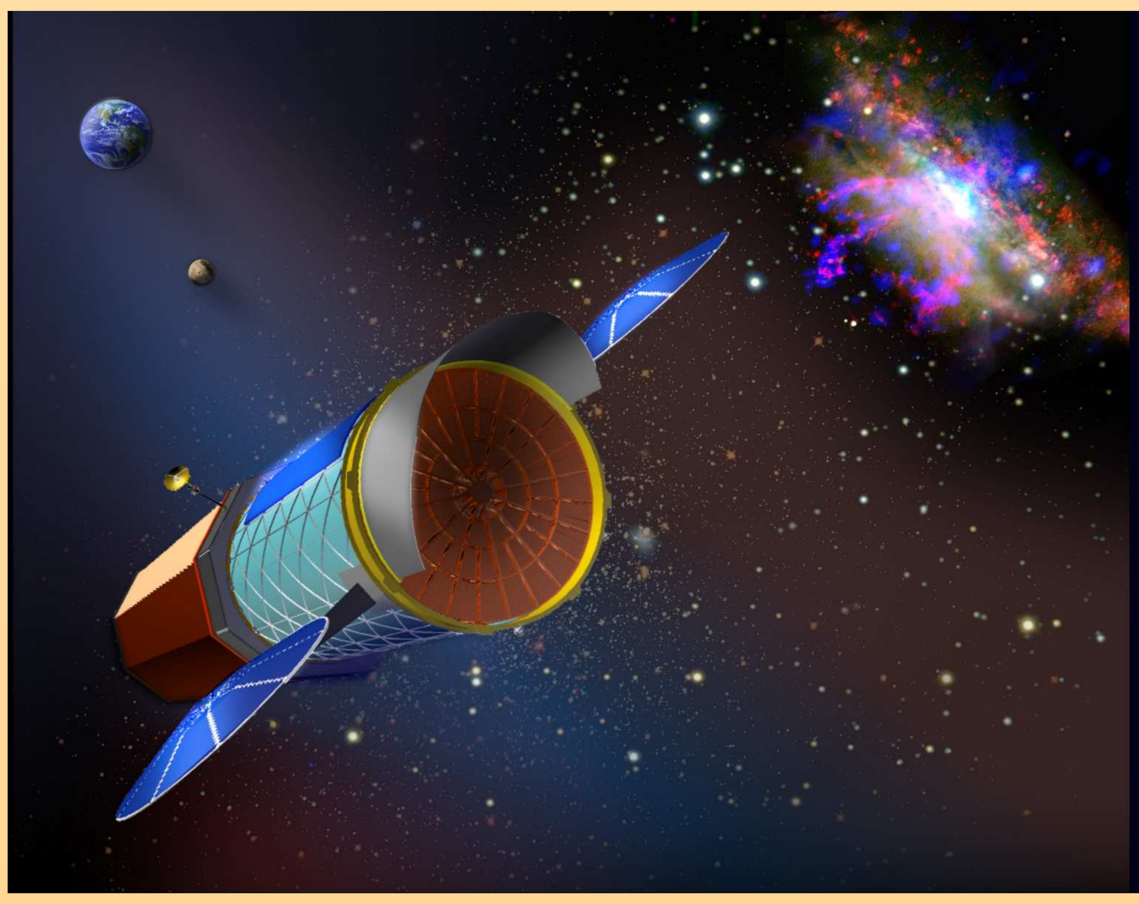

Simulations of the performance of the WFI, the HTRS, and the XMS

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Abstract

We present a generic X-ray instrument simulation tool appropriate for studies of future X-ray missions. According to the concept of Monte Carlo simulations the software generates a sample of photons for different kinds of X-ray sources characterized by realistic spectra and light curves. The imaging by a Wolter telescope and the detection process are modelled by means of standard calibration files like the point spread function and the detector response. The resulting event files have FITS format and can be analysed with standard tools.

With this software we have studied the detector-specific pile-up behaviour of the Wide Field Imager, the High Time Resolution Spectrometer, and the X-ray Microcalorimeter Spectrometer on the International X-ray Observatory in order to estimate the bright source performance of these instruments. In addition, the alignment requirements for the HTRS have been analysed with the simulation.

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 a sample of individual photons generated for either point-like or extended X-ray sources with realistic spectra and time variability. In order to model the imaging process by the mirror shells of a Wolter telescope, we use the corresponding Point Spread Function (PSF) 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 modes of the different kinds of detectors and analyse pile-up and split events.

