

SIMX Manual
for ASTRO-H members
updated for version 2.1.0

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SIMX home page at CfA
<http://hea-www.harvard.edu/simx/index.html>
(The latest version can be found at this URL.)

Wiki page for the ASTRO-H members
<http://www.astro.isas.jaxa.jp/next/astroh-simx/wiki/index.php?FrontPage>

Chapter 1

What is “SIMX”?

The software package SIMX is an event simulator to estimate a response of photon-counting detectors on board future missions, including ASTRO-H. (Note that SIMX itself is not for ASTRO-H but can be used to simulate observations with other missions, e.g., NuSTAR and Athena, although this document focuses on simulations of ASTRO-H.) The simulation is based on a mission/instrument description and/or information (unofficial in some cases) provided by each satellite team, combined with source information (e.g., flux, image, and spectrum) supplied by users. The output of SIMX will be **event data** with standard OGIP FITS format that can be viewed by the SAO `ds9` software and analyzed with the FTOOLS and CIAO tools. SIMX can also calculate pile-up fraction for ASTRO-H SXS (relative numbers of “high”, “mid”, and “low” resolution events). Flow chart of the SIMX simulation is shown in figure 1.1.

SIMX is not a full ray-tracing code but can simulate very quickly the PSF, vignetting, and instrumental responses including non X-ray background. User should understand that SIMX is a ‘first approximation’ tool to demonstrate the detectors’ performance and to estimate source confusion, background effects, pileup, and other similar issues. To build a more accurate response function, a ray-tracing simulator, like `xissim` and `xissimarfgen`, is developed and used independently (see table 1.1).

Table 1.1: Comparison between SIMX and ray-tracing simulators.

	SIMX	ray-tracing
PSF	1-D & 2-D*	2-D
Vignetting	available	available
NXB	available	N/A
Stray light	N/A	available
Pile-up estimation	SXS only	available
Out-of-time events	N/A	N/A?
Simulation time	rapid	slow

* Using images of PSF from measurements at specific energies and on- or off-axis positions.

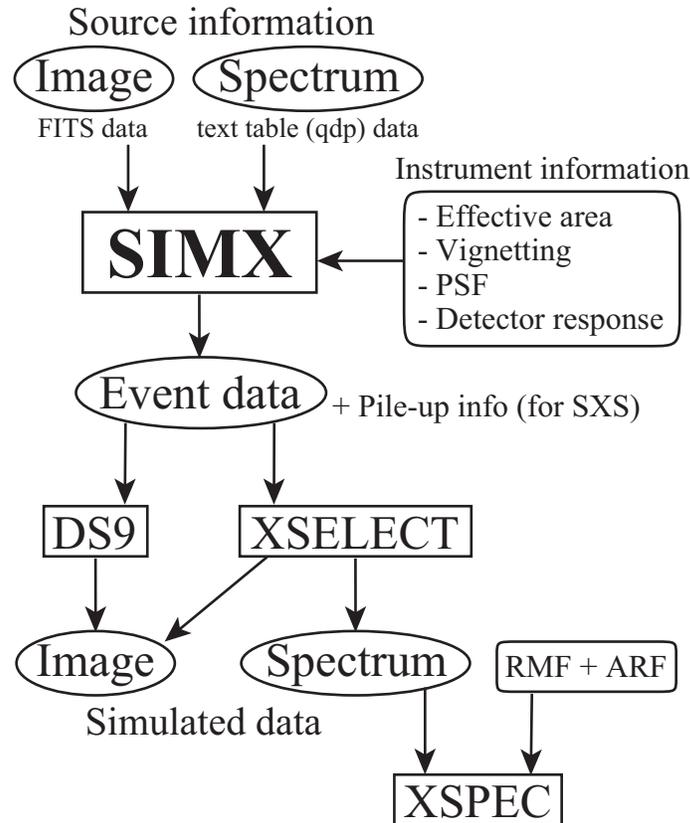


Figure 1.1: Flow chart of simulation using SIMX. — *Note:* Source image and spectrum are optional. A point-like source or a monochromatic-energy spectrum can be simulated without them. For spectral analysis, an ARF file should be created separately (using something like `xissimarfgen`), although the SIMX package contains some representative ARFs (e.g., one for a point source with $r < 1/8$).

Chapter 2

Installation and Setup

2.1 Installation

SIMX is distributed as a source code, and requires C compiler to install. It has been tested on Linux and Mac OS X. After downloading the SIMX tarball from the URL, <http://hea-www.harvard.edu/simx/download.html> execute the following commands to compile and install the code:

```
unix% tar zxf simx-X.Y.Z.tar.gz
unix% tar cd simx-X.Y.Z
unix% ./configure
unix% make
unix% make install
```

If the code is compiled correctly, you should now have a `bin` directory with a copy of SIMX. We have tested this on Mac's running 10.6-10.9 (Snow Leopard-Mavericks) and a Linux machine running Scientific Linux 5, Kernel 2.6.18-371.6.1.

If you would like to test your version, you can then run the following commands (warning: test comparisons require that you have FTOOLS installed and ready to run):

```
unix% cd test
unix% make test
```

Please report any odd behavior on the part of the code to:

`astroh-simx@astro.isas.jaxa.jp`

When reporting problems, please don't hesitate to look at the code and suggest fixes.

Notes from the Field

1. The 'make install' step is required. Otherwise, simx will bomb out immediately complaining that it cannot find the simx par file.
2. In some cases, the `make` command will fail with a message along the lines of "`ld: in ../src/libsimx.a, archive has no table of contents`". In this case, you may be able to fix the problem by typing "`cd src ; ranlib libsimx.a ; cd ..`".
3. If run on a 32-bit computer, `make test` may fail on the Cas A simulation with the Astro-H SXI, reporting differences in the number of events. However, the different numbers are quite close to the canonical values, and the difference is likely

due to differences in how the random number function works on 32-bit and 64-bit computers. This can be ignored, as it should not be a problem with running SIMX.

2.2 Setup

2.2.1 Setting up to run SIMX

The mission and/or instrument description is provided by data in the file `xselect.mdb`, in the `simx/inputs` directory. SIMX must be able to find this file as a default, which it does via the SIMX system variable. This is set by the `simx-setup.csh` or `-.sh` script, found in `simx/bin`. Thus, before running SIMX, you must first run the setup script via:

```
unix% source /path/to/simx/bin/simx-setup.csh (for CSH version)
unix% ./path/to/simx/bin/simx-setup.csh (for BASH version)
```

2.2.2 Running SIMX

SIMX uses the ever-popular IRAF interface that should be familiar to FTOOLS and CIAO users. It expects to find its parameter file in a directory pointed to by the PFILES system variable. If you are an FTOOLS user, you probably have a directory ‘`pfiles`’ in your home directory, e.g., `/home/user/pfiles`. Running `simx-setup.[csh/sh]` as shown above will set up the PFILES environment properly so that this is done automatically. However, it can be done directly as well using:

```
unix% cp /path/to/simx/pfiles/simx.par /home/user/pfiles/simx.par
```

Alternatively, you can simply set the PFILES environment variable to point to the `pfiles` directory in SIMX:

```
unix% setenv PFILES /path/to/simx/pfiles (for CSH version)
unix% set PFILES /path/to/simx/pfiles
unix% export PFILES (for BASH version)
```

Note that the `syspfiles` directory contains a ‘pristine’ version of the same file in case the one in `pfiles` is corrupted somehow.

To run SIMX, simply set the simulation parameters in `simx.par` to the desired values by editing the file directly in an editor (this method is somewhat risky) or installing FTOOLS and using `pset`, e.g.:

```
unix% pset simx OutputFileName = MySimRun
unix% pset simx Exposure = 10000
```

(see also chapter 3) and then run SIMX:

```
unix% /path/to/simx/bin/simx
```

The code will generate an output event file in the current directory which can be viewed with ds9 or used with the CIAO tools dmextract or the FTOOLS `xselect`. **The specially-modified version of `xselect.mdb` is needed to use these files with `xselect`.** To use this file with `xselect` instead of the default `xselect.mdb` that comes with FTOOLS, set the following environment variable:

```
unix% setenv XSELECT_MDB /path/to/simx/inputs/xselect.mdb (for CSH version)
```

```
unix% set XSELECT_MDB /path/to/simx/inputs/xselect.mdb
```

```
unix% export XSELECT_MDB (for BASH version)
```

After that, `xselect` will automatically pick up the correct mission when the SIMX output files are read and will use the proper binning and column names for the extraction.

Chapter 3

Input Parameters & Files

3.1 Standard parameter options

As explained in the previous chapter, the input parameter list for simulation can be modified by using the `pset` command, but you can also give the parameters listed below interactively after running the SIMX program.

