Abstract

For the ATHENA Wide Field Imager (WFI), the SIXTE package is provided with up-to-date configuration files to study the performance of the instrument. This document describes all relevant files included in the current release (version 1.9.10_public).

Change Record

Issue	Date	Description of Change	Affected Pages
1	2014 October 02	Initial Release	All
2	2015 April 02	Update to new configuration	All
3	2017 August 17	Update to the QE table, include Be filter	All
4	2019 June 25	Update to new configuration	All
5	2019 Nov 12	Add background file description	11
6	2021 Nov 16	Revise text for public release 1.9.10_public	all
		Update RMF and defocused PSF	10,11

Distribution List

Organization	Name	Organization	Name	Organization	Name
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List of Acronyms

ARF: Ancillary Response File
Athena: Advanced Telescope for High ENergy Astrophysics
DEPFET: Depleted p-channel Field-Effect
OBF: Optical Blocking Filter
PSF: Point Spread Function
RMF: Redistribution Matrix File
WFI: Wide Field Imager
LDA: Large Detector Array
FD: Fast Detector

Documentation

Reference Documents

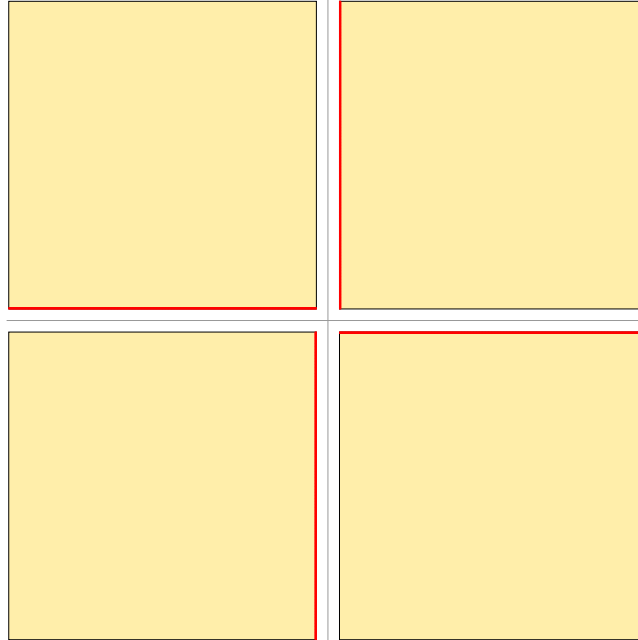| Ref.	Title	Ref. Doc.-No.
RD1	*Athena* WFI Response Files	ECAP-ATHENA-WFI-RSP-20201117
RD2	WFI Defocus Study	ECAP-WFI-DFOPT-20160711
RD3	WFI Detector Spectral Resolution - input for RMF generation (Rau, A.)	WFI-MPE-ANA-0180

Reference Articles

Figure 1: Geometry of the `ld_wfi_ff_chip[0,1,2,3].xml` configuration of the LDA. The gray cross marks the default intersection point with the optical axis. The gap width chosen for this configuration file is 5 mm.

1 Introduction

The SIXTE simulator is capable to simulate X-ray observations with pixelized detectors like the WFI. To achieve a high flexibility, the telescope and detector properties are fed into the program via a descriptive file in an XML-like format, which gives optical and detection parameters as well as links to files containing calibration information. These information are contained in FITS-files encoding for example the PSF, the vignetting curve, the ARF or the RMF. This document lists all available configurations and calibration files for the current iteration of the *Athena* WFI.

2 Chip layouts and readout modes

The available WFI setups for SIXTE simualtions are listed in table 1. There are options for the full Large Detector Array (LDA) of the WFI with 4 large chips, called the Large Detectors (LD). Moreover, readout modes for the separate Fast Detector (FD) are given, which will be mounted defocused by default. All WFI chips will employ the Depleted p-channel Field-Effect (DEPFET) technology, which is desribed below and requires a different implementation of the readout than the CCDs used for previous missions like *XMM-Newton* or *SRG*/*eROSITA*. In the following the single modi and their implementation is described in more detail.