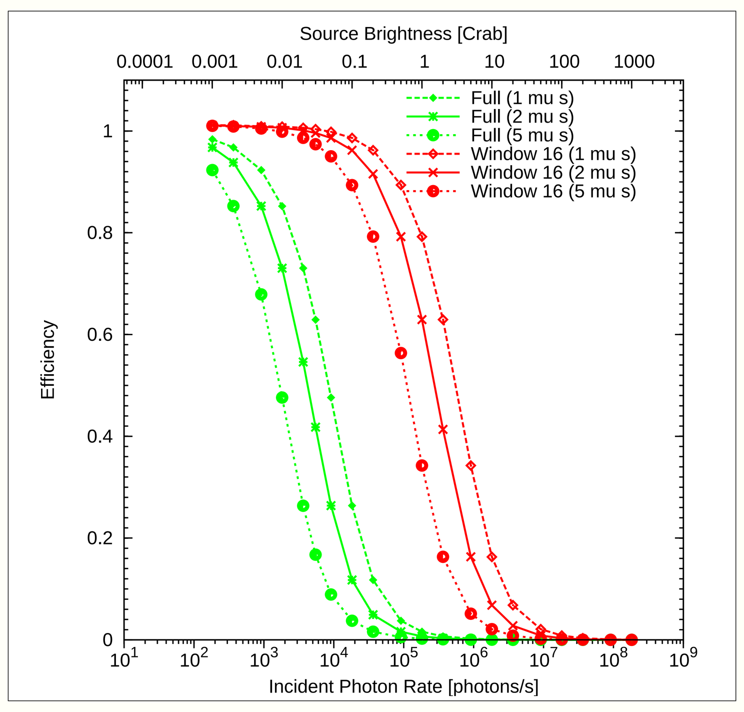
Currently the software package contains models for the eROSITA pn-CCD framestore detector and for several instruments on IXO. According to its modular concept common parts of the simulation like the PSF model for Wolter telescopes or the implementation of detector-specific effects in the respective response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

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 data analysis software and the generated event data can be evaluated with common tools.

Wide Field Imager

The WFI can be operated in different read-out modes: in the full mode the whole detector array is read out during one cycle of $1024\,\mu s$ ($2\,\mu s$ per line with 2 active lines), whereas in the window mode only a small subset of 16×16 pixels is operated in order to achieve a faster read-out of $16\,\mu s$.

We have performed simulations of the WFI with full frame and window read-out mode for sources of different brightness in order to study the impact of the particular detector read-out scheme on the pile-up. Apart from the nominal value of $2\,\mu s$ different values of $1\,\mu s$ and $5\,\mu s$ have been selected for the read-out time per line in order to estimate the impact of modifications in the read-out electronics on the detector performance.



Bright Source Performance of the WFI: The graph displays the fraction of valid event patterns vs. the incident photon rate. Valid patterns are either singles, double, triples, or quadruples with a proper charge distribution among the individual pixels. Other pattern types can only be generated by multiple photons and are therefore discarded, since the energy information about the individual photons cannot be recovered.

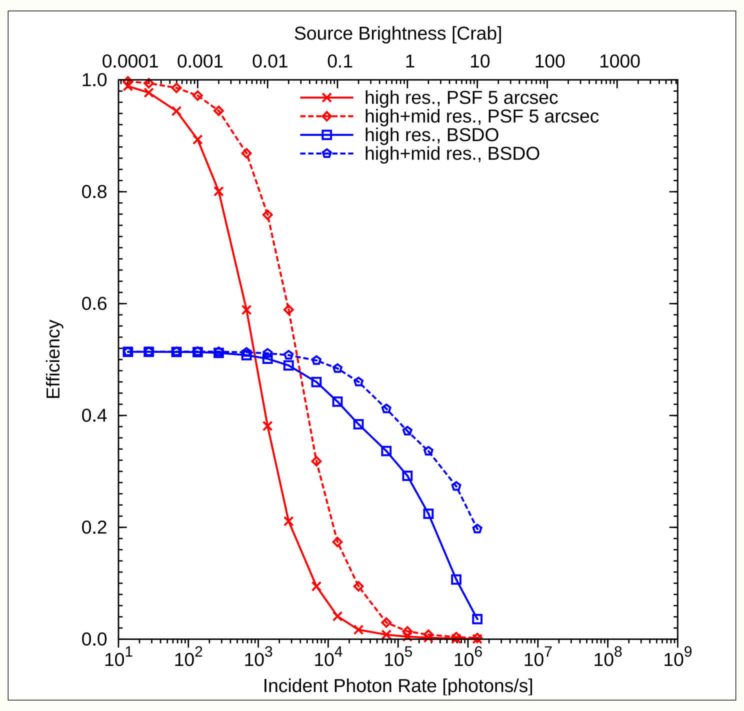
For higher source fluxes the probability for pile-up significantly increases resulting in a larger fraction of invalid pattern types. In the full frame read-out mode the efficiency already decreases for source fluxes of some mCrab, whereas the faster window mode can be operated up to a few 100 mCrab.

