Simulations of the Bright Source Performance of the GRAVITAS Telescope

Christian Schmid[1], Jörn Wilms[1], Alexander Stefanescu[2], Didier Barret[3], Michael Martin[4], Eckhard Kendziorra[4], Benjamin Mück[4]

[1] Dr. Remeis-Observatory & Erlangen Centre for Astroparticle Physics, Germany
[2] Max Planck Institute for Extraterrestrial Physics, Germany
[3] Centre d'Etude Spatiale des Rayonnements de Toulouse, France
[4] Institute for Astronomy and Astrophysics Tübingen, Germany

e-mail: christian.schmid@sternwarte.uni-erlangen.de

Abstract

We present the results of our simulations of the bright source performance for the GRAVITAS telescope with respect to energy and pattern pile-up. The analysis has been performed with a generic simulation software package developed for IXO studies.

The simulation is designed in a modular way such that it can be easily adopted for different missions. It is a Monte-Carlo simulation based on real calibration data like the telescope Point Spread Function (PSF) and the detector response (RSP).

General Features of the Simulation

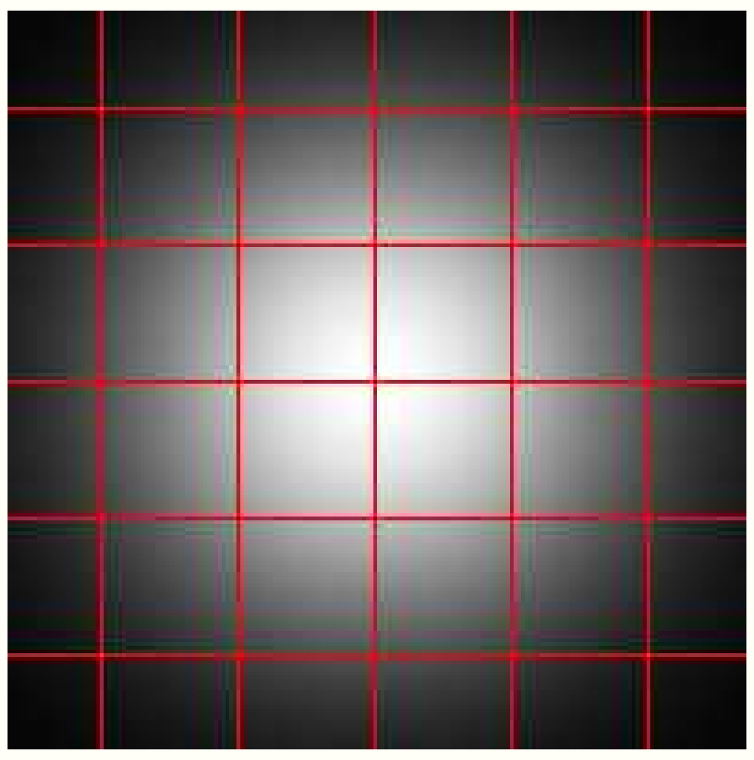
In order to analyse the properties of future X-ray missions we are developing a simulation software package (Schmid et al. 2010) containing models for different detector concepts. The simulation processes samples of individual Poisson-distributed photons generated for either point-like or extended X-ray sources with realistic spectra and time variability. The imaging process by the mirror shells of a Wolter telescope is modelled with the corresponding Point Spread Function (PSF). In addition to the PSF one can also specify a Vignetting function for off-axis observations.
The simulation of the detection process itself uses the detector-specific response file in order to model the absorption and measurement of the photon energies in the particular detector channels. Split events between neighboring pixels are generated assuming a Gaussian Charge Cloud model spreading over several pixels. The read-out of the charges collected in the pixels is done in a similar way as in the real detector: for CCDs the charges are shifted to the read-out nodes, for Active Pixel Sensor (APS) arrays individual detector lines can be read out separately in a sequential mode.

The simulation software is designed in a modular way, such that it can be easily adopted to different mission setups. There is a set of tools for common tasks like the photon imaging process. Detector-specific algorithms are implemented in separate tools, which can be integrated in the software pipeline. Currently the software package contains models for several different telescope and detector setups, such as the eROSITA framestore pn-CCD detector, the WFI, HTRS (Barret et al. 2010), and XMS on IXO, the XMM-Newton EPIC-pn camera, and the GRAVITAS HIFI detector. For each instrument we are using the appropriate calibration data and model the particular read-out modes.
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 X-ray astronomy data analysis software. The output of the simulation are event list files, which can be analysed with the common tools.

