Bright Source Capabilities of the WFI and X-IFU

T. Dauser[1], T. Brand [1], J. Wilms[1], P. Peille[2], S. Bandler[3], B. Cobo[4], M.T. Ceballos[4], R. den Hartog[5], N. Meidinger[6], J. de Plaa[5], A. Rau[6], S. Smith[3], R. Smith[7]

[1]ECAP, [2]IRAP, [3]GSFC, [4]IFCA, [5]SRON, [6]MPE, [7]CfA

Abstract

We use end-to-end simulations to quantify the bright source capabilities of the *Athena* WFI and X-IFU instruments. For this purpose, source images and spectra are used as input to fully simulate the predicted events on the detector, which are then converted to event lists, spectra, and images. This contribution will explain the different pile-up effects for both instruments and analyze their impact on the efficiency of the detector and the spectral shape. With this approach, we are able to estimate limiting fluxes below which spectra are not significantly affected by pile-up effects. Additionally, the direct impact of pile-up on estimated parameters for core science cases such as measuring the spin of black holes is presented.

The Baseline Geometry

We use the current baseline configuration of *Athena* with the nominal mirror setup (1496 mm diameter). The PSF is 5" in this setup. The SIXTE software, which is the official simulator of for *Athena*, is used to perform full end-to-end simulations. **See the posters 12.14 (J. Wilms) and 12.10 (P. Peille) for additional information.**

In order to quantify source brightness, we use the unit of a *Crab*, which is defined as absorbed power law with $\Gamma = 2.1$, $N_{\mathrm{H}} = 4\times10^{21}\mathrm{cm}^{-2}$, and a flux of 9.5 ph/kev/cm^2/s at 1keV. With the aforementioned mirror configuration this leads to 106 532 cts/sec for the WFI and 94974 cts/sec in case of the X-IFU, respectively for 1 Crab.

Wide Field Imager (WFI)

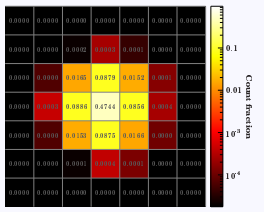
The WFI consists of 4 DePFET chips with 512x512 pixels and an additional small chip (64x64), which can be read out faster. Different read-out modi are possible for these chips, which is especially important for a larger source flux. All presented results are with external filter.

Name	Size	Time Res.
large	512×512	$1280\,\mu$s
w16	16×512	$40\,\mu$s
is1l	16×64	$20\,\mu$s
is2l	16×64	$10\,\mu$s
w64df	64×512	$160\,\mu$s
is1df	64×64	$80\,\mu$s
is2df	64×64	$40\,\mu$s

The table gives an overview of the studied modi. Modi marked with *is* are for the fast chip, which allows the read-out of 1 or 2 lines per half of the detector as indicated in the name (e.g., *is1l* and *is2l*). The suffix *df* means that the optic is defocused with a HEW of 80", which allows the count rate to be split onto more pixels.

X-ray Integral Field Unit (X-IFU)

The simulated X-IFU sensor has a hexagonal shape with a 5′ field of view. The baseline consists of an array of square pixels (large pixel array, LPA) with a pixel size of $\approx 300\,\mu$m). The imageshows the distribution of events for the LPA. Currently under investigation is to replace the inner part with a small pixel array (SPA, 110 μm pixel size). The SPA could observe point sources of up to 10 mCrab with high energy resolution, as the counts are distributed over more pixels.

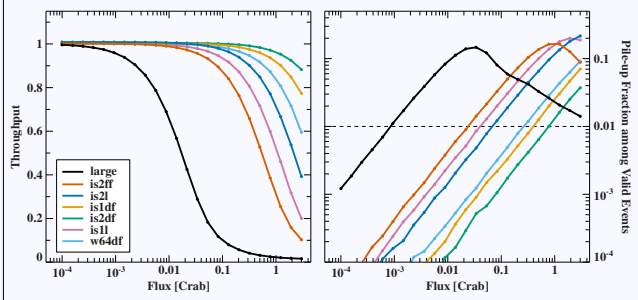


Depending on how far the single pulses are separated, the energy resolution varies (**see poster 12.10 (P. Peille) for more information**). The definition of the energy resolution of the SPA is given in the table below.