Due to the particular read-out scheme of the WFI with 2 active lines there might be split events with their individual components assigned to different frames: when a photon hits one of the active lines during the read-out, it might also generated a split partner in the previously read line, which will be measured in the subsequent detector frame. Both split partners can form valid patterns, and might therefore result in a false detection of two valid events. This can be seen in the displayed efficiency, which for low count rates is slightly bigger than one.

X-ray Microcalorimeter Spectrometer

The XMS (Kelley et al., 2009) consists of an array of Transition Edge Sensor (TES) pixels measuring the energy of detected photons with a very high accuracy. A photon impact induces a temperature increase in the affected pixel, resulting in a change of the electric current, which can be measured by a SQUID. The shape of the corresponding current pulse is sampled by the subsequent read-out electronics in order to determine the energy of the photon.

For an energy measurement with the nominal accuracy the current has to be sampled during a particular interval of time before and after the pulse. If there this another photon impact during this period, the measurement process is disturbed and the exact energy information is lost. For an event with the high energy resolution of $2.5\,\mathrm{eV}$ a shaping time of $6\,\mathrm{ms}$ is required, whereas a shorter shaping time of $1.5\,\mathrm{ms}$ only allows a degraded energy resolution. (These numbers apply only for the inner high resolution 40×40-array. They are subject of current investigations and it might therefore be necessary to adapt them in the future.)



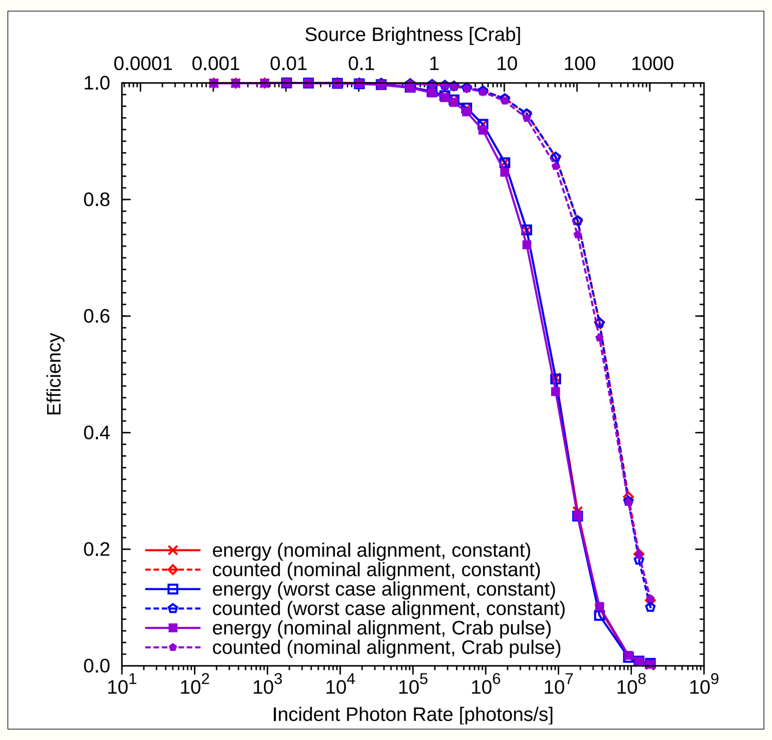
Bright Source Performance of the XMS: The graph displays the fraction of properly detected high resolution and intermediate resolution events vs. the incident photon rate. The simulations have been done for the XMS with the plain PSF (with a Half Energy Width of 5 arcsec) and with the Bright Source Defocussing Optics (BSDO) proposed by Willingale (2009), which reduces the incident flux by about 50 %. At higher source fluxes the time intervals between subsequent photons hitting the same pixel is too short for high resolution energy measurements. In this regime most photons can be either detected with intermediate energy resolution or have to be completely discarded.

As shown in the plot the XMS without the BSDO is only applicable for sources up to a brightness of a few mCrab. With the BSDO the XMS might be used up to 100 mCrab, but at very high fluxes of about 1 Crab there are also mainly events with degraded energy resolution.

High Time Resolution Spectrometer

The HTRS (Barret et al., 2008) consists of 31 Silicon Drift Detector (SDD) pixels. In order to be able to observe bright sources the incident photons are quite homogeneously distributed among these pixels. The charge created by a photon results in an increase of the output voltage of the affected SDD. The voltage pulse is measured in order to determine the photon energy.

This process requires the so-called shaping time equivalent to a particular number of samplings. If another photon hits the same SDD during the shaping process, the pulse shape and therefore the photon energy cannot be determined with the required accuracy. If the time difference between the two subsequent events is even shorter, below some minimum interval, both events cannot be distinguished from each other and will be detected as ONE event with a wrong energy. The probability of this kind of pile-up is, of course, strongly dependent on the brightness of the observed X-ray source.