GRAVITAS Science Team Meeting @MPE, 25th & 26th October 2010

GRAVITAS Simulation

For the GRAVITAS mission we are investigating the bright source performance of the detector with our simulation software. We have used the following instrument setup:



Photon Imaging

- 7 identical sub-telescopes
- 10′ FoV
- 12 m focal length
- Gaussian PSF with a FWHM of 20″

Photon Detection

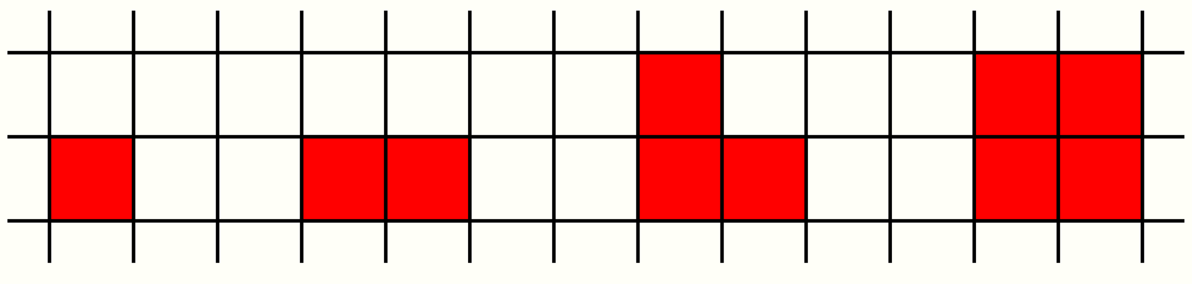
- array of 96×96 pixels
- $370 \times 370\,\mu\mathrm{m}^2$ per pixel
- line-wise read-out with 2×4 lines
- $4\,\mu$s per line
- full frame and window read-out modes
- detector response (RSP)
- Gaussian charge cloud model with $\sigma = 13.5\,\mu$m for split events

The image on the left-hand side displays the photon distribution represented by the PSF on detector array. The FWHM of 20″ corresponds to roughly 3 pixels.

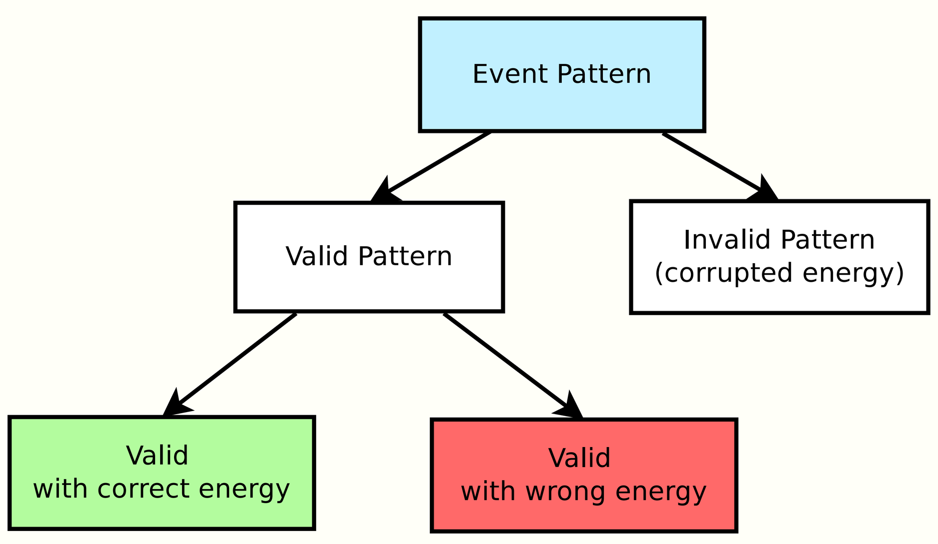
The presented setup corresponds to the current baseline configuration of the HIgh Framerate Imager (HIFI) Active Pixel Sensor (APS) detector. We have also investigated a further optional setup with 64×64 slightly bigger pixels, which turned out to be less suitable with respect to performance.