- **OutputFileName:** ‘Output Event file stem[]’; The output event file name stem. Final event file name will be this step with “_evt.fits” appended.
- **PointingRA:** ‘Pointing right ascension (decimal degrees)[]’; Right Ascension (in decimal degrees) of the pointing direction of the satellite.
- **PointingDec:** ‘Pointing declination (decimal degrees)[]’; Declination (in decimal degrees) of the pointing direction of the satellite.
- **Exposure:** ‘Exposure time (seconds)[]’; Exposure time (in seconds).
- **SourceFlux:** ‘Source Flux in erg/cm²/s[]’; Total source flux (in erg cm⁻² s⁻¹). **The energy range of the flux must match the range of the model spectrum.**
- **SourceImageType:** ‘Source Image Type (Point|Flat|Image)[]’; One of Point, Flat, or Image; If Point is chosen, the point source position must be provided as the “SourcePointRA” and “SourcePointDec” parameters. If Image is chosen, a FITS image file must be provided in “SourceImageFile”. If Flat is chosen, neither position parameter nor input image is needed but flat-surface-brightness sky is assumed. **The input flux is assumed to be that of the entire FoV of the individual instrument: $(Flux) = (Surface\ brightness) \times (FoV\ size)$.** The angular size of the FoV of each instrument aboard ASTRO-H is listed in Table 3.1.
- **SourcePointRA:** ‘Source right ascension (decimal degrees)[]’; Right Ascension (in decimal degrees) of the point source; only used when “SourceImageType = Point”. If you aim to simulate an on-axis observation, this and the “SourcePointDec” values should match “PointingRA” and “PointingDec”.
- **SourcePointDec:** ‘Source declination (decimal degrees)[]’; Declination (in decimal degrees) of the point source; only used when “SourceImageType = Point”.
- **SourceImageFile:** ‘Source Image File[]’; FITS-format file containing the image to simulate; only used when “SourceImageType = Image”.

- SourceSpectrumType:** ‘Source Spectrum Type (XSPEC_File|Sherpa_File|Mono) []’;
 One of XSPEC_File, Sherpa_File, or Mono. If set to Mono, the source is assumed to be monoenergetic with the energy set in the “MonoEnergy” parameter. If XSPEC_File, it is assumed the spectrum is output from XSPEC using the commands

```
XSPEC> ...define model spectrum...
XSPEC> plot model
XSPEC> iplot
PLT> wdata model.dat
PLT> quit
```

In this case, the file will have at least 3 columns, Energy (in keV), delta-Energy, and flux (in photons/cm²/s/keV); the first three rows are ignored as they normally contain text.

If Sherpa_File is the parameter, it is assumed the spectrum file comes from a Sherpa model created (in CIAO 3) via:

```
sherpa> ...define model spectrum...
sherpa> write source source.dat
```

In this case, the file will have 2 columns, Energy (in keV), and Flux (in photons/cm²/s/keV). If you generate the spectrum file some other way than XSPEC or Sherpa, simply output the spectrum in this format (two columns, energy and flux) and SIMX should be able to read it.
- SourceSpectrumFile:** ‘Source Spectrum File []’; The name of the source spectrum file, if “SourceSpectrumType = XSPEC_File or Sherpa_File” (see next).
- MonoEnergy:** ‘Energy (in keV) if monoenergetic []’; The energy (in keV) of the mono-energetic spectrum if “SourceSpectrumType = Mono”.
- RandomSeed:** ‘Initial Random Seed; use -1 to generate internally[0]’;
 The initial random seed. If you set this to -1, the code will use the current time to seed the random number generator, while any other value will always generate the same sequence of random numbers.
- MissionName:** ‘Mission Name []’; Available missions are summarized in Section 3.3.
- InstrumentName:** ‘Instrument Name []’; Allowable settings for this depend upon the “MissionName” setting. See Section 3.3.
- FilterName:** ‘Filter Name []’; Allowable settings for this depend upon the “InstrumentName” setting. See Section 3.3.
- ScaleBkgnd:** ‘Linear scaling factor for testing background sensitivity (0.0:10.0) [1.0]’ Linear scaling factor for the background. By default set to 1.0, but can be varied to test the impact of higher or lower background level.

3.2 Non-standard options

You can also change the parameters given below by using the `pset` command, although these are not able to be changed interactively when SIMX is running. The default of

the first three parameters is “\$XSELECT_MDB”. The `xselect.mdb` file is found in the `simx/inputs` directory.

- **File_bkgnd**: Background PHA file.
- **File_arf**: On-axis effective area file.
- **File_rmf**: Instrumental response matrix.
For example, the default RMF file assumes the energy resolution (FWHM) of 5 eV for ASTRO-H/SXS, but SIMX includes the RMF files with FWHM of 4eV and 7eV as well (in the directory `inputs/Astro-H/response/SXS`). If you want to perform simulation using these RMFs, modify this parameter as:

```
unix% pset simx File_rmf = $SIMX/inputs/Astro-H/response/SXS/
ah_sxs_4ev_basefilt_20090216.rmf
```
- **clobber**: Default is “yes”. If you want to forbid overwriting any existing output file, change this parameter to “no”.

You can also directly edit the `xselect.mdb` file to change parameters (but this method is risky). For example, to simulate different PSF, you may want to modify the parameter `PSFfile` by this method.

3.3 Available missions

This is a complete list of the available Astro-H instruments and filter choices. Note that there are **two** options now for the SXS and SXI instruments. The standard SXS and SXI choices use the axially-symmetric EEF functions that have been provided by the SXT team. However, the new SXSPSF and SXIPSF choices will use recently-measured images of the SXT-I and SXT-S PSFs taken at the ISAS beam line. Using these options will allow users to test the effect of the full 2D PSF, including scattering effects due to struts and other support structures.

Detailed information is found in the document `doc/Available_Satellites.txt`.

- Astro-H / SXS / Open
- Astro-H / SXS / CBF
- Astro-H / SXS / Be
- Astro-H / SXS / ND
- Astro-H / SXSPSF / Open
- Astro-H / SXSPSF / CBF
- Astro-H / SXSPSF / Be
- Astro-H / SXSPSF / ND
- Astro-H / SXI / None
- Astro-H / SXIPSF / None

- Astro-H / HXI / None
- Astro-H / HXI-toponly / None
- Astro-H / SGD / None

3.4 Design parameters of ASTRO-H

The design parameters of each instrument aboard ASTRO-H in SIMX version 2.1.0 are summarized in Table 3.1. Note that all values are approximate. For example, the HPD values are estimates; the actual values are derived from the encircled energy functions provided by the telescope teams.

Table 3.1: Current design parameters for ASTRO-H

	SXS	SXI	HXI	SGD
FoV (arcmin ²)	3.05×3.05	38×38	9×9	33×33/600×600
HPD (arcmin)	1.3	1.3	1.7	–
Effective Area (cm ²)	50/225	214/360	300	20
	(@0.5/6 keV)	@0.5/6 keV	(@30 keV)	(@100 keV)
Energy Band (keV)	0.3–12	0.4–12	5–80	40–600
FWHM (eV)	5	150 @6 keV	< 2000 @60keV	< 4000 @40 keV

Chapter 4

Tutorial 1: Simple Simulation

4.1 SXS for a thermal X-ray source

In this section, we learn how to run SIMX assuming a virtual point-like source with a simple optically-thin thermal plasma spectrum. The latest version of SIMX is v2.1.0. Hereafter, users are assumed to use this version.

Preparing input model spectra

SIMX can simulate not only monoenergetic events but also an arbitrary model spectrum. In the latter case, we need to prepare a spectral data prior to running SIMX. The spectrum is assumed to be output from either XSPEC or Sherpa. The XSPEC-type spectrum data have three columns of Energy (in keV), delta-energy (in keV), and flux (in photon/cm²/s/keV). The first three rows normally contain text (e.g., “READ SERR 1”) which will be ignored in the SIMX simulation. On the other hand, the Sherpa-type spectrum has only two columns, Energy (in keV) and flux (in photon/cm²/s/keV).

Important note : To derive an appropriate simulation result, an input spectrum should have sufficiently small bin size. Since the energy bin of the SXS RMF is given for each 1 eV, **users are recommended to create a model spectrum with the energy bin of 1 eV or less for SXS (and SXI) simulation.** Otherwise, an incorrect result will potentially be obtained.

Using XSPEC, we here create a model spectrum of a thermal plasma in collisional ionization equilibrium (APEC model; Smith et al. 2001) with an electron temperature kT_e of 2.0 keV, absorbed by a hydrogen column density N_H of $1 \times 10^{21} \text{ cm}^{-2}$.

```
unix% xspec
XSPEC12>dummysp 0.1 10 9900 linear < – important!
XSPEC12>model wabs * apec
1:wabs:nH>0.1
2:apec:kT>2
3:apec:Abundanc>1
4:apec:redshift>0
5:apec:norm>1
```

Important note : Here you don’t need to care about normalization. SIMX uses only the shape of the spectrum from the input data, while the normalization is given by the input