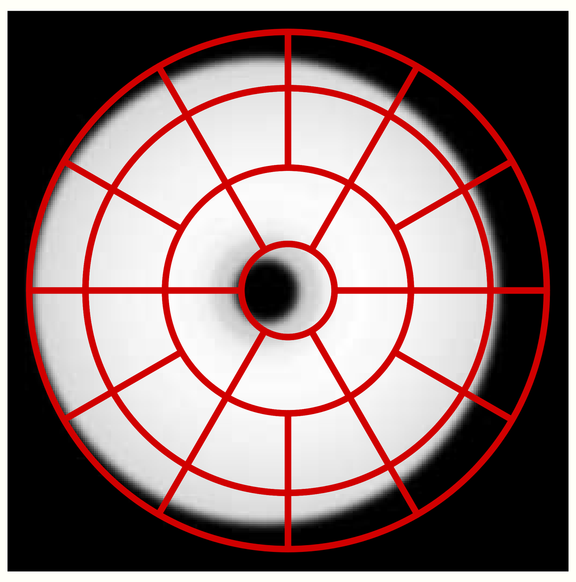
Bright Source Performance of the HTRS: The graph displays the fraction of properly detected events vs. the incident photon rate. The straight line represents the fraction of events with properly measured energy, and the dashed line the fraction of events that can still be detected separately. They are known to originate from individual photons, but their energy cannot be determined.

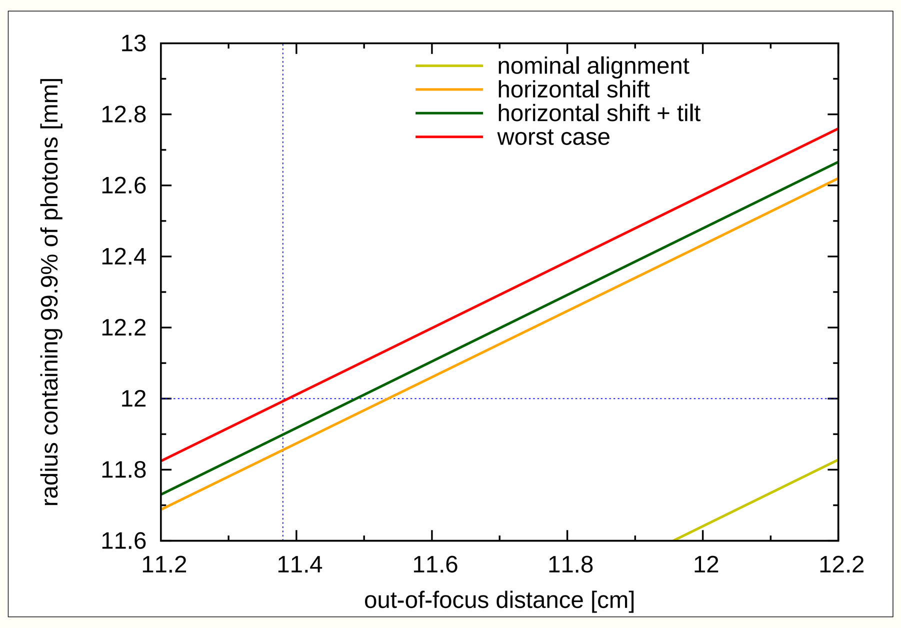
The detector efficiency has been simulated for different observation setups, for constant and time-variable sources assuming an analog shaper. It turns out that the performance is almost the same for all regarded setups. At higher source fluxes more and more pile-up occurs resulting in a decrease of the detector efficiency.

But in comparison to the WFI and the XMS the HTRS is quite suitable for observing X-ray sources with a brightness of up to 1 Crab.

In addition to the pile-up for observations of bright X-ray sources we have also studied the impact of misalignment on the performance of the HTRS. In the nominal case the detector is located with its center on the optical axis and the detector plane is perfectly perpendicular to the optical axis. The following margins have been taken into account to construct possible misalignment scenarios:

- accuracy of the horizontal detector position of $\pm1\,\mathrm{mm}$ (in order to account for pointing inaccuracies)
- tilt of the detector plane by 2°
- accuracy of the out-of-focus position of $\pm1\,\mathrm{mm}$





Top: photon distribution (for $1\,\mathrm{keV}$ photons) on the HTRS in the worst case scenario.

Left-hand: radius of a circle around the detector center containing 99.9 % of the incident photons. The detector radius and the out-of-focus distance have to be chosen such that even in the worst case alignment scenario 99.9 % of the incident photons fall onto the detector surface. Currently the setup indicated by the blue dased lines has been selected for the HTRS pixel geometry.

The calculation of the photon distribution on the detector has been performed for the Silicon Pore Optics mirror design according to an idea proposed by Tim Oosterbroek.

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