2.1 Chip geometry

The individual chips are realized as rectangular surfaces with a rectangular, uniform subdivision. The resulting rectangles are the equivalent of the pixels. The number of pixels and their sizes are listed in table 1.
The first entry in this table corresponds to the four large chips with their individual alignment and rotation (LDA). The gap between the chips is 5 mm, and the optical axis is located at the center of the assembly. The geometrical configuration of this case can be seen in Fig. 1.

Table 1: Chip and read-out data of the simulated DEPFET setups. The read-out time per line is set to $9.8\,\mu$s for the LDs and $2.5\,\mu$s for the FD. The LD modes are given for the nominal on-axis HEW requirement (5"). The FD is assumed to be defocused by default. Most configurations are given without (wo) and with (w) Optical Blocking Filter (OBF). These two different options are provided in separate directories (`wfi_wo_filter_B4C` and `wfi_w_filter_B4C`).

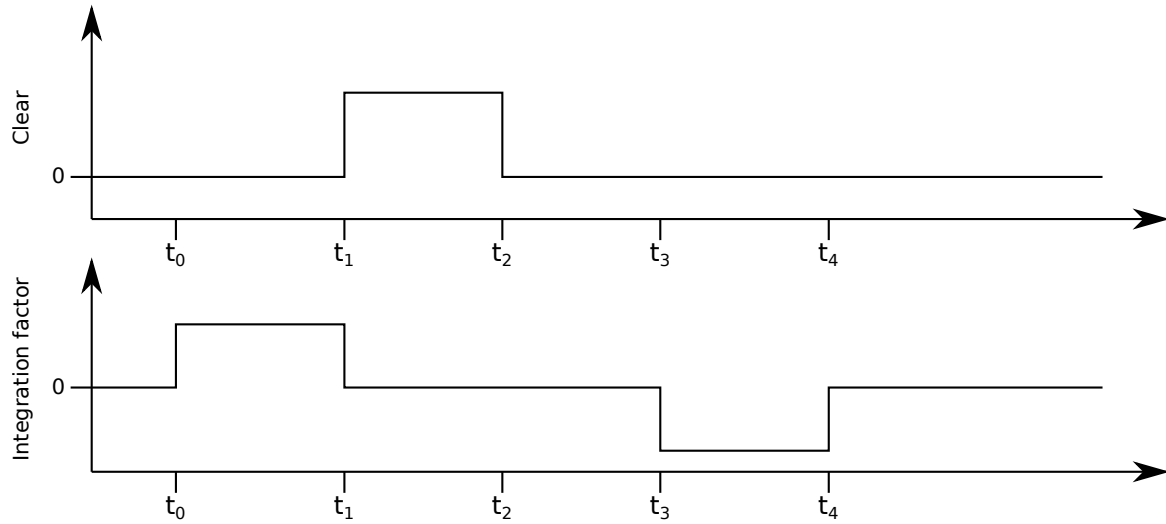| Name	Filename	Size (rows × columns)	time resolution	defocusing	filter	HEW
full	`ld_wfi_ff_chip[0,1,2,3].xml`	(4×) 512×512	$5018\,\mu$s	—	wo/w	5"
large	`ld_wfi_ff_large.xml`	512×512	$5018\,\mu$s	—	wo/w	5"
w128	`ld_wfi_w128.xml`	128×512	$1254\,\mu$s	—	wo/w	5"
w256	`ld_wfi_w256.xml`	256×512	$2509\,\mu$s	—	wo/w	5"
fast	`fd_wfi_df35mm.xml`	64×64	$80\,\mu$s	35 mm	w	
fastBe	`fd_wfi_df35mm_Be100.xml`	64×64	$80\,\mu$s	35 mm	w	

Figure 2: A basic scheme for the DEPFET readout.

2.2 Chip Readout

Setups for the LDA (*full*), a full frame mode of a single chip (*large*), and window modes (*w128* and *w256*), where only part of the chip is read out in order to mitigate pile-up, are available.