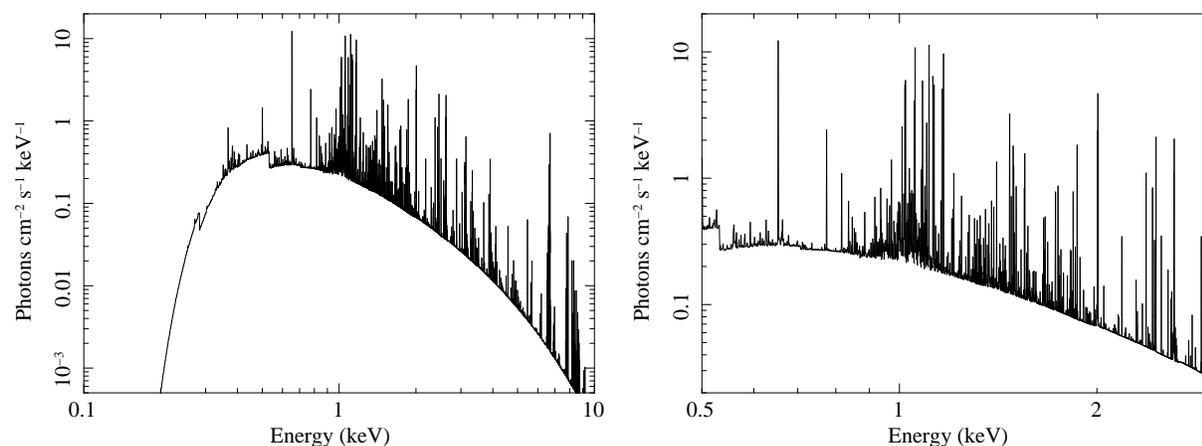


Figure 4.1: Model spectrum of optically-thin thermal plasma ($kT_e = 2.0$ keV, $N_H = 1 \times 10^{21}$ cm $^{-2}$).

command as shown later.

```
XSPEC12>cpd /xw
XSPEC12>plot model
```

Then, you may see a photon spectrum shown in figure 4.1. Dump this into ascii text table data.

```
XSPEC12>iplot
PLT>wenv model_apec_100-10000
PLT>quit
```

For later use, make a similar spectrum but of which energy range is different. The range in the model spectrum will be assumed by SIMX to be the energy range of the flux that will be given as an input parameter.

Important note : SIMX does not have an option to limit the range of the flux input, but assumes the flux given as input matches the spectrum file; if the input spectrum covers 0.1–10.0 keV, the flux value is assumed to cover that range.

```
XSPEC12>dummysp 0.5 3 2500 linear
XSPEC12>plot model
XSPEC12>iplot
PLT>wenv model_apec_500-3000
PLT>quit
XSPEC12>quit
```

Now, you have the spectrum data `model_apec_100-10000.qdp` and `model_apec_500-3000.qdp` (and `**pco`) which will be used as the input files for the SXS simulation.

```
unix%less model_apec_100-10000.qdp | head -7
READ SERR 1
```

```

@model_apec_100-10000.pco
!
0.1005 5.00000024E-4 0
0.1015 5.00000024E-4 0
0.1025 5.00000024E-4 0
0.1035 5.00000024E-4 0

unix%less model_apec_100-10000.qdp | tail -4
9.9965 5.00000024E-4 2.02651878E-4
9.9975004 5.00000024E-4 2.02720272E-4
9.9984999 5.00000024E-4 2.0240208E-4
9.9995003 5.00000024E-4 2.02512281E-4

unix%less model_apec_500-3000.qdp | head -7
READ SERR 1
@model_apec_500-3000.pco
!
0.50050002 5.00000024E-4 1.4454185
0.50150001 5.00000024E-4 0.43789926
0.5025 5.00000024E-4 0.40159792
0.50349998 5.00000024E-4 0.39090225

unix%less model_apec_500-3000.qdp | tail -4
2.9965 5.00000024E-4 2.61854846E-2
2.9974999 5.00000024E-4 2.61666924E-2
2.9985001 5.00000024E-4 2.61504054E-2
2.9995 5.00000024E-4 2.61206795E-2

```

Running SIMX

You are now ready to run SIMX. However, you can set the input parameter before SIMX is executed. (This process can be skipped, if you prefer to input the parameters interactively after running SIMX.)

Set the stem of the output event file name.

```
unix%pset simx OutputFileName=AH_SXS_point_apec_100-10000
```

(The file name will be this with "_evt.fits" appended.)

Set the pointing position.

```
unix%pset simx PointingRA = 0.0
unix%pset simx PointingDec = 0.0
```

Set the exposure (in sec).

```
unix%pset simx Exposure=50000
```

Set the flux (in $\text{erg}/\text{cm}^{-2}/\text{s}$).

```
unix%pset simx SourceFlux=1e-10
```

Set the input image or pointing position. (Here we simulate a point-like source. There

are other options, Flat and Image, which will be explained in the next chapter.)

```
unix%pset simx SourceImageType=Point
unix%pset simx SourcePointRA=0.0
unix%pset simx SourcePointDec=0.0
unix%pset simx SourceImageFile=None
```

Set the input spectrum.

```
unix%pset simx SourceSpectrumType=XSPEC_File
unix%pset simx SourceSpectrumFile=model_apec_100-10000.qdp
```

Set the mission/instrument/filter names.

```
unix%pset simx MissionName=Astro-H
unix%pset simx InstrumentName=SXS
unix%pset simx FilterName=Open
```

Set the linear scaling factor of the background level. The available range is from 0.0 to 10.0. (This option is useful to investigate impact of change in the background level.)

Here we simply ignore the background. `unix%pset simx ScaleBkgnd=0.0`

Finally, run SIMX to create an event file `AH_SXS_point_apec_100-10000_evt.fits`. Do not forget setup SIMX:

```
unix% source /path/to/simx/bin/simx-setup.csh (for CSH version)
unix% ./path/to/simx/bin/simx-setup.csh (for BASH version)
```

```
unix%simx
*****
*** simx version 2.1.0 ***
*****
Output Event file stem[AH_SXS_point_apec_100-10000]
Pointing right ascension (decimal degrees)[0.0]
Pointing declination (decimal degrees)[0.0]
Exposure time (seconds)[50000]
Use Simput File for source definition?[no]
Source Flux in erg/cm2/s[1e-10]
Source Image Type (Point|Flat|Image) [Point]
Source right ascension (decimal degrees)[0.0]
Source declination (decimal degrees)[0.0]
Source Image File[None]
Source Spectrum Type (XSPEC_File|Sherpa_File|Mono) [XSPEC_File]
Source Spectrum File[model_apec_100-10000.qdp]
Energy (in keV) if monoenergetic[2]
Initial Random Seed; use -1 to generate internally[0]
Mission Name[Astro-H]
Instrument Name[SXS]
Filter Name[Open]
Linear scaling factor for testing background sensitivity (0.1:10.0) [0.0]
...
...

```

```

...
generate_events: Adding background events: 0
generate_events: Actual number of events : 426148
...
...
generate_events: Vignetted or otherwise lost events: 128497
generate_events: Best-resolution events : 380102 ( 89.19%)
generate_events: Mid-resolution events : 34412 ( 8.08%)
generate_events: Low-resolution events : 11634 ( 2.73%)

```

The numbers of the detected and lost (to outside of the detector) events are displayed on your terminal. For SXS simulation, the best-, mid-, and low-resolution event numbers are also calculated.

Next, make another event file using the model spectrum with the energy range of 0.5–3.0 keV.

```

unix%pset simx OutputFileName=AH_SXS_point_apec_500-3000
unix%pset simx SourceSpectrumFile=model_apec_500-3000.qdp
unix%pset simx SourceFlux=1e-10
unix%simx
...

```

Keep in mind that the flux value assumed here is the same as that used in the previous simulation.

Analyzing the output data

The output event data can be analyzed with the FTOOL XSELECT (or the other software packages such as CIAO). **Do not forget to modify the environment variable XSELECT_MDB:**

```

unix%setenv XSELECT_MDB /path/to/simx/inputs/xselect.mdb (csh)
unix%export XSELECT_MDB=/path/to/simx/inputs/xselect.mdb (bash)

```

Otherwise, you will fail to read the event file with XSELECT and encounter with the following error message:

```

Unidentified mission? :
Failed to identify instrument in MDB

```

Run XSELECT and read the SXS event file.

```

unix%xselect
...
...
xsel:*** > read event AH_SXS_point_apec_100-10000_evt.fits
> Enter the Event file dir >[./]
Got new mission: ASTRO-H
> Reset the mission ? >[yes]
...

```

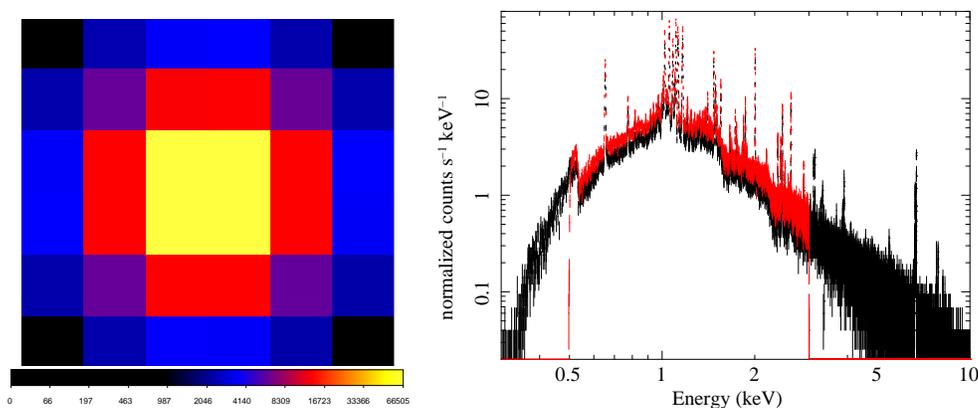


Figure 4.2: Left: Simulated SXS image of the point source. Right: Simulated SXS spectra of the optically-thin plasma. Black and red are the results with `AH_SXS_point_apec_100-10000_spec.pi` and `AH_SXS_point_apec_500-3000_spec.pi`, respectively.