	High Res	Med Res	Low Res
Energy Resolution (SPA)	2.5 eV	3.0 eV	15 eV

Basic High Count Rate Performance

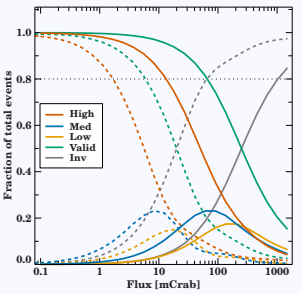
WFI



Performance of the described detector model for different modes taking into account all valid events (i.e., valid split patterns as events are often distributed over more than one pixel). *Left:* Throughput representing the number of valid events divided by the number of simulated photons. *Right:* Fraction of pile-up events among the valid events. The horizontal dashed line denotes a pile-up of 1%.

⟹ Defocused modes are necessary to stay below 1% pile-up for bright sources!

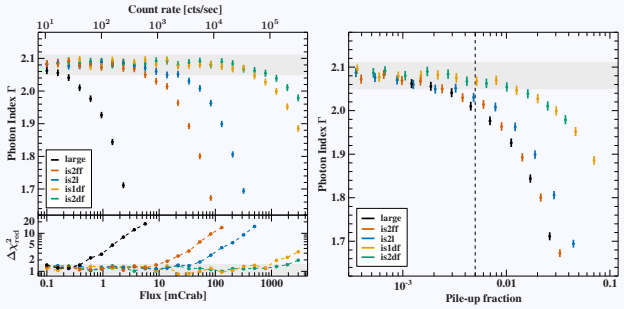
X-IFU



Fraction of the different event grades as a function of the count rate for the SPA. The dashed line denotes the goal to have more than 80% high resolution events at 10 mCrab for the SPA. Above 100 mCrab, the low resolution events dominate (but note that these still have a better energy resolution than non-calorimetric detectors). Above a few 300 mCrab, the invalid events exceed the valid events. This is due to the fact that the total number of valid events steeply drops due to saturation of the innermost pixel.

⟹ SPA excellent up to 10 mCrab and good up to 200 mCrab!

Spectral Stability (WFI)

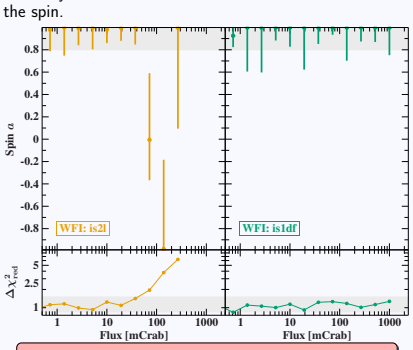


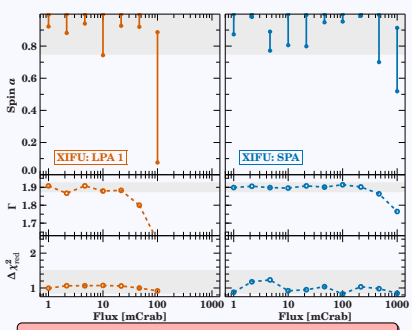
In order to quantify the **change of the spectral shape** we conduct a full end-to-end simulation of a source with a Crab-like spectrum at different count rates. *Left:* The plot shows how well the original power law index ($\Gamma = 2.1$) can be recovered. The gray area shows the allowed range of values. *Right:* This plot shows how a certain pile-up fraction in the spectrum translates to the actual spectral distortion.

above 0.5% pile up, the WFI spectrum becomes significantly distorted

Measuring Black Hole Spin

Simulated observations for the WFI (*left*) and X-IFU (*right*) with strong relativistic reflection are analyzed for increasing flux. Specifically, we used a height of $h = 3r_{\mathrm{g}}$, a spin of $a = 0.99$, an ionization parameter of $\log\xi = 1$, and an inclination to the system of $\theta = 30°$. This data is then fitted with the `relxill` model in order to determine the uncertainty on the spin.





fast mode good until a few 10 mCrab, while defocused mode shows no degradation

SPA extends X-IFU capabilities to beyond 100 mCrab, while uncertainties increase

Acknowledgments

This work has been funded by the Bundesministerium für Wirtschaft und Energie under Deutsches Zentrum für Luft- und Raumfahrt grant 50 QR 1402. We thank J. E. Davis for developing the SLxfig module used for plotting all figures. This research has made use of ISIS functions provided by ECAP/Remeis observatory and MIT (`http://www.sternwarte.uni-erlangen.de/isis/`).

X-IFU

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