The Fast Detector (FD) will be read out almost a factor four faster than the LDA ($2.5\,\mu$s per row). In addition, each half of the detector is read out separately, additionally increasing the readout speed by a factor of two. The FD will be mounted 35 mm out of focus. An out-of-focus distance of around 35 mm was determined to be most favourable. More details on this study can be found in [RD2].

2.3 DEPFET readout implementation

The following section describes the implementation of the WFI DEPFET. The DEPFET readout is not an instantaneous determination of the photon's energy but it integrates first the photon's voltage signal together with the signal baseline, and after the photon's charge is removed by the clear, the baseline is integrated again to remove it from the measurement. In a simplified scheme, the measurement can be described with three time intervals and the corresponding integration factors, as depicted in Fig. 2.

After the initial settling, the readout of a DEPFET begins at t_0. Between t_0 and t_1, the signal present at the internal gate is integrated. Between t_1 and t_2, any charge is removed from the DEPFET's internal gate. Between

Table 2: The DEPFET time characteristics used in the simulations for the LD and FD.

	integration time [μs]	settling time [μs]	clear time [μs]
Large Detector	0.8	3.7	0.8
Fast Dectector	0.8	0.3	0.3

t_2 and t_3, the second settling occurs. Between t_3 and t_4, the signal is integrated again but with negative sign. The result is, that the baseline signal can be substracted from the first measurement, providing an estimate of the photon's signal.

Misfits are photons which hit the detector during the integration time intervals. As their signal is not integrated for the full integration time, they can produce wrong measurements. The resulting measurement E_m of their true energy E_p can be described dependent on their impact time t_p:

- $t_p < t_0$ or $t_p > t_4$: $E_m = E_p$

- $t_0 < t_p < t_1$: $E_m = E_p \times (t_1 - t_p)/(t_1 - t_0)$

- $t_2 < t_p < t_3$: $E_m = -E_p$

- $t_3 < t_p < t_4$: $E_m = -E_p \times (t_4 - t_p)/(t_4 - t_3)$

In the case of $t_3 < t_p < t_4$, the charge is not removed in this readout cycle and will be measured again during the next cycle, before it is cleared.

Another effect to be simulated is the limited clear speed. Instead of removing the charge instantaneously, it is cleared linearly between t_1 and t_2. If a photon hits the detector during this interval and causes a charge q_p, it is only partially cleared and leaves a remaining charge q_r, according to

$$q_r = q_p \times (t_p - t_1)/(t_2 - t_1) \ .$$

The remaining charge will be measured in the second integration time and causes a negative energy measurement of the value

$$E_m = -E_p \times (t_p - t_1)/(t_2 - t_1) \ .$$

The charge will be measured again in the next readout cycle.

If the impact is between t_2 and t_3, the charge is remaining completely. If two photons impact in the same pixel during one readout cycle, their signals add to each other.

2.4 Pattern analysis in the DEPFET-case

The normal pattern analysis is used also for DEPFET-data. Patterns which include at least one split partner with a negative energy measurement are flagged as invalid. Patterns are not traced over more than one frame.

2.5 Simulated DEPFET chip layouts and readout modes

In table 1, the implemented DEPFET versions are listed.
The DEPFET-characteristics are listed in table 2.

3 Calibration data

For simulations of astronomical observations with the *Athena* WFI, calibration files such as the ARF, RMF, or their product, the RSP, are needed. In this section, we describe the current set of ARFs and RMFs. The general WFI response files are described in the separate document [RD1].

4 ARF

The WFI ARF is composed of two inputs: The mirror effective area and the instrument quantum efficiency (incl. sensor and optical light blocking filter).