...

The next step is to filter out all unwanted grades. The SXS team recommends only using High-resolution and Medium-resolution primary events; secondary events or Low-resolution events will have resolutions worse than the default 5 eV. This can be done with the following filter command (note that the quotes are required):

```
xsel:ASTRO-H-SXS> filter column "STATUS=0:1"
```

Then one can extract events from all the pixels and save the image and spectrum. The resultant image viewed by `ds9` is shown in figure 6.1 left.

```
xsel:ASTRO-H-SXS > extract all
...
...
xsel:ASTRO-H-SXS > save image AH_SXS_point_apec_img.fits
Wrote image to file AH_SXS_point_apec_img.fits
xsel:ASTRO-H-SXS > save spec AH_SXS_point_apec_100-10000_spec.pi
Wrote spectrum to AH_SXS_point_apec_100-10000_spec.pi
xsel:ASTRO-H-SXS > quit
> Save this session? >[yes]
Session saved, goodbye
```

You can make `AH_SXS_point_apec_500-3000_spec.pi` using a similar approach. The spectrum can be viewed and analyzed using `xspec`. As mentioned in Section 1, *SIMX is not an ARF generator*. Therefore ideally, something like `xissimarfgen` should be used to create an ARF file for each specific case. However, some representative ARF files are already provided by the instrument team¹, and `SIMX` contains them in the `inputs` directory. For the SXS, the ARF files for all 35 pixels are prepared. It would be convenient to link the RMF and ARF files to your work directory.

¹<http://www.astro.isas.jaxa.jp/next/astroh-sct/wiki/>

```
unix% ln -s /path/to/simx/inputs/Astro-H/response/SXS/
ah_sxs_5ev_basefilt_20100712.rmf .
unix% ln -s /path/to/simx/inputs/Astro-H/response/SXS/
sxt-s_100208_ts02um_of_intallpxl.arf .
```

```
unix% xspec
...
XSPEC12>data 1 spec AH_SXS_point_apec_100-10000_spec.pi
XSPEC12>response 1 ah_sxs_5ev_20130806.rmf
XSPEC12>data 2 spec AH_SXS_point_apec_500-3000_spec.pi
XSPEC12>response 2 ah_sxs_5ev_20130806.rmf
```

```
XSPEC12>cpd /xw
XSPEC12>setplot energy
XSPEC12>ignore **:**-0.3
XSPEC12>ignore *:10.0-**
XSPEC12>plot ldata
```

The resultant spectrum is shown in figure 6.1 right. The obtained normalization (flux) is slightly higher in the result with `AH_SXS_point_apec_500-3000_spec.pi` (red). This is because the same *integrated* flux of 1×10^{-10} ergs cm^{-2} s^{-1} is assumed in both cases but the energy range for the integration is different with each other.

4.2 SXI and HXI for a nonthermal X-ray source

In this section, we simulate SXI and HXI spectra of a a Crab-like nonthermal X-ray source. We assume a spectrum of which the shape is similar as Crab with flux of 1 mCrab. In addition, NXB will be taken into account.

Preparing input model spectra

First, we have to prepare model spectra for input files of SIMX. The energy range and bin size of the SXI RMF are 0.2–16 keV and 8 eV, respectively (at Jan 26, 2012. The SXI team is now working to update the RMF in which the bin size will be 2 eV). On the other hand, those of the HXI are 1–100 keV and 100 eV. Therefore, the input model data should reflect these values; the energy ranges of the model spectra should not exceed the above ranges and the bin size should be the same or smaller than those of the RMF. We assume spectral parameters of $N_{\text{H}} = 3 \times 10^{21}$ cm^{-2} and $\Gamma = 2.1$ (Figure 4.3).

```
unix% xspec
XSPEC12>model wabs * pow
1:wabs:nH>0.3
2:powerlaw:PhoIndex>2.1
3:powerlaw:norm>1
(for the SXI)
XSPEC12>dummysp 0.5 15 7250 linear
XSPEC12>plot model
XSPEC12>iplot
PLT>wenv model_crab_500-15k.qdp
```

< – important!

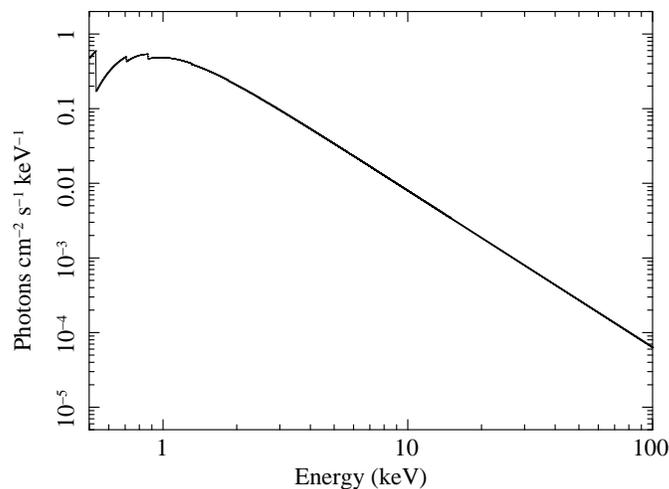


Figure 4.3: A model spectrum for the Crab nebula in the 0.5–100 keV band.

```
PLT>quit
(for the HXI)
XSPEC12>dummysp 1 100 990 linear
XSPEC12>plot model
XSPEC12>iplot
PLT>wenv model_crab_1k-100k.qdp
PLT>quit
XSPEC12>quit
```

< – important!

Confirm the model data you have obtained.

```
unix%less model_crab_500-15k.qdp | head -7
READ SERR 1
@model_crab_500-15k.pco
!
0.50099999 1.00000005E-3 0.47590923
0.50300002 1.00000005E-3 0.48406029
0.505 1.00000005E-3 0.4921779
0.50700003 1.00000005E-3 0.50025946
```

```
unix%less model_crab_1k-100k.qdp | tail -4
14.993 1.00000005E-3 3.39051429E-3
14.995 1.00000005E-3 3.38956574E-3
14.997 1.00000005E-3 3.38861765E-3
14.999 1.00000005E-3 3.38767003E-3
```

```
unix%less model_crab_1k-100k.qdp | head -7
READ SERR 1
@model_crab_1k-100k.pco
!
1.05 5.00000007E-2 0.47681072
1.15 5.00000007E-2 0.45300671
1.25 5.00000007E-2 0.42109907
1.35 5.00000007E-2 0.37774515
```

```

unix%less model_crab_1k-100k.qdp | tail -4
99.650002 5.00000007E-2 6.35618489E-5
99.75 5.00000007E-2 6.34281168E-5
99.849998 5.00000007E-2 6.32947849E-5
99.949997 5.00000007E-2 6.3161875E-5

```

Running SIMX

Here, we take into account contribution of the non X-ray background. Fluxes of the Crab nebula in the 0.5–15 keV and 1–100 keV band are approximately 4×10^{-8} erg cm⁻² s⁻¹ and 6×10^{-8} erg cm⁻² s⁻¹, respectively. Thus, we give 0.1% of these flux values.

(For SXI)

```

unix%pset simx OutputFileName=AH_SXI_crab
unix%pset simx PointingRA = 83.63
unix%pset simx PointingDec = 22.02
unix%pset simx Exposure=50000
unix%pset simx SourceFlux=4e-11
unix%pset simx SourceImageType=Point
unix%pset simx SourcePointRA=83.63
unix%pset simx SourcePointDec=22.02
unix%pset simx SourceImageFile=None
unix%pset simx SourceSpectrumType=XSPEC_File
unix%pset simx SourceSpectrumFile=model_crab_500-15k.qdp
unix%pset simx MissionName=Astro-H
unix%pset simx InstrumentName=SXI
unix%pset simx FilterName=None
unix%pset simx ScaleBkgnd=1.0
unix%simx

```

(For HXI)

```

unix%pset simx OutputFileName=AH_HXI_crab
unix%pset simx SourceFlux=6e-11
unix%pset simx SourceSpectrumFile=model_crab_1k-100k.qdp
unix%pset simx MissionName=Astro-H
unix%pset simx InstrumentName=HXI
unix%simx

```

Note that pileup calculation is currently not available for these instruments. You may see a message as below.

```

generate_events: Pileup calculation not available for this detector

```

Analyzing the output data

Images in the obtained event files can be viewed with ds9. The SXI and HXI images are shown in Figure 4.4 left and right, respectively. Run XSELECT to save the spectra.