Analysis of the Simulated Events

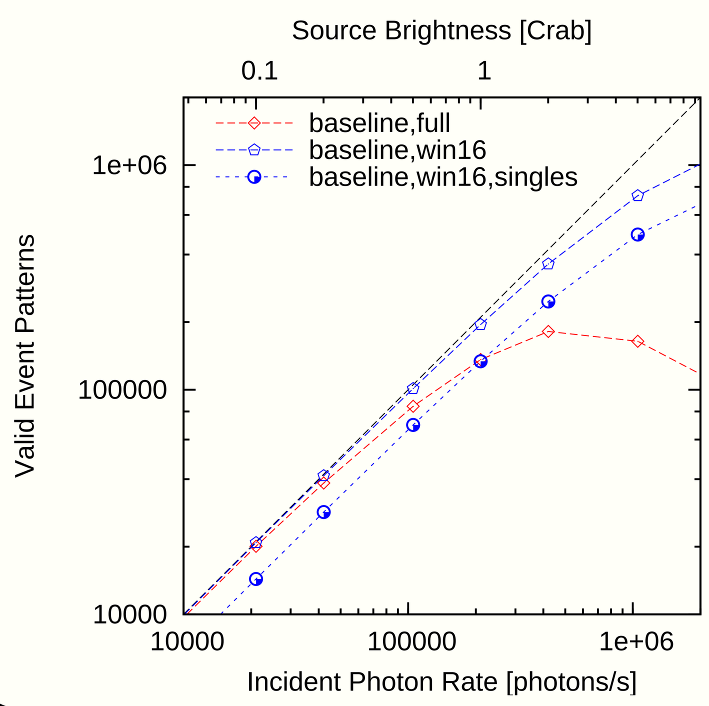
The output of the detector simulation are event files with single pixel events. We run a pattern recombination algorithm on these event files in order to select valid split patterns of the 4 main types: singles, doubles, triples, and quadruples.



Other pattern types cannot be created by an individual photon impact and, therefore, their energy information is corrupted. We declare them as invalid events and neglect them in the subsequent analysis.
For the valid pattern types it is usually assumed that they originate from a single photon splitting up the generated charge cloud among several neighboring pixels. Although this assumption might be true in most cases, some of these patterns may have been generated by more than one photon, which is denoted as pile-up. In real observations the information about the number of photons contributing to a pattern cannot be reconstructed. However, in our simulation we know about the origin of each pattern. Therefore we can analyse the fraction of valid event patterns with wrong energy information corrupting the scientific measurement.