4.1 Mirror Effective Area

The mirror effective area is based on the mirror geometry of the Athena Telescope Design version 2.4 where the requirements are implemented through the following mirror configuration:

- Mirror assembly with 15 rows

- Mirror plate rib spacing (pitch) of 2.3 mm

- Ir+B4C overcoating.[1]

4.2 Quantum Efficiency

The final quantum efficiency depends on the configuration used. The single contributions are:

Sensor QE Absorbing layer (450μmSi) and on-chip OBF ($20\,\mathrm{nm}\ SiO_2$ + $30\,\mathrm{nm}\ Si_3N_4$ + $86.5\,\mathrm{nm}$ Al + $3.5\,\mathrm{nm}$ Al_2O_3)

Filter transmission Filter wheel OBF (150nm Polyimide + 23nm Al + 7nm Al_2O_3) and mesh made of Au plated SS with 96% open area (available for Large Detector Array and Fast Detector)

Be Filter 100μm Be filter (available for Fast Detector only)

The Sensor QE and filter transmission were provided by M. Barbera. From this information we can define the three cases of interest for the WFI. The sensor quantum efficiency is used for each of the cases.

- Case **1**: only Sensor QE (`WFI-eff_wo_filter_450sensor_20190122.dat`)

- Case **2**: Sensor QE and OBF transmission (`WFI-eff_w_filter_450sensor_20190122.dat`)

- Case **3**: Sensor QE and thick $100\,\mu$m Be filter (`WFI-eff_Be100mum_filter_450sensor_20190122.dat`)

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[1]The data file containing the mirror effective area for this coating are called `15_row_rib_2.3_B4C_1_15_vs_kev.dat`, downloaded from `https://www.cosmos.esa.int/web/athena/resources-by-esa`
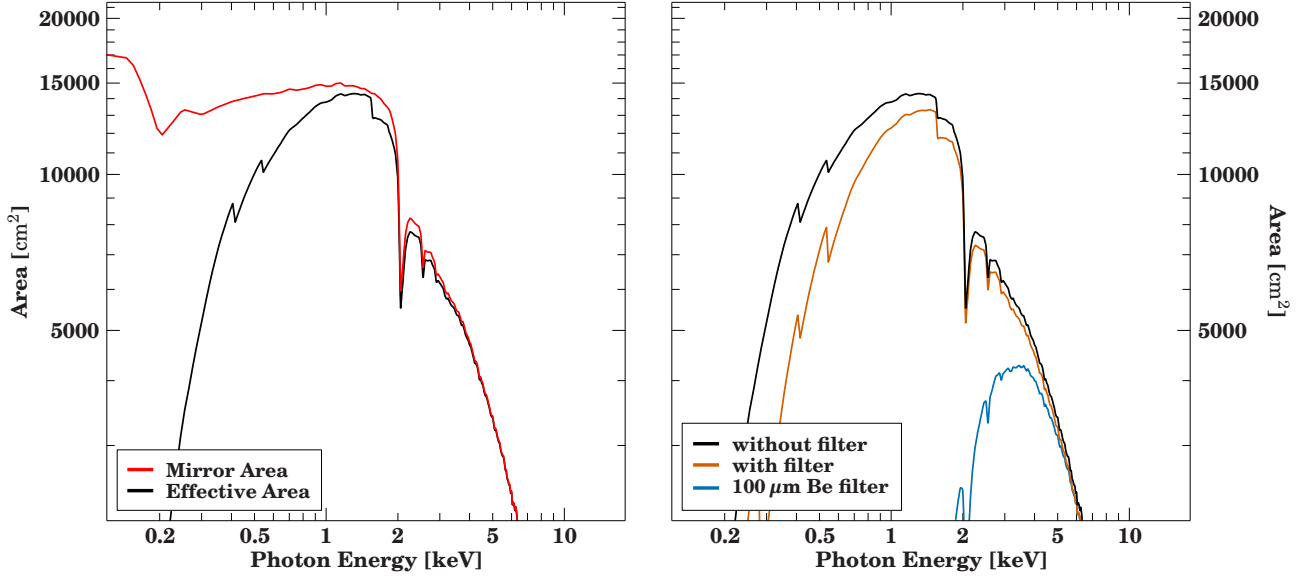
Figure 3: The mirror effective area (red) and the final ARF configuration without OBF are shown on the left. The right panel shows the effect of including an OBF (orange) and a thick $100\,\mu$m Be filter (blue). The assumptions entering the effective area are described in the text.

4.3 ARF Construction

The ARF is the result of the multiplication of the mirror effective area and the quantum efficiency. Taking the above cases of the quantum efficiency effects and the mirror area into account, the following ARFs are provided:

1. `athena_sixte_wfi_wo_filter_v20190122.arf` (without OBF)

2. `athena_sixte_wfi_w_filter_v20190122.arf` (with OBF)

3. `athena_sixte_wfi_Be100mum_filter_v20190122.arf` (with $100\,\mu$m BE filter)

The mirror effective area and ARFs for all cases are shown in Fig. 3.

4.4 RMF

The RMF has been constructed in an energy range from $0.02\,$keV to $15\,$keV with a step size of $0.01\,$keV in both Energy and EBOUNDS.
The RMF is composed of a Gaussian curve integrated in the respective EBOUNDS-bins, with a width that was fit to FD lab measurements as described in [RD3].
The width is described by the formula

$$\sigma(E) = (A * E + B)/2.355, \tag{1}$$

where E is the energy in electronvolts, $A = 0.01221$ and $B = 64.62$.
The resolution is shown in Fig. 4. The RMF is available as `athena_wfi_rmf_v20200925.rmf` .

4.5 Vignetting

The vignetting is described in the file `athena_vig_20171016.fits` (provided by R. Willingale) and can be seen in Fig. 5.
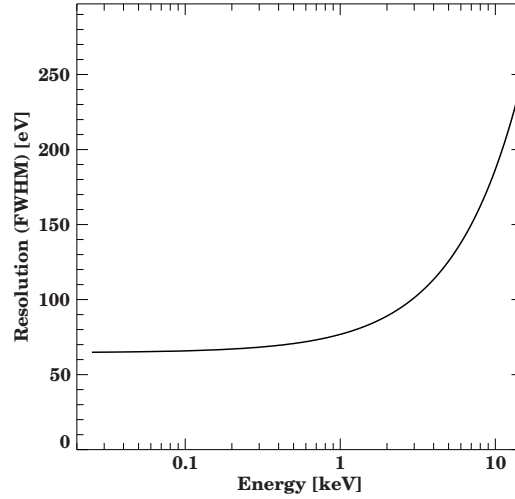
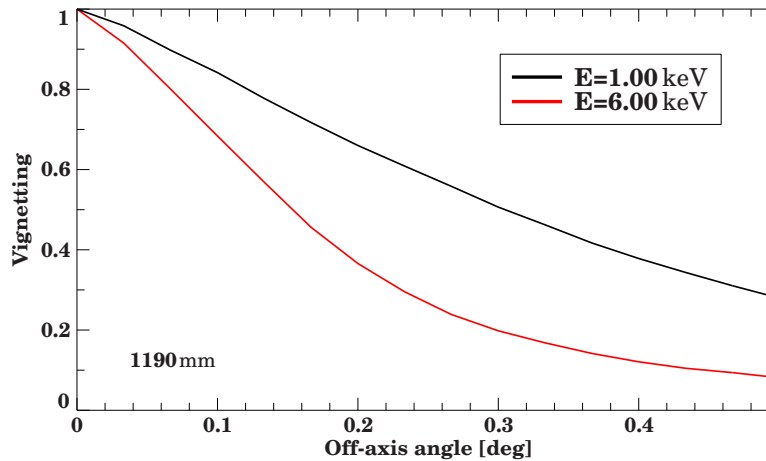Figure 4: The width of the RMF in the relevant energy range.

Figure 5: The vignetting as a function of the off-axis angle for different photon energies.

4.6 PSF

For the PSF we use the file `athena_psf_15row.fits`. A Gaussian model is used for the PSF with parameters provided by R. Willingale (based on the Athena Telescope Design version 2.4). The relevant on-axis values for the HEW are: 4.8 arcsec at 1 keV and 5.2 arcsec at 6.0 keV. The defocused PSF (`athena_defocus_35mm_keV_psf_v20200921.fits`) is taken from ray-tracing simulations by R. Willingale, based on the mirror geometry as described in the Athena Telescope Reference Document version 3.1 by Tim Oosterbroek (ESA/ESTEC).

The PSFs are shown in the left panel of Fig. 6 for different energies and off-axis angles.

4.7 PHA background

The instrumental background is specified in the file `sixte_wfi_particle_bkg_20190829.pha`. It corresponds to a flat spectrum of $5 \cdot 10^{-3}$ cts s^{-1} cm^{-2} keV^{-1} across the whole instrument ARF, as specified in the
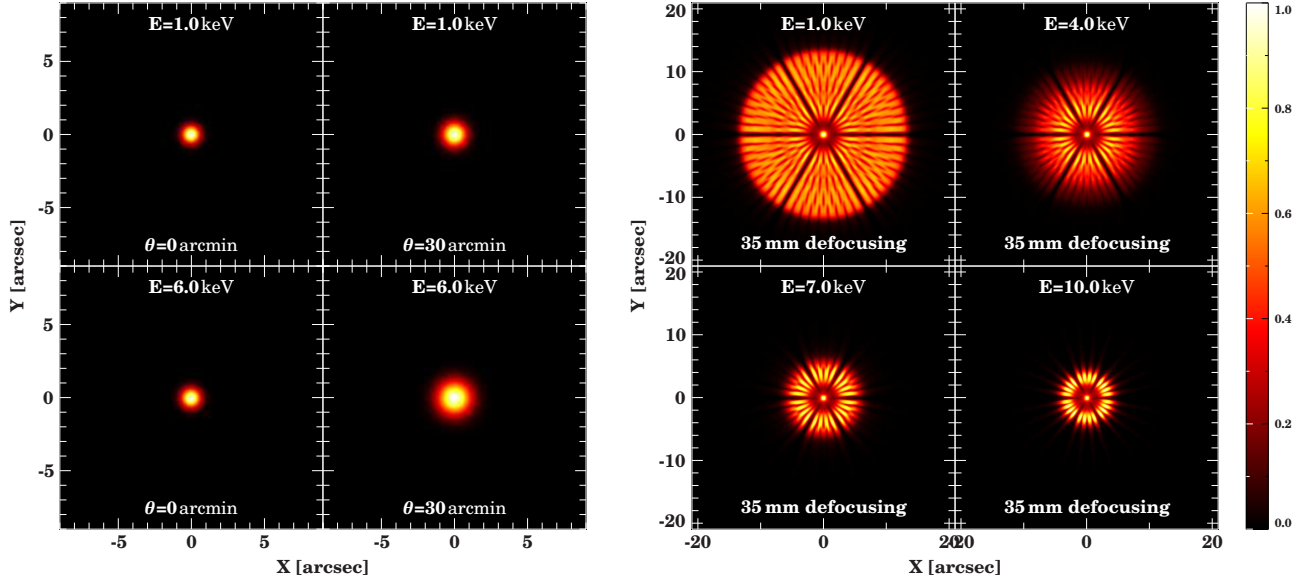
Figure 6: The PSF at different energies and off-axis angles. The left panel shows the on-axis PSF, while the right panel shows the defocused PSF for the FD for 35 mm defocusing at different energies. Note that the effect of defocusing is strongly energy dependent.

official WFI background files[2].

4.8 Charge cloud size

The charge cloud size is fixed to $11\,\mu$m.

5 Conclusions

The setups described in this document can be used to run up-to-date simulations for the *Athena* WFI with the SIXTE package. The version described in this document is v1.9.10_public and can be download at `http://www.sternwarte.uni-erlangen.de/research/sixte/`.

These files should only be used with SIXTE. Questions regarding the setup and the simulations should be directed to `sixte-support@lists.fau.de`.

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[2]online under `www.mpe.mpg.de/ATHENA-WFI/public/resources/background/WFI-MPE-ANA-Background-20150372.pdf`