations have confirmed, for bright sources defocusing optics 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, the HTRS, and the XMS have achieved a development stage, where realistic data can be produced. Evidence for that is given in the plots below.

Another purpose of the software 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.

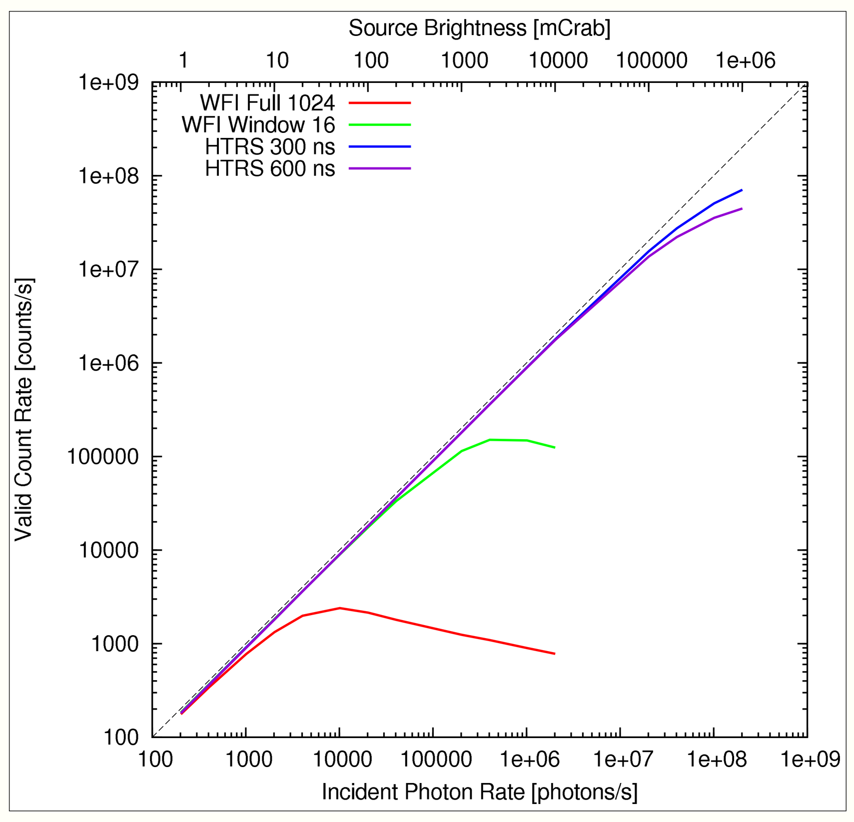
WFI and HTRS bright source performance

The simulated ratios of split pattern types from two different simulation codes have been compared with measurements on a WFI prototype with X-rays from radioactive sources in the laboratory. As shown in the figure below, the simulated data provide a quite suitable approximation to the measurement.



Ratios of the different split pattern types for the WFI as a function of the read-out time with a constant source flux: For longer read-out there is more pattern pile-up, so splits with more pixels tend to form invalid patterns. Due to the longer exposure the detector noise is higher, resulting in an increased event threshold. Therefore more low-energy split partners are not detected, so the fraction of singles and doubles with respect to the total number of valid events is increasing.

We have performed simulations of the WFI with full frame and window read-out modes and of the HTRS with 300 ns and with 600 ns dead time for observations with different source brightness to study the energy and pattern pile-up depending on the 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 measure even very bright sources, but without the high angular resolution of the WFI. As our simulations show, these two instruments complement one another.

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