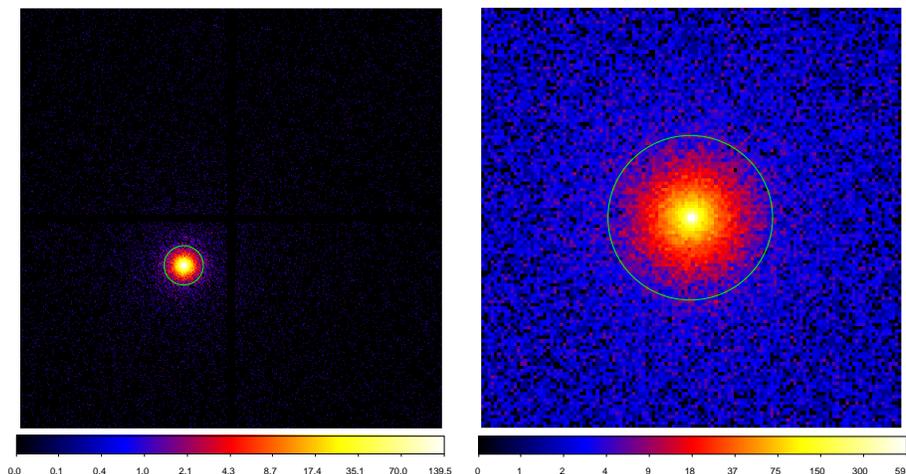


Figure 4.4: Simulated SXI (left) and HXI (right) images of the point-like source in logarithmic scale. The green circle indicates the $r = 1.8$ circle used for the spectrum extraction.

```

unix%xselect
...
...
xsel:*** > read event AH_SXI_crab_evt.fits
> Enter the Event file dir >[./]
Got new mission:  ASTRO-H
> Reset the mission ? >[yes]
...
...

```

Here we extract events from a circular region with a radius of 1.8 arcmin using the following region file `sxi_nominal_1.8min.reg`:

```

physical
circle(508,505.1,61.00)

```

You can extract a spectrum from another region with different size or shape, but are strongly recommended to select a 1.8 arcmin circular region because of current limitation. See Important notes below.

```

xsel:ASTRO-H-SXI > filter region sxi_nominal_1.8min.reg
xsel:ASTRO-H-SXI > extract spec
...
...
xsel:ASTRO-H-SXI > save spec AH_SXI_crab_spec.pi
Wrote spectrum to AH_SXI_crab_spec.pi
xsel:ASTRO-H-SXI > quit
> Save this session? >[yes]
Session saved, goodbye

```

You can also extract the HXI spectrum `AH_HXI_crab_spec.pi`. Again, the spectrum should be extracted from a 1.8-arcmin circular region:

```
physical
circle(64.5,64.5,25.1)
```

Important notes :

- (1) Currently, the SXT/HXT team provides only the ARF data for point-like sources with a circular integration region with a radius of 1.8 arcmin. Thus, user should extract events from these regions to measure the source flux precisely.
- (2) You can simulate an off-axis source as well. Note, however, that the current version of SIMX includes the PSF/EEF information only for the on-axis. Thus, the EEF of the off-axis regions will always be under-estimated.

It would be useful to make links of the RMF, ARF, and NXB files in your work directory.

(For SXI)

```
unix% ln -s /path/to/simx/inputs/Astro-H/response/SXI/
ah_sxi_20120702.rmf .
unix% ln -s /path/to/simx/inputs/Astro-H/response/SXI/
sxt-i_140505_ts02um_int01.8r.arf .
unix% ln -s /path/to/simx/inputs/Astro-H/bkgnd/SXI/
ah_sxi_pch_nxb_r1p80_20110530.pi . (for the 1.8-arcmin region)
unix% ln -s /path/to/simx/inputs/Astro-H/bkgnd/SXI/
ah_sxi_pch_nxb_full_20110530.pi . (for the entire FoV)
```

(For HXI)

```
unix% ln -s /path/to/simx/inputs/Astro-H/response/HXI/ah_hxi_20090217.rmf .
unix% ln -s /path/to/simx/inputs/Astro-H/response/HXI/
ah_hxt_pnt_r1p80_20130527.arf .
unix% ln -s /path/to/simx/inputs/Astro-H/bkgnd/HXI/
ah_hxi_nxb_r6p3mm.pha . (for the 1.8-arcmin region)
unix% ln -s /path/to/simx/inputs/Astro-H/bkgnd/HXI/
ah_hxi_nxb_30x30mm2.pha . (for the entire FoV)
```

Note that there are two different NXB files for both SXI and HXI: one for on-axis 1.8-arcmin regions and the other for the entire FoV. Since we have extracted the source spectra from the 1.8-arcmin regions, one may consider that the former NXB files should be used for background subtraction. However, **you should subtract the latter NXB from the source spectra.** This is because both NXB files contain the BACKSCAL value of unity, while the extracted source spectra has the value of the ratio A/D , where A and D are the area from which the spectrum is extracted) and the total detector area, respectively. For more detailed information of the BACKSCAL keyword, refer to the URL http://heasarc.gsfc.nasa.gov/docs/asca/abc_backscal.html .

Instead of this, you can modify the BACKSCAL keyword (using the `fparkey` command) by yourself as it matches the value of the source spectrum. On the other hand, you should use the former NXB files for direct comparison of the source and NXB spectra, as performed in the following.

```
unix% grppha
Please enter PHA filename[] AH_SXI_crab_spec.pi
Please enter output filename[] AH_SXI_crab_spec_grp.pi
GRPPHA[] gr min 100
```

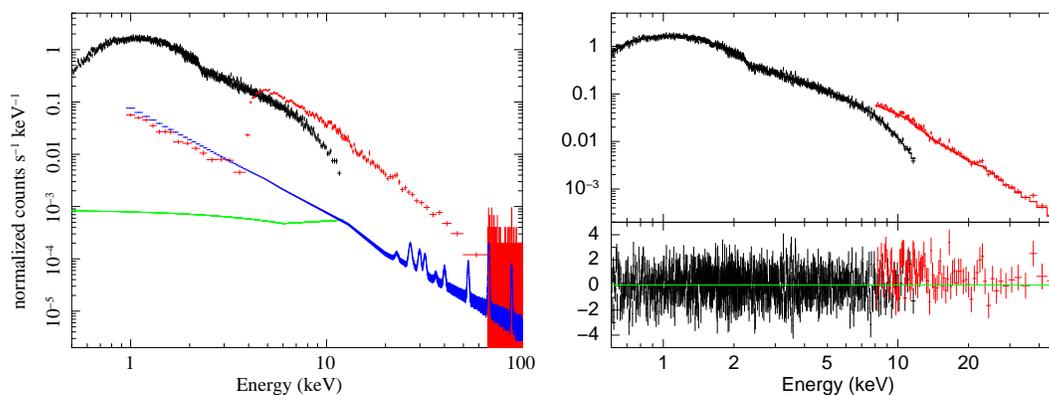


Figure 4.5: left: Simulated spectra of SXI (black) and HXI (red). NXB spectra are also shown with green and blue. right: Background-subtract spectra fitted with an absorbed power-law model.

```
GRPPHA [] chkey respfile astroH_sxi_Pch_20110330.rmf
GRPPHA [] chkey ancfile sxt-i_110426_ts02um_int01.8r.arf
GRPPHA [] exit
```

```
unix% grppha
Please enter PHA filename[] AH_HXI_crab_spec.pi
Please enter output filename[] AH_HXI_crab_spec_grp.pi
GRPPHA [] gr min 100
GRPPHA [] chkey respfile ah_hxi_20090217.rmf
GRPPHA [] chkey ancfile ah_hxt_pnt_r1p80_20090217.arf
GRPPHA [] exit
```

```
unix% xspec
XSPEC12>data 1 AH_SXI_crab_spec_grp.pi
XSPEC12>data 2 AH_HXI_crab_spec_grp.pi

XSPEC12>data 3 ah_sxi_pch_nxb_r1p80_20110511.pi
XSPEC12>data 4 ah_hxi_nxb_r6p3mm.pha
XSPEC12>resp 3 astroH_sxi_Pch_20110330.rmf
XSPEC12>resp 4 ah_hxi_20090217.rmf
XSPEC12>arf 3 sxt-i_140505_ts02um_int01.8r.arf
XSPEC12>arf 4 ah_hxt_pnt_r1p80_20130527.arf
```

```
XSPEC12>cpd /xw
XSPEC12>setplot energy
```

```
XSPEC12>ignore 1:**-0.5
XSPEC12>ignore 1:12.0-**
XSPEC12>ignore 3:**-0.5
XSPEC12>ignore 3:12.0-**
```

```
XSPEC12>plot ldata
```

The resultant spectra are shown in Figure 4.5. If you want to fit the spectra, you should

subtract the background. In this case, the NXB data from 1.8-arcmin region should be used for the reason mentioned above.

```
XSPEC12>back 1 ah_sxi_pch_nxb_full_20110530.pi  
XSPEC12>back 2 ah_hxi_nxb_30x30mm2.pha
```

Important notes :

- (1) The SXI (and SXS) NXB data currently include no instrumental-fluorescence-line component, but only the continuum component.
- (2) The default output from SIMX does not include cosmic X-ray background (CXB), but only the NXB. — In this chapter, we ignore contribution of CXB. The CXB data are need to be created by users separately. The method will be introduced in the next chapter.

Chapter 5

Tutorial 2: More Detailed Simulation

In the previous chapter, we learned how SIMX works for very simple cases. However, real observations will often be more complicated; X-ray sources are extended, contributions of diffuse background components (i.e., CXB, LHB, etc.) are not negligible, multiple sources with different spectra are observed in one FoV. Here, we learn how to treat such complex situation with SIMX.

5.1 Image mode

For simulation of specific diffuse sources, the option `SourceImageType=Image` can be used. This mode requires a surface brightness map in FITS format. Spatially-high-resolution images, such as ROSAT or Chandra observation data, are recommended as an input.

Some example images are available in the `test/reference` directory. Here, we use the Chandra ACIS image of the supernova remnant Cas A (Figure 5.1(left)).

```
unix% ln -s /path/to/test/reference/casa.fits .
```

A spectral model for the energy band above 10 keV (the HXI band) is assumed to be a power-law with $\Gamma = 3$ and $F_{10-100 \text{ keV}} = 1.3 \times 10^{-10} \text{ erg cm}^{-2} \text{ s}^{-1}$.

```
XSPEC12>model pow
1:powerlaw:PhoIndex>3
2:powerlaw:norm>1
XSPEC12> dummyrsp 10 100 900 linear
XSPEC12>plot model
XSPEC12>iplot
PLT>wenv model_casa_10k-100k.qdp
```

Set simulation parameters and then run SIMX. The input flux should be that from the entire object. SIMX scatters input photons in accordance with the surface brightness map.

```
unix%pset simx OutputFileName=AH_HXI_casa
unix%pset simx PointingRA=350.86
unix%pset simx PointingDec=58.82
unix%pset simx Exposure=50000
unix%pset simx SourceFlux=1.3e-10
```

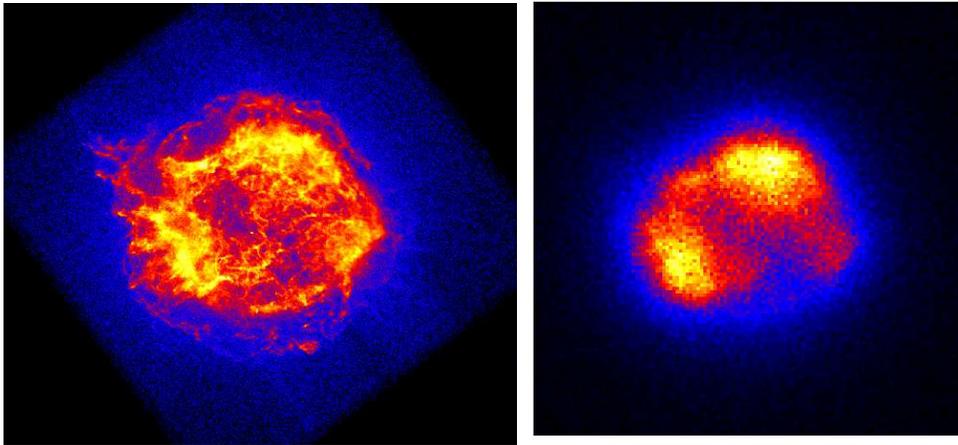


Figure 5.1: (left) Chandra image of Cas A. (right) Simulated HXI image for which the left image is used as an input.

```

unix%pset simx SourceImageType=Image
unix%pset simx SourceImageFile=casa.fits
unix%pset simx SourceSpectrumType=XSPEC_File
unix%pset simx SourceSpectrumFile=model_casa_10k-100k.qdp
unix%pset simx MissionName=Astro-H
unix%pset simx InstrumentName=HXI
unix%pset simx FilterName=None
unix%pset simx ScaleBkgnd=1.0
unix%simx

```

The resultant image is shown in Figure 5.1(right). (*Note – In this simulation, we used the Chandra image of the full X-ray band. Ideally, however, an image only of the hard X-rays should be used, since the actual morphologies in the soft and hard X-ray bands are different from each other. See e.g., Maeda et al. 2009, PASJ, 61, 1217.*)

5.2 Flat mode

As mentioned in the previous chapter, the default output from SIMX includes no X-ray background component, and hence it should be simulated separately by users. To perform this, we can consider to use the option `SourceImageType=Flat`. If this mode is chosen, SIMX assumes flat-surface-brightness sky with the same size as the FoV of the simulated instrument, and the input flux is assumed to be that of the entire FoV. Therefore, users must remember the FoV size of each instrument, which are summarized in Table 3.1. *This rule is somewhat complicated and hence should be improved in future.*

Here, we simulate the CXB for the Cas A observation in the previous section. The CXB spectrum is assumed to be a power-law with $\Gamma = 1.4$. FYI, the mean flux in the 2–10 keV and 10–100 keV bands are $\sim 5.6 \times 10^{-15}$ erg cm $^{-2}$ s $^{-1}$ arcmin $^{-2}$ and $\sim 2.8 \times 10^{-14}$ erg cm $^{-2}$ s $^{-1}$ arcmin $^{-2}$, respectively.

```

XSPEC12>model pow
1:powerlaw:PhoIndex>1.4

```

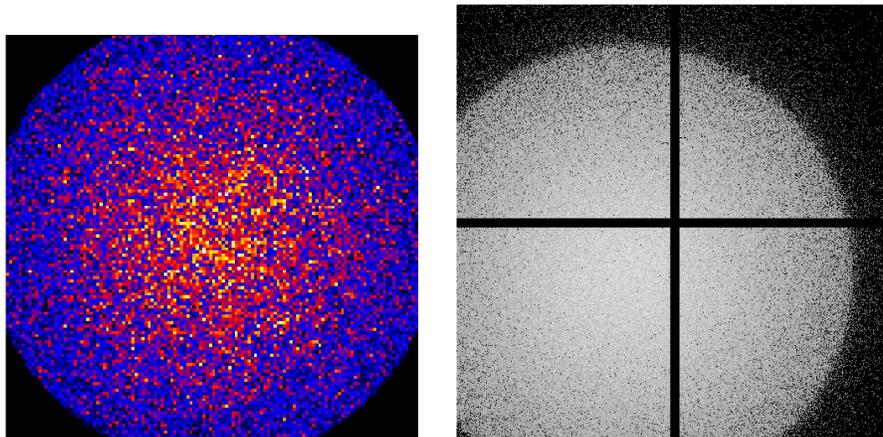


Figure 5.2: Simulated HXI (left) and SXI (right) images of the Flat mode.

```
2:powerlaw:norm>1
XSPEC12> dummyrsp 10 100 900 linear
XSPEC12>plot model
XSPEC12>iplot
PLT>wenv model_cxb_10k-100k.qdp
```

Since the HXI FoV is $9' \times 9'$, the input flux should be $(2.8 \times 10^{-14}) \times 9 \times 9 = 2.3 \times 10^{-12}$.

```
unix%pset simx OutputFileName=AH_HXI_cxb
unix%pset simx PointingRA=350.86
unix%pset simx PointingDec=58.82
unix%pset simx Exposure=50000
unix%pset simx SourceFlux=2.3e-12
unix%pset simx SourceImageType=Flat
unix%pset simx SourcePointRA=83.63
unix%pset simx SourcePointDec=22.02
unix%pset simx SourceSpectrumType=XSPEC_File
unix%pset simx SourceSpectrumFile=model_cxb_10k-100k.qdp
unix%pset simx MissionName=Astro-H
unix%pset simx InstrumentName=HXI
unix%pset simx FilterName=None
unix%pset simx ScaleBkgnd=1.0
unix%simx
```

Figure 5.2 (left) shows the results of the Flat mode, but the 100-times-longer exposure is assumed in order to increase photon statistics. Note that events only in the circular region with a radius of $5'$ are created for the HXI. Similarly, the SXI Flat mode can properly simulate only in the region with a radius of $20'$ centered on the nominal point (Figure 5.2 (right)). This is because the vignetting function over this radius is currently not given.

5.3 Merging multiple event data

The event data from multiple SIMX simulation can be merged together using the `simxmerge` utility. Here, we merge the Cas A and CXB data created in the previous sections.

Important note : `simxmerge` should not be used to merge event files from any other source besides SIMX.

```
unix%pset simxmerge OutputFileName=merged
unix%pset simxmerge MergeFiles=AH_HXI_casa_evt.fits,AH_HXI_cxb_evt.fits
unix%simxmerge
```

Then, you will obtain the merged event data `merged_evt.fits`. You can, of course, merge multiple sources in the same FoV with different spectra using this utility.

5.4 Application for clusters of galaxies

In this section, we demonstrate simulations for a cluster of galaxies, which is characterized by the diffuse emission and variation of the spectral shape in regions of the cluster. We pick up Abell 2199 cluster. The cluster is a nearby and bright cluster of galaxies ($z = 0.03$) characterized by a smooth distribution of the intra-cluster medium (ICM). Recent Chandra, XMM-Newton and Suzaku observations show the ICM properties from the central to outer region of the cluster (e.g., Sanders & Fabian 2006, Snowden et al. 2008, Kawaharada et al. 2010).

5.4.1 Preparation for simulations

We need several information for simulations, such as the temperature, flux, surface brightness profiles, etc. Fundamental parameters of Abell 2199 for simulations are summarized in table 5.1.

Table 5.1: Fundamental parameters of Abell 2199 cluster.

(R.A., Dec.) (degree)	z	N_{H} (cm^{-2})	β^*	r_c^* kpc
(247.1604, +39.5517)	0.03	8.92×10^{19}	0.650/0.531	10.3/51.0
	$r < 1.5'$	$1.5' < r < 4.5'$	$4.5' < r < 7.5'$	$7.5' < r < 10.5'$
kT^\dagger (keV)	3.5	4.2	4.0	3.8
Abundance (solar)	0.8	0.8	0.6	0.6
Flux † (0.3-10 keV) ($\text{erg}/\text{cm}^2/\text{s}/\text{SXS}$)	3×10^{-11}	9×10^{-12}	2×10^{-12}	7×10^{-13}

*: Double β -model profile from Kawaharada et al. 2010

†: Temperature profile and flux from Snowden et al. 2008

5.4.2 Fits image

As for simulations of diffuse sources such as clusters of galaxies, you have to provide the fits image of the source. As the input fits images, you can use X-ray images observed with

astronomical satellite such as Chandra, XMM and Suzaku, and also use the fits image assumed the surface brightness profile of the source. Here, we make a fits image assumed the double β -model surface brightness profile reported by Kawaharada et al. (2010) as shown in figure 5.3 and table 5.1.

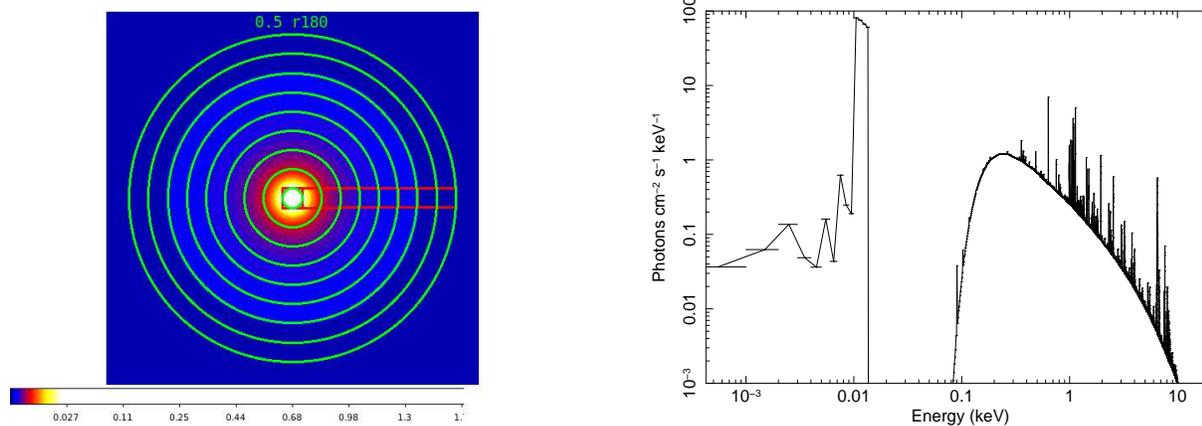


Figure 5.3: Left: X-ray image of Abell 2199 assumed the double β -model profile. Red squares correspond to SXS FOV. Right: A model spectrum with bapec for the innermost region of Abell 2199 with SXS.

5.4.3 Model spectrum

Generally, spectra from the ICM are well represented by thermal models such as mekal and apec model. Here we use the bapec model, which is a model of a velocity- and thermally-broadened emission spectrum from collisionally-ionized diffuse gas calculated using the ATOMDB code v2.0. The parameters of the model are assumed as shown in table 5.1. In the model, we also assume zero turbulence, which means that only a thermally-broadened is taken into account.

For example, we make a spectral model for the innermost region ($r < 1.5'$) of Abell 2199 with SXS as followings.

```

unix% xspec
XSPEC version: 12.7.0g
XSPEC12>model phabs*bapec
1:phabs:nH>8.92e-3
2:bapec:kT>3.5
3:bapec:Abundanc>0.8
4:bapec:Redshift>0.03
5:bapec:Velocity>0
6:bapec:norm>1
...
XSPEC12>fakeit none
For fake spectrum #1 response file is needed: ah_sxs_5ev_basefilt_20100712.rmf
...and ancillary file:
Use counting statistics in creating fake data? (y):
Input optional fake file prefix:
Fake data file name (ah_sxs_5ev_basefilt_20100712.fak): model_a2199.fak
Exposure time, correction norm, bkg exposure time (1.00000, 1.00000, 1.00000):

```

```

XSPEC12>setplot energy
XSPEC12>plot model
XSPEC12>iplot
PLT>wenv model_bapec_a2199
PLT>quit
XSPEC12>quit

```

5.4.4 Running SIMX

Using the above model and parameters, you can now run SIMX for SXS. You can also simulate event files for SXI by the same way. The resultant simulated SXS/SXI images are shown in figure 5.4.

```

pset simx OutputFileName=AH_SXS_a2199_cen
pset simx PointingRA=247.1604
pset simx PointingDec=39.5517
pset simx Exposure=50000
pset simx SourceFlux=3.2e-11
pset simx SourceImageType=Image
pset simx SourcePointRA=247.1604
pset simx SourcePointDec=39.5517
pset simx SourceImageFile=a2199-2beta_reg1.fits
pset simx SourceSpectrumType=XSPEC_File
pset simx SourceSpectrumFile=model_bapec_a2199.qdp
pset simx MissionName=Astro-H
pset simx InstrumentName=SXS
pset simx FilterName=None

unix% simx
*****
*** simx version 2.1.0 ***
*****
Output Event file stem[AH_SXS_a2199_reg1]
Pointing right ascension (decimal degrees)[247.1604]
Pointing declination (decimal degrees)[39.5517]
Exposure time (seconds)[50000]
Use Simput File for source definition?[no]
Source Flux in erg/cm^2/s[3.2e-11]
Source Image Type (Point|Flat|Image) [Image]
Source right ascension (decimal degrees)[247.1604]
Source declination (decimal degrees)[39.5517]
Source Image File[a2199-2beta.fits]
Source Spectrum Type (XSPEC_File|Sherpa_File|Mono) [XSPEC_File]
Source Spectrum File[model_bapec_a2199.qdp]
Energy (in keV) if monoenergetic[1.0]
Initial Random Seed; use -1 to generate internally[0]
Mission Name[Astro-H]
Instrument Name[SXS]
Filter Name[None]

```

```

Linear scaling factor for testing background sensitivity (0.1:10.0) [1.0]
generate_events: Adding background events: 576
generate_events: Actual number of events : 94589
generate_events: Analyzing deadtime and pileup
generate_events: Vignetted or otherwise lost events: 36929
generate_events: Best-resolution events : 93424 ( 98.77%)
generate_events: Mid-resolution events : 878 ( 0.93%)
generate_events: Low-resolution events : 287 ( 0.30%)

```

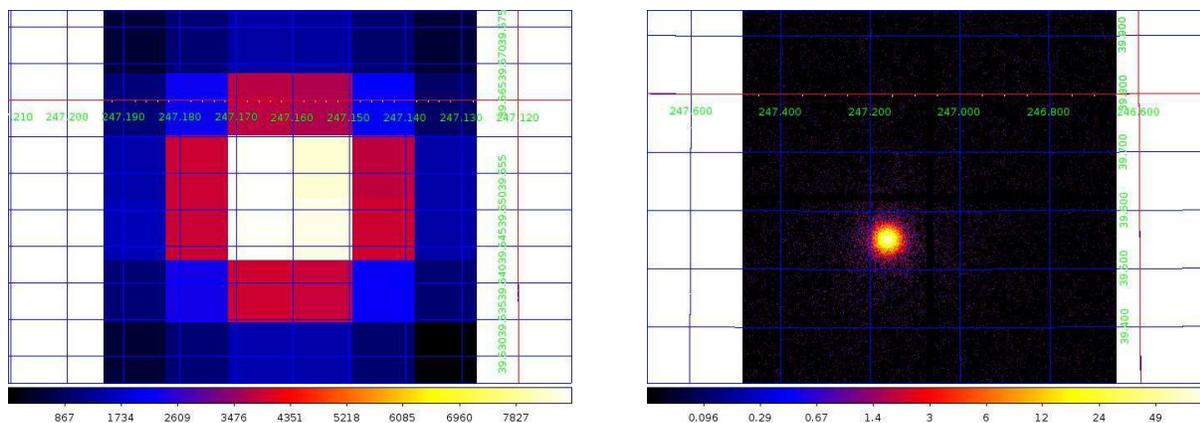


Figure 5.4: Left: Simulated SXS image for the central region of Abell 2199. Right: Simulated SXI image for the central region of Abell 2199.

5.4.5 Analyzing the output data

Run XSELECT and read the SXS/SXI event files.

```
unix%xselect
```

```
...
...
```

```
xsel:SUZAKU > read event AH_SXS_a2199_cen_evt.fits
```

```
> Enter the Event file dir >[./]
```

```
Got new mission: ASTRO-H
```

```
> Reset the mission ? >[yes]
```

```
...
...
```

Extract events from whole region on SXS, and save image and spectrum. The resultant image viewed by ds9 is shown in figure 5.4 left.

```
xsel:ASTRO-H-SXS > extract all
```

```
...
...
```

```
Fits light curve has 94589 counts for 1.892 counts/sec
```

```
Spectrum has 94589 counts for 1.892 counts/sec
```

```
... written the PHA data Extension
```

```
Image has 94589 counts for 1.892 counts/sec
```

```
xsel:ASTRO-H-SXS>save image AH_SXS_a2199_cen_img.fits
```

```
Wrote image to file AH_SXS_a2199_cen_img.fits
```

```

xsel:ASTRO-H-SXS>save spec AH_SXS_a2199_cen_spec.pi
Wrote spectrum to AH_SXS_a2199_cen_spec.pi
xsel:ASTRO-H-SXS>quit
> Save this session? >[no]

```

The spectrum can be viewed and analyzed with `xspec`. For the analysis, it is useful to link the ancillary response files (arf) and non X-ray background (NXB) files to your directory.

```

unix% ln -s /path/to/simx/inputs/Astro-H/response/SXS/
ah_sxs_5ev_basefilt_20100712.rmf .