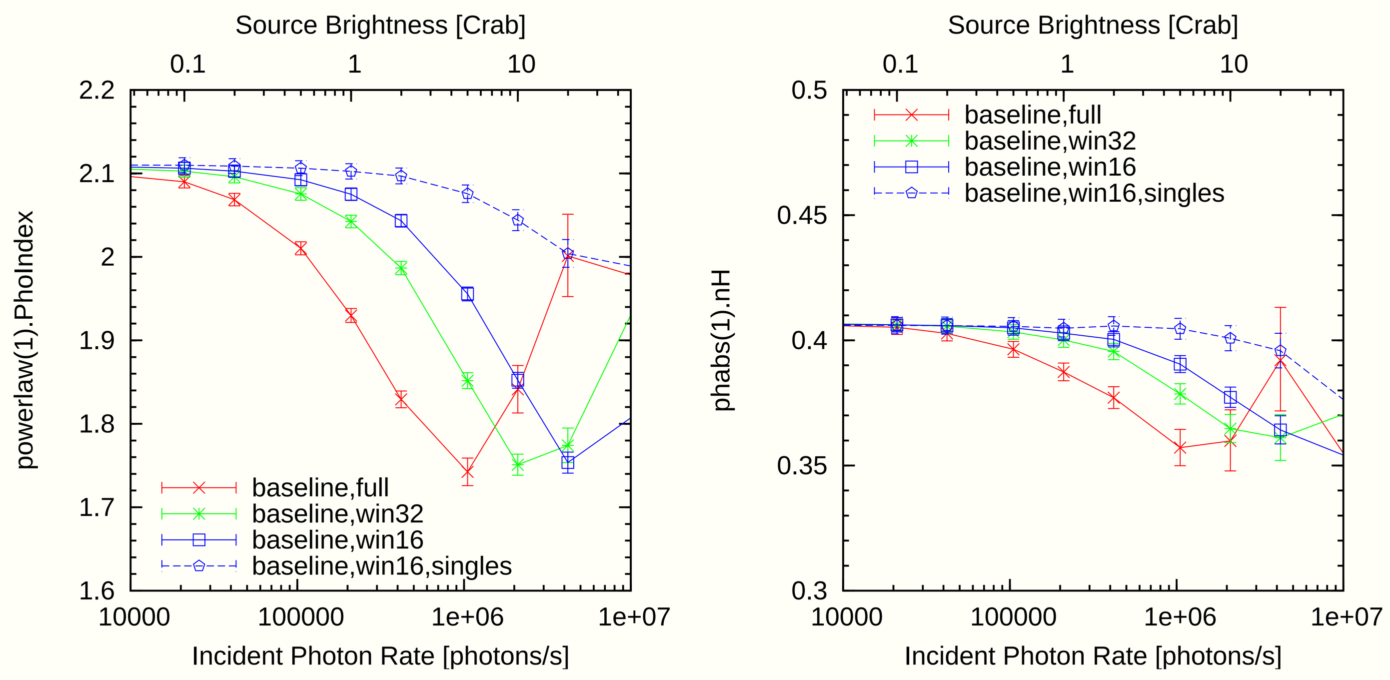
Detector Throughput



In the figure on the left-hand side the throughput of the HIFI instrument, i.e. the number of valid event patterns vs. the incident photon rate is displayed for simulated observations with different source brightness. The throughput is shown for the full frame and 16×16 window mode. For observations of very bright sources the instrument has to be operated in a window mode in order to cope with the high count rates resulting in pile-up problems.

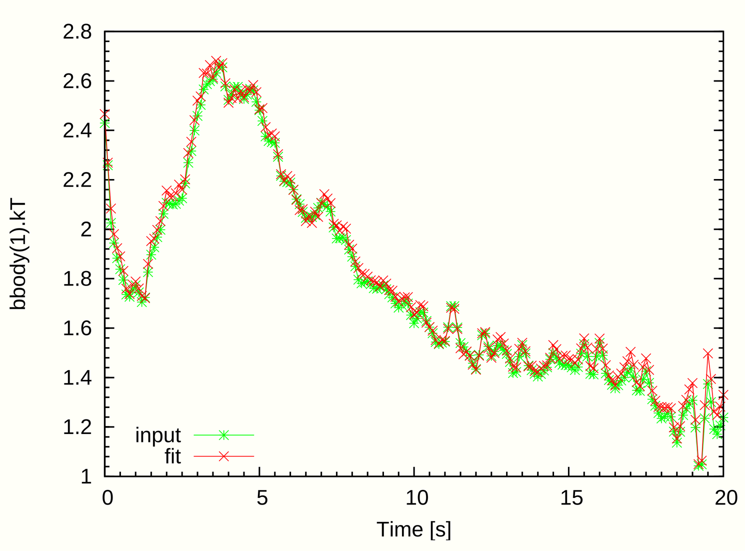
Crab Spectrum

We have simulated several observations of point sources with a Crab-like spectrum (absorbed powerlaw with norm 9.5, photon index 2.1, and $n_H = 0.4 \cdot 10^{22}$) and a brightness in the range from 10 mCrab to 50 Crab. The simulated spectra have been fitted in order to reconstruct the initial parameters. This allows us to estimate the affordable pile-up level, without distorting the spectrum too much.



For moderate count rates up to a few 100 mCrab the fitted parameters agree quite well with the input values, whereas for higher count rates around 1 Crab the spectrum is hardened by pile-up events. Therefore observations in this regime have to be performed in window mode. For even higher count rates the fraction of valid events is too low for reasonble spectral fitting. (At extreme count rates the spectrum softens again because the central highly piled-up region in the core of the PSF contains no valid patterns any more.)

X-ray Burst KS 1731–26



In the left-hand figure the observed temperature evolution of the thermonuclear (type I) X-ray burst KS 1731–26 (Galloway 2008) is displayed (green). According to the spectral parameters we have simulated the observation of this burst with the GRAVITAS HIFI in 16×16 window mode (the maximum count rate during the burst is about 48 000 counts/s). The resulting temperature obtained from the fitted spectra (red) matches quite well the observed evolution, which has been used as input for the simulation. (The typical error of the fitted kT is ± 0.1). To study the instrument performance we are investigating X-ray bursts with different brightness.

References

Barret et al., 2010, Proc. of SPIE 7732, 1M-1–1M-12

Galloway et al., 2008, ApJS 179, 360–422

Schmid et al., 2010, AIP Conf. Proc. 1248, 591–592

Friedrich-Alexander-Universität Erlangen-Nürnberg

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS