JX-ISAS-SUZAKU-MEMO-2011-01
Title: A fast ARF generator ‘xisarfgen’
Category: XRT, XIS
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Date: 2011-07-26

The fast ARF generator “xisarfgen”

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July 26th, 2011

1 Introduction

This document describes a fast generator of XIS Ancillary Response Files (ARFs) and the related CALDB files released in 2011, which are used in Guest Observers’ analysis. Description of the calibration files released is found at
`http://www.astro.isas.jaxa.jp/suzaku/caldb/doc/`
or
`http://suzaku.gsfc.nasa.gov/docs/heasarc/caldb/suzaku/docs/`

The software ‘xisarfgen’ is designed to calculate ARFs for point-like sources using pre-calculated files (via ray-tracing) in the CALDB. This is usually much faster than ‘xissimarfgen’, which always carries out ray-tracing. The different methods of calculation make only a small difference between the effective areas in the ARFs produced by ‘xissimarfgen’ and ‘xisarfgen’, which is reported in section 6.

2 ‘xissimarfgen’ and ‘xisarfgen’

Both ‘xissimarfgen’ and ‘xisarfgen’ calculate Suzaku XIS ARF. The output file format is the same, but the method of calculating the ARF is different: ‘xissimarfgen’ runs ray-tracing program while ‘xisarfgen’ refers pre-calculated tables. The arguments for ‘xisarfgen’ are more limited than those for ‘xissimarfgen’. Users should choose one of the programs to fit with their science purposes. A summary of the comparison between the two programs is given in table 1.

‘xissimarfgen’ generates the ARFs of the Suzaku XIS detectors through Monte-Carlo simulations for many combinations of user-input, such as arbitrary X-ray emitting region and event extraction region. Its core-tool ‘xissim’ simulates detected photon events in each energy band, and then calculates the detection efficiency for each selected source region. ‘xissimarfgen’ can simulate incoming X-ray photons and event extraction regions in both the SKY (X,Y) and DETECTOR (DETX, DETY) coordinates. Different coordinate systems can be used for the source emitting region and event extracting region. Users can simulate the incoming X-ray photons from celestial sources including their morphology and their positions using the option “source_mode” and its additional options. ‘xissimarfgen’ can simulate ARFs for a point source, by setting the “source_mode” to J2000, SKYXY or DETXY, or for a circularly extended source centered at the optical axis (source_mode=UNIFORM). Alternatively if “source_mode” is set to SKYFITS or DETFITS, a FITS image may be input.

Table 1: Comparisons between ‘xissimarfgen’ and ‘xisarfgen’

	‘xissimarfgen’	‘xisarfgen’
method	Ray-tracing (Monte-Carlo)	Linear interpolation of the PSF and EA tables. Energy dependence of the PSF is NOT considered.
source mode	SKYFITS, DETFITS, J2000, SKYXY, DETXY, UNIFORM (point or extended source)	J2000, SKYXY (point source only)
region mode	SKYFITS, DETFITS, SKYREG, DETREG, SKYCIRC, DETCIRC	SKYFITS, SKYREG, SKYCIRC
contaminant	at a detector position of simulated photons (PSF is considered)	at a detector position of the source position (PSF is NOT considered)
no. of regions	1 – 200 †	1 – 200 †
accuracy	User defined	Equivalent to num_photon=100000
attitude	“none” or filename	“none” or filename
energy step	user defined (estepfile)	2 eV

† Users must add parameters, “regfile$N$” and “arffile$N$”, manually, to increase the “num_region” more than 20.

‘xisarfgen’ generates the ARFs by referring to the pre-calculated EA and PSF tables for a limited combination of user-input, point-source for the source shape and one extraction region. The pre-calculated EA and PSF tables are products of the ray-tracing programs with high photon numbers of 100,000 and 1,000,000, respectively. ’xisarfgen’ can simulate the ARF for a point-like source in the SKY (X,Y) coordinates.

Users can calculate the ARF with ‘xisarfgen’ more quickly than with ‘xissimarfgen’. If users ignore the error of the pointing control in one observation (”attitude=none”), the ARF can be generated in one minute or so. If the pointing error is taken into account (“attitude=attitude”), the ARF can be generated in a few hours. The larger the error, the longer the calculation time. For example, ‘xisarfgen’ run with the machine of CPU AMD Phenom(tm) 9600 Quad-Core Processor, 2.3GHz Memory 4GB. The time needed for calculating an ARF is 20-30 sec and 2-3 hours for the attitude option “none” and “filename”, respectively.

3 New ftools

3.1 Name

‘xisarfgen’

3.2 Versions

2011-04-21 at the first release in 2011.

3.3 Brief description

Calculate a Suzaku XIS ARF referring to the pre-calculated PSF and effective area. Those calibration files are products of the same XRT ray-tracing library used in 'xissim' or 'xissimarfgen'. The 'xisarfgen' can calculate an ARF for only a point-like source. The coordinates of the calculated region must be given in sky or J2000.

3.4 Usage

The usage is similar to that of 'xissimarfgen'. Examples are as follows.

```
xisarfgen phafile=filename rmffile=filename \
source_mode=J2000 source_ra=value source_dec=value \
region_mode=SKYREG num_region=1 regfile1=filename arffile1=filename \
attitude=filename
```

```
xisarfgen phafile=filename rmffile=filename \
source_mode=J2000 source_ra=value source_dec=value \
region_mode=SKYREG num_region=1 regfile1=filename arffile1=filename \
attitude=none ea1=value ea2=value ea3=value
```

4 New CALDB Files

The EA files:
ae_xrt0_effarea_20110505.fits
ae_xrt1_effarea_20110505.fits
ae_xrt2_effarea_20110505.fits
ae_xrt3_effarea_20110505.fits

The PSF files:
ae_xrt0_psf_20090605.fits
ae_xrt1_psf_20090605.fits
ae_xrt2_psf_20090605.fits
ae_xrt3_psf_20090605.fits

5 Calculation of the effective area in an ARF file

'xisarfgen' outputs an ARF that contains the effective area of the XIS system except the detection efficiency. The effective area is calculated with the CALDB including the PSF and EA files listed above.

The PSF file is prepared for each XIS system. Images in the PSF file are calculated at offset angles of 0, 4, 8, 12, 16, and 20 arcmin and at azimuth angles of 0, 45, 90, 135, 180, 225, 270, and 315 deg. The offset is calculated not from the detector center but from the optical axis of the XRT. The calculation was made at the monochromatic X-rays of 4.51 keV. In total, one on-axis and 40 off-axis images are contained in the PSF file. The value integrated from 0 to 6 mm from the focus is set as unity, i.e., each image is normalized at the radius of 6 mm. The 6 mm length corresponds to 250 XIS pixels. Figure 1 shows the image in which the 41 images in the PSF file are overlaid. The off-axis and azimuth angles are defined in the XRT coordinate (see Ishisaki et al. 2006 for the definition of the coordinate system).

The effective area in the EA file is calculated at offset angles of 0, 0.3, 0.6, 1.0, 1.5, 2.0, 3.0, 4.0, 5.0, 7.0, 10.0, and 20.0 arcmin and at azimuth angles of 0, 45, 90, 135, 180, 225, 270, and

315 deg. In total, one on-axis and 88 off-axis effective areas are contained in each EA file. The integrated radius used for the effective area in the EA file is 6 mm. Figure 2 shows the effective area at the azimuth angle of 0 deg.

The 'xisarfgen' calculates the offset and azimuth angles for the source position. It identifies the images in the PSF files at the four positions of the two closest offsets and the two closest azimuth angles. An image at the source position is calculated by linearly interpolating the images at the four positions. A *weight* is calculated by simply counting up the values of the image within the extracted region.

The effective area at the source position is also made by interpolating the EA file in a similar way as for images. The effective area of the XRT is calculated by multiplying the interpolated effective area by the *weight*. The effective area of the XRT is further multiplied by the transmissivity of the thermal shield of the XRT, and also the transmissivity of the contamination on the XIS OBF. The transmissivity of the contamination on the detector system is calculated at the source position. Scatter of photons by the PSF of the XRT is NOT considered. This is similar to the case users use the ftools, 'xiscontamicalc', to multiply the transmissivity of the contamination to ARFs afterwards. The effective area of the XRT is corrected with the contamination transmissivity and is written into the ARF.

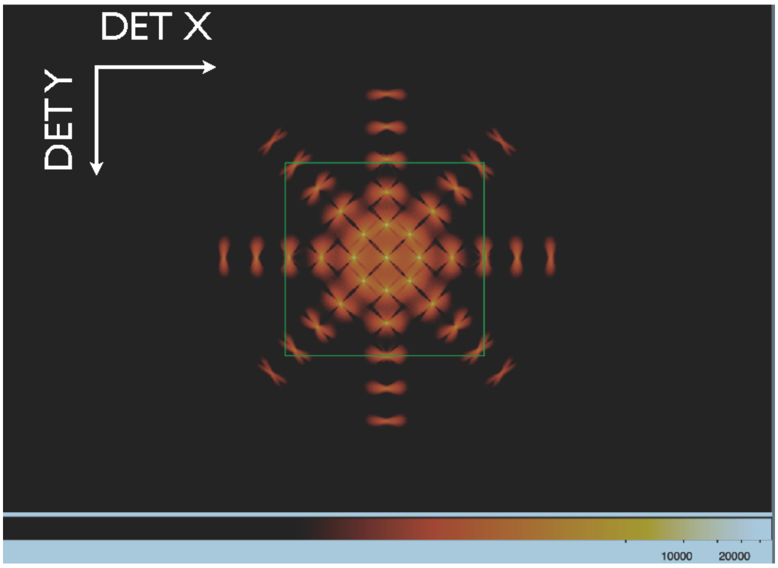

Figure 1: Images overlaid with all the data in the PSF CALDB fits for XIS-1 (ae_xrt1_psf_20090605.fits). The images were calculated at an offset angle $\theta = 0, 4, 8, 12, 16, 20$ arcmin and an azimuth angle of $\phi = 0, 45, 90, 135, 180, 225, 270, 315$ deg. One side of the green square is 24.576 mm long which corresponds to the size of the XIS detector.

6 Difference of ARFs made by 'xissimarfgen' and 'xisarfgen'

'xisarfgen' refers to the pre-calculated products of the ray-tracing program with the combination of the recent CALDB. To simplify the logic of producing the ARF, 'xisarfgen' further makes the three assumptions as follows.

- Linear interpolation of the EA and PSF table.
- Non energy dependency in PSF.

- Single transmissivity of the OBF contaminant at the source position.

Therefore, there are included two kinds of the calculation uncertainties for the ARF produced by 'xisarfgen'. One is the uncertainty of the ray-tracing library. Please refer the calibration uncertainty of the ray-tracing program to Suzaku MEMOs 2006-04/05/06. The other is the uncertainty due to the simplification of the calculation and is discussed below.

In 'xisarfgen', we assume that the PSF is independent of the energy. At the beginning of the Suzaku operation, this assumption is valid in the energy band below ∼10 keV and is slightly worse above this energy. After the contamination on the entrance of the detector unit becomes significant, the approximation becomes slightly worse also below ∼1 keV.

Below ∼6 keV, the incident angles into the reflectors are within the critical angle of the total reflection at on-axis. In the energy range, all the reflectors contribute to make the image, so that the images are the same below ∼6 keV. At the higher energy, X-rays reflected at inner reflectors can focus onto the detector. The difference of the reflectors becomes remarkable above ∼10 keV and changes the image slightly. The approximation of the energy-independent image is a good approximation below ∼10 keV.

Note that the detector contamination slightly changes the image in the low energy band, roughly below ∼1 keV. The amount of contamination is dependent on the location of the detector. This effect changes the image focused by the XRT. The approximation of energy-independent image gets slightly worse as the contamination evolves with time.

'xisarfgen' also calculates the image and the effective area by a simple interpolation of the images in the PSF files and the effective-area tables in the EA file. This process makes the difference in the effective area created by the two ARF generators, 'xissimarfgen' and 'xisarfgen'.

6.1 Comparisons between the outputs of 'xisarfgen' and 'xissimarfgen'

We show several comparisons of the ARF made with two softwares, 'xisarfgen' and 'xissimarfgen' below. The versions of 'xissimarfgen' and 'xisarfgen' are 2008-04-05 and 2011-04-21, respectively.

Acknowledgment

We appreciate for the tests made by Someya, K., Shionome, T., Hayahida, K., Hayashi, T., Saitoh, K., Ebisawa, K. for running the 'xisarfgen'software. We thank A. Lorella and K. Ebisawa and the Suzaku software folks for endeavoring to release the software and the CALDBs.

References

Ishisaki, Y., et al. 2007, PASJ, 59, S113

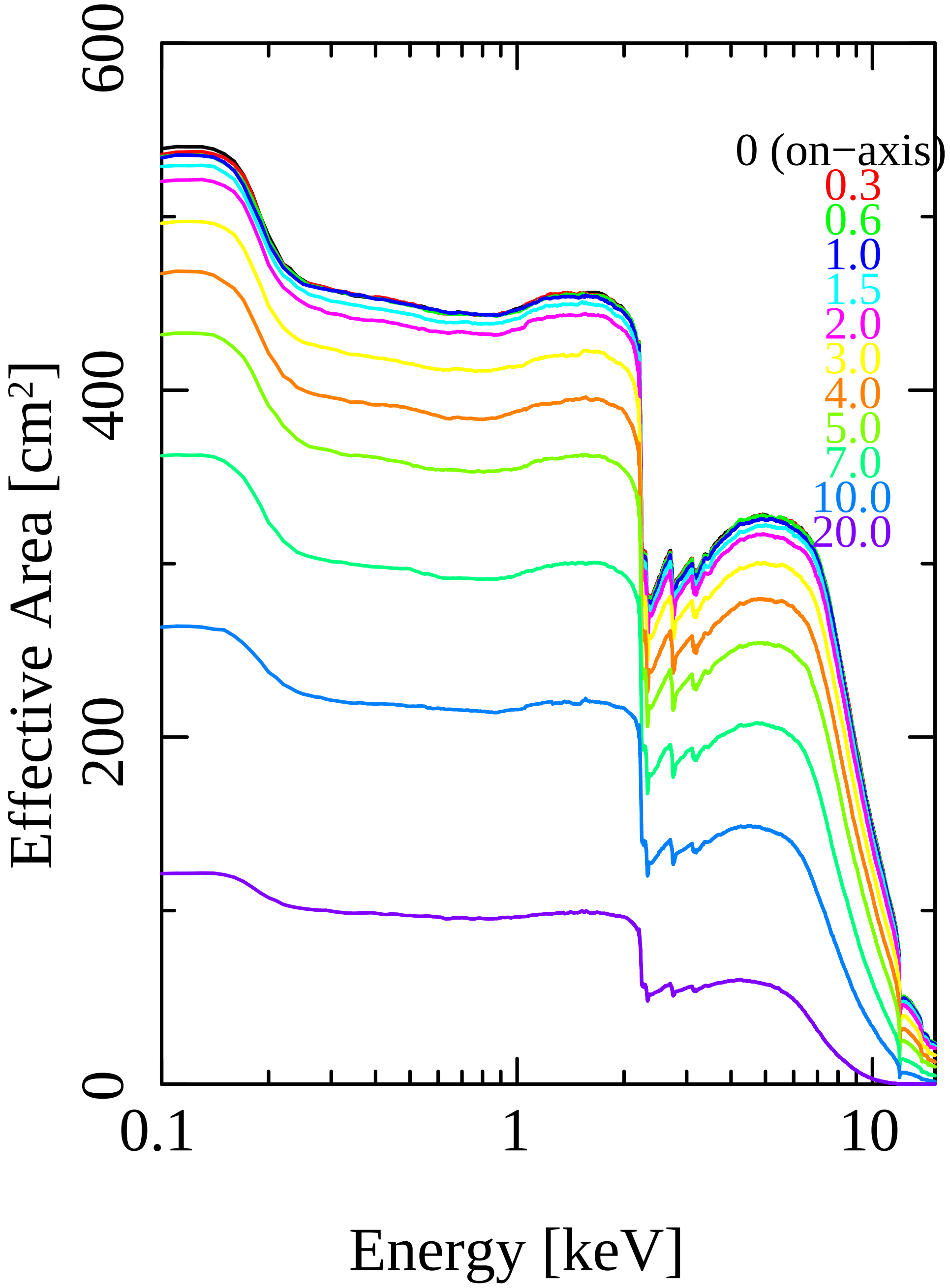

Figure 2: Plot of the tables in the EA CALDB fits for XIS-1 (ae_xrt1_effarea_20110505.fits). The tables for the azimuth angle of zero are used for the plot. The effective area give as the table were calculated at an offset angle $\theta = 0, 0.3, 0.6, 1.0, 1.5, 2.0, 3.0, 4.0, 5.0, 7.0, 10.0, 20.0$ arcmin and an azimuth angle of $\phi = 0, 45, 90, 135, 180, 225, 270, 315$ deg.

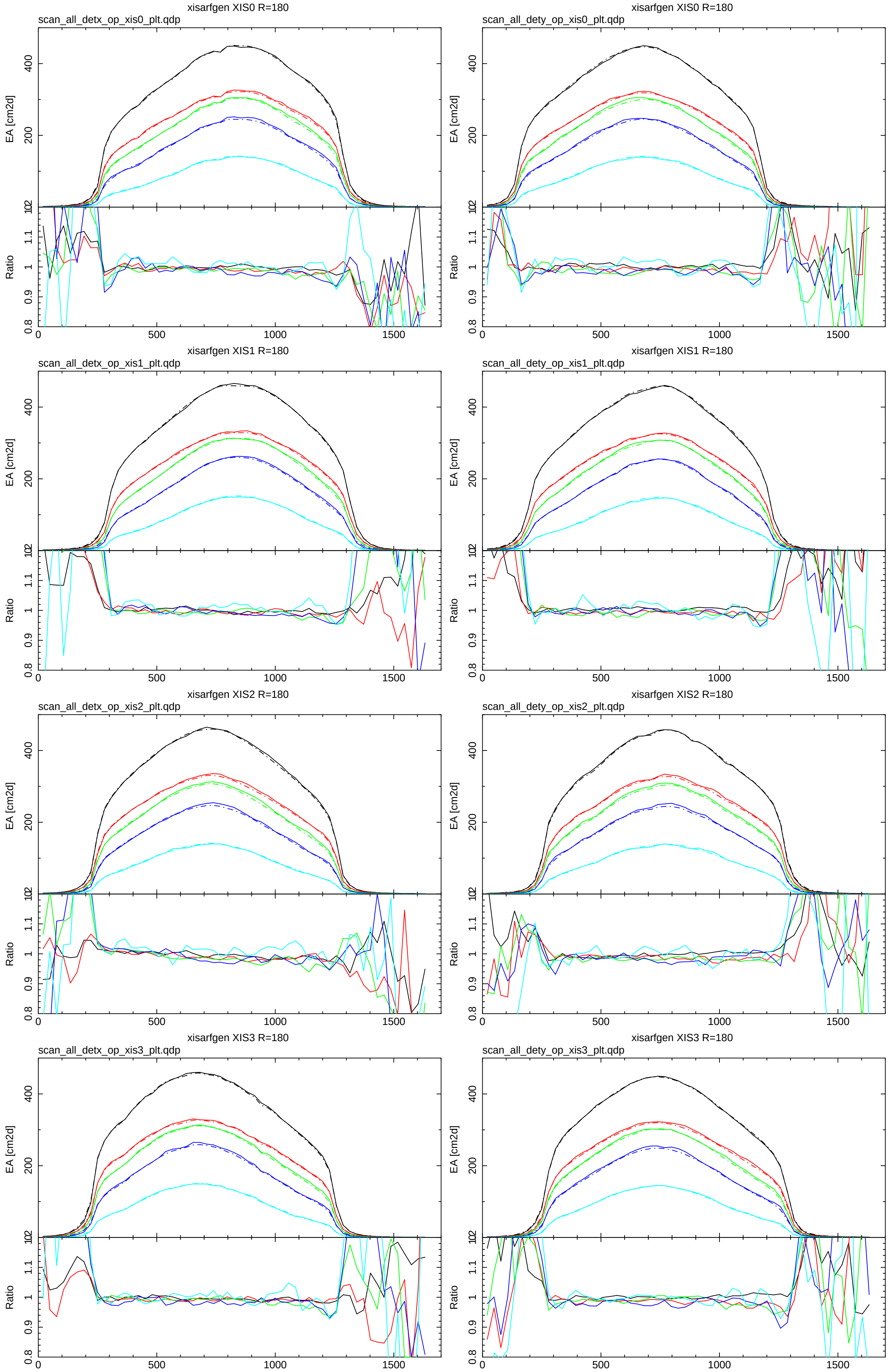

Figure 3: Plots of the effective area calculated with the 'xisarfgen' and 'xissimarfgen'. The source position of the point source was changed from the optical axis of each telescope along the DET-X (left) and DET-Y (right) directions. The integrated radius of 180 pixels are adapted. From top to bottom, the effective area of XIS-0, -1, -2 and -3 are plotted. The solid and dashed lines correspond to the effective area in the ARF file created by the 'xisarfgen' and the 'xissimarfgen', respectively. The bottom panel shows the ratio of the effective area by 'xisarfgen' to 'xissimarfgen'.

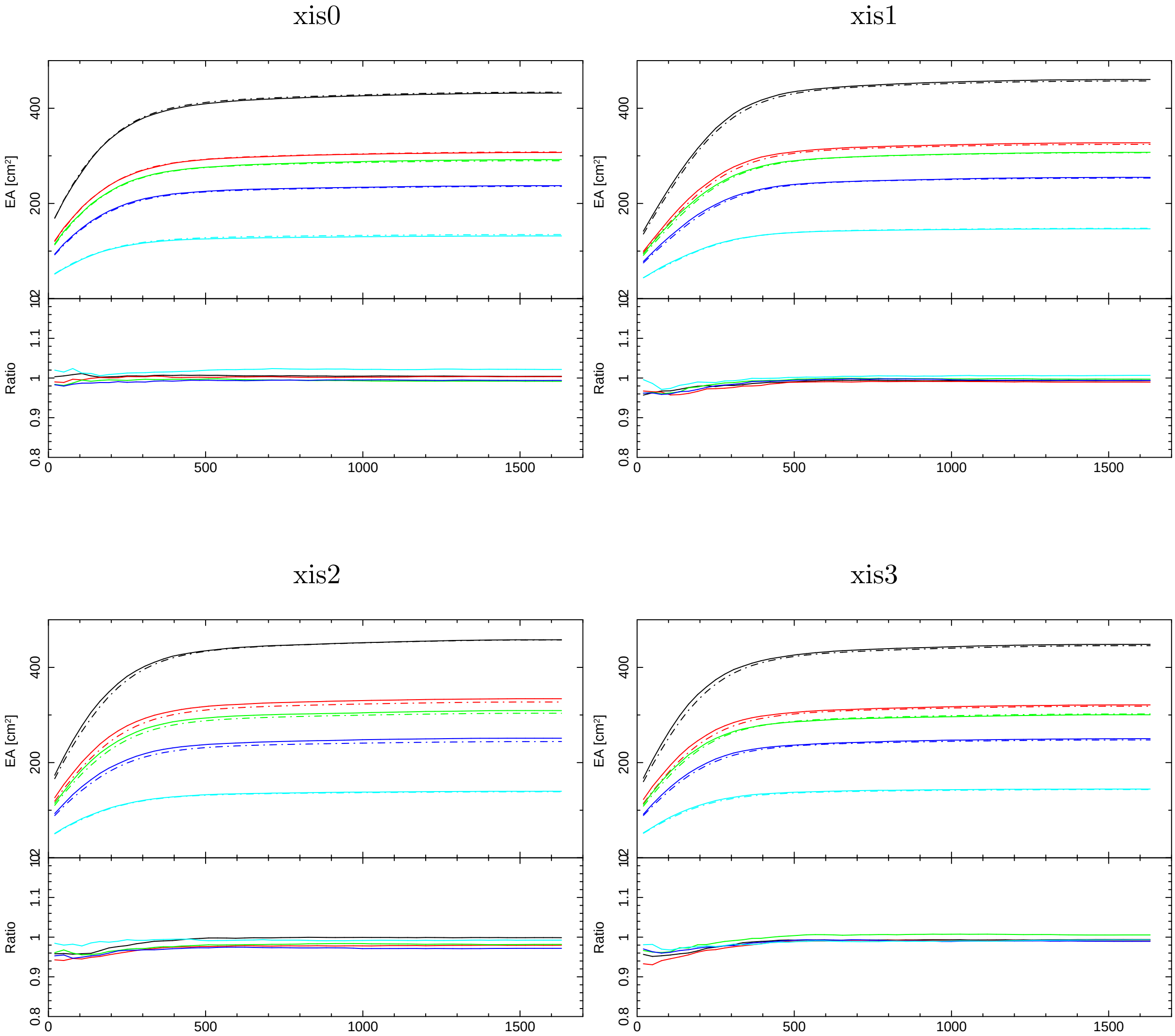

Figure 4: Effective area at on-axis with a given radius for integration. The source position of the point source is always pointed on-axis, but with changing the integrated radius (horizontal axis). The bottom panel at each plot shows the effective area ratio of the 'xisarfgen' to the 'xissimarfgen'.

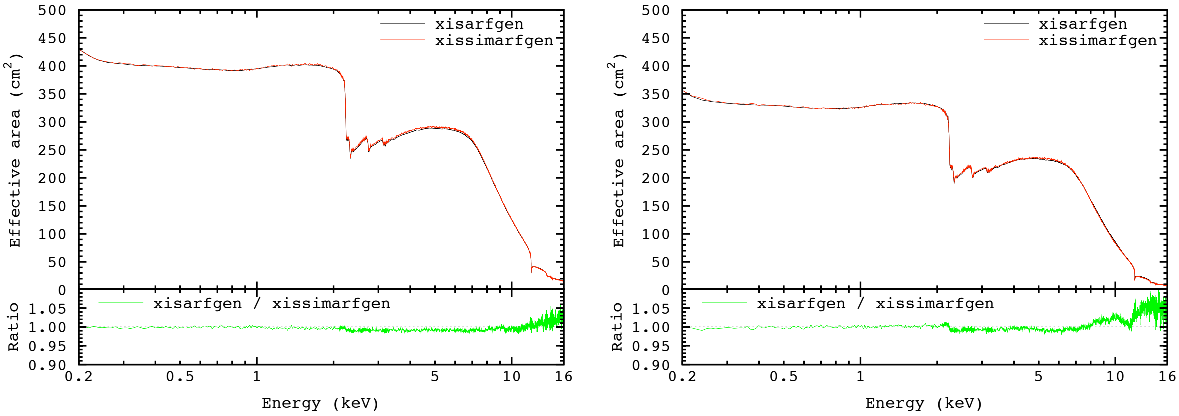

Figure 5: Effective area of the XRT and its ratio of the ARF files produced by the two generators. Left and right figures correspond to examples for xis- (ID 403029010) and hxd-nominal positions (ID 403002010), respectively. The XIS-0 is adapted for testing the softwares. These figures were made by K. Saitoh.

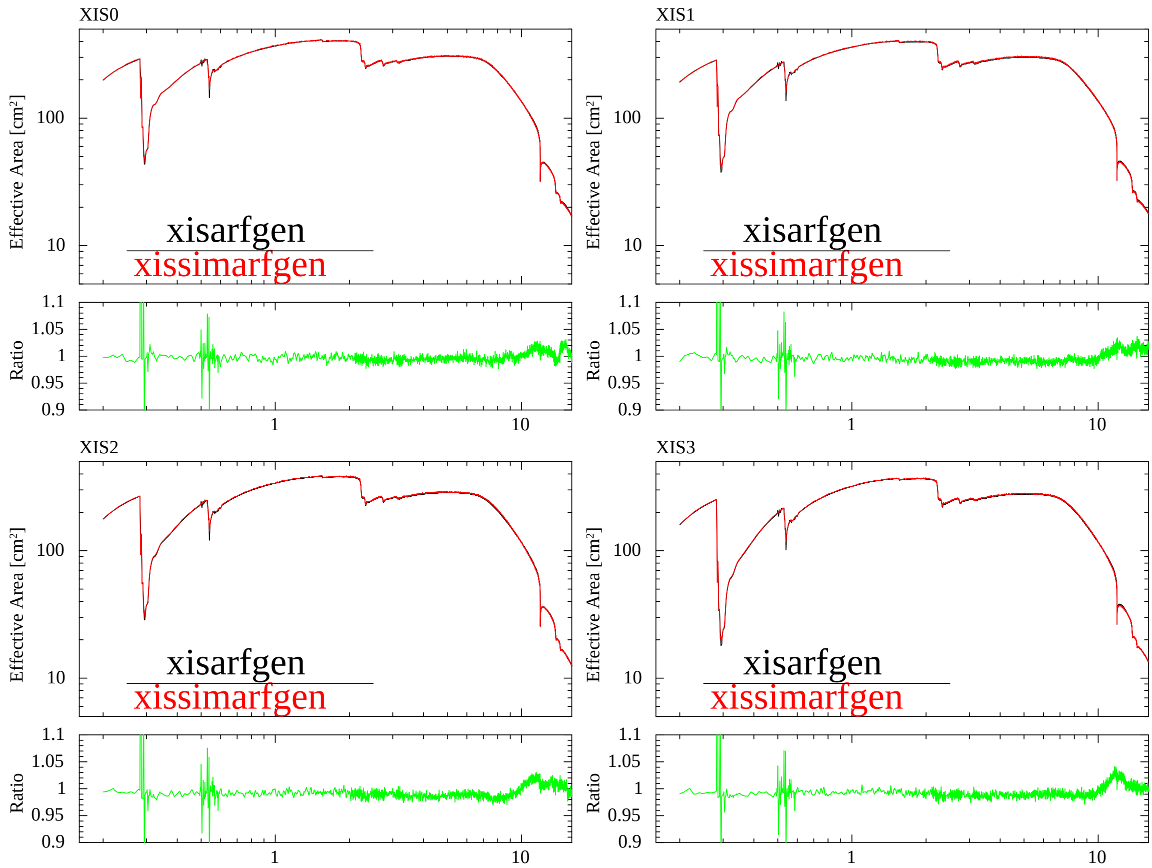

Figure 6: Effective area and its ratio of the ARF files produced by the two generators for XIS-0, 1, 2, and 3. Obs. ID. is 100016010. The pointing was made at the XIS nominal position.