```

```

unix% ln -s /path/to/simx/inputs/Astro-H/response/SXS/
sxt-s_100208_ts02um_of_intallpxl.arf .

```

```

unix% ln -s /path/to/simx/inputs/Astro-H/bkgnd/SXS/
sxs-bck_20100219_1Gs.pha .

```

(For SXI)

```

unix% ln -s /path/to/simx/inputs/Astro-H/response/SXI/
astroH_sxi_Pch_20110330.rmf .

```

```

unix% ln -s /path/to/simx/inputs/Astro-H/response/SXI/
sxt-i_110426_ts02um_int01.8r.arf .

```

```

unix% ln -s /path/to/simx/inputs/Astro-H/bkgnd/SXI/
ah_sxi_pch_nxb_r1p80_20110511.pi .

```

```

unix% xspec
XSPEC version: 12.7.0g
...
XSPEC12>data 1 spec AH_SXS_a2199_cen_spec.pi
XSPEC12>response 1 ah_sxs_5ev_basefilt_20100712.rmf
XSPEC12>arf 1 sxt-s_100208_ts02um_intallpxl.arf
XSPEC12>backgrnd 1 sxs-bck_20100219_1Gs.pha

```

```

XSPEC12>cpd /xw
XSPEC12>setplot energy
XSPEC12>ignore **-0.3
XSPEC12>ignore *:8.0-**
XSPEC12>setplot rebin 10 50
XSPEC12>plot ldata

```

The resultant spectrum is shown in figure 5.5.

5.4.6 background estimations

For the ICM measurement in lower surface brightness regions of clusters, especially for outer region of clusters, estimations of fore- and background, the Galactic and cosmic X-

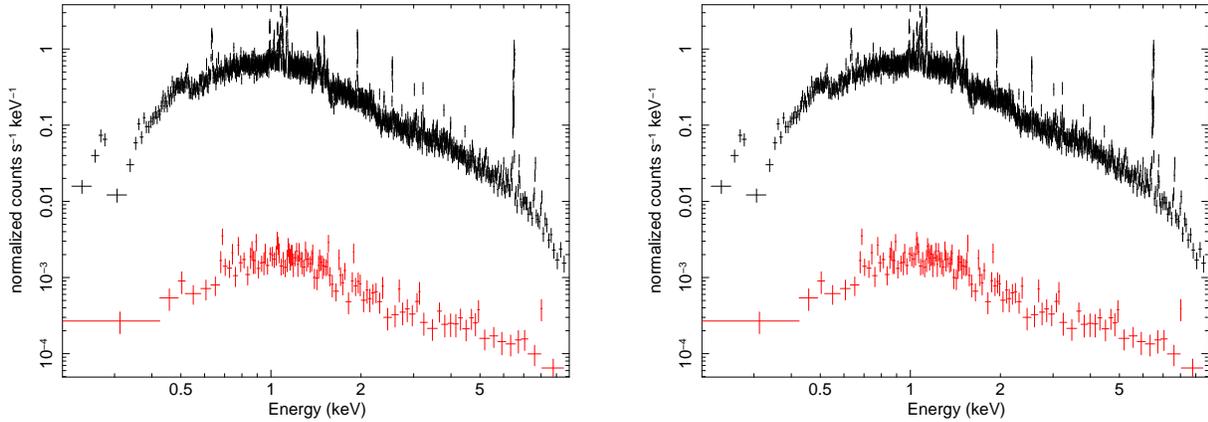


Figure 5.5: Left: Simulated SXS spectra for Abell 2199 center (black) and CXB (red). Right: Simulated SXI spectra for Abell 2199 center (black) and CXB (red).

ray background (CXB), respectively, would be important for the data analysis. Because these components have a flat sky distribution, we have to deal with the components using flat sky response functions.

In this section, we demonstrate how to make the CXB spectrum. We assume parameters of the CXB components as shown in table 5.2 reported in Kushino et al. (2002) (see also Moretti et al. 2009). Note that the CXB intensity has 20% directional fluctuation in the sky, and the Galactic components also have a strong directional dependence. Also note that the values in Kushino et al. (2002) can be used only in a case that point-like sources brighter than $\sim 2 \times 10^{-13}$ erg cm $^{-2}$ s $^{-1}$ in 2–10 keV are subtracted.

Table 5.2: The CXB sample parameters without the Galactic absorption reported in Kushino et al. (2002).

Γ	1.41
Flux	erg cm $^{-2}$ s $^{-1}$ deg $^{-2}$
2–10 keV	1.94×10^{-11}
0–16.4 keV	4.24×10^{-11}
0.2–15.0 keV	3.70×10^{-11}
1–103 keV	1.17×10^{-10}

You can simulate the CXB spectrum using XSPEC or SIMX. In both cases, the first step is a spectrum modeling in XSPEC.

```

unix% xspec
unix% XSPEC version: 12.7.0g
XSPEC12>model phabs*powerlaw
1:phabs:nH>8.92e-3
2:powerlaw:PhoIndex>1.41
3:powerlaw:norm>1
...
XSPEC12>fakeit none
For fake spectrum #1 response file is needed: ah_sxs_5ev_basefilt_20100712.rmf
...and ancillary file:
Use counting statistics in creating fake data? (y):

```

Input optional fake file prefix:

Fake data file name (ah_sxs_5ev_basefilt_20100712.fak): cxb_sxs.fak

Exposure time, correction norm, bkg exposure time (1.00000, 1.00000, 1.00000):

XSPEC12>plot model

XSPEC12>iplot

PLT> wenv cxb_sxs_model

Chapter 6

Tutorial 3: A Point Source with Full PSF Information

6.1 SXI for a monochromatic X-ray source

In this section, we learn how to run SIMX assuming a virtual point-like source with a simple monoenergetic spectrum, but also using the full 2-D point spread function. This requires the at least version 2.1.0 of SIMX. Hereafter, users are assumed to use this version.

Running SIMX

As this is simply a monoenergetic spectrum, the run can be done directly in SIMX. However, you can set the input parameter before SIMX is executed. (This process can be skipped, if you prefer to input the parameters interactively after running SIMX.)

Set the stem of the output event file name.

```
unix%pset simx OutputFileName=AH_SXIPSF_point_2kev  
(The file name will be this with "_evt.fits" appended.)
```

Set the pointing position.

```
unix%pset simx PointingRA = 0.0  
unix%pset simx PointingDec = 0.0
```

Set the exposure (in sec).

```
unix%pset simx Exposure=100000
```

Set the flux (in $\text{erg}/\text{cm}^{-2}/\text{s}$).

```
unix%pset simx SourceFlux=5e-11
```

Set the input image or pointing position. (Here we simulate a point-like source. There are other options, Flat and Image, which will be explained in the next chapter.)

```
unix%pset simx SourceImageType=Point  
unix%pset simx SourcePointRA=0.0  
unix%pset simx SourcePointDec=0.0  
unix%pset simx SourceImageFile=None
```

Set the input spectrum.

```
unix%pset simx SourceSpectrumType=Mono
```

```
unix%pset simx MonoEnergy=2.0
```

Set the mission/instrument/filter names.

```
unix%pset simx MissionName=Astro-H
unix%pset simx InstrumentName= SXIPSF
unix%pset simx FilterName=None
```

Set the linear scaling factor of the background level. The available range is from 0.0 to 10.0. (This option is useful to investigate impact of change in the background level.)

Here we simply use the default background. `unix%pset simx ScaleBkgnd=1.0`

Finally, run SIMX to create an event file `AH_SXI_point_2kev_evt.fits`. Do not forget setup SIMX:

```
unix% source /path/to/simx/bin/simx-setup.csh (for CSH version)
unix% ./path/to/simx/bin/simx-setup.csh (for BASH version)
```

```
unix%simx
*****
*** simx version 2.1.0 ***
*****
Output Event file stem[AH_SXIPSF_point_2kev]
Pointing right ascension (decimal degrees)[0.0]
Pointing declination (decimal degrees)[0.0]
Exposure time (seconds)[100000]
Source Flux in erg/cm2/s[5e-11]
Source Image Type (Point|Flat|Image) [Point]
Source right ascension (decimal degrees)[0.0]
Source declination (decimal degrees)[0.0]
Source Image File[None]
Source Spectrum Type (XSPEC_File|Sherpa_File|Mono) [Mono]
Energy (in keV) if monoenergetic[2.0]
Initial Random Seed; use -1 to generate internally[0]
Mission Name[Astro-H]
Instrument Name[SXI]
Filter Name[None]
Linear scaling factor for testing background sensitivity (0.1:10.0) [1.0]
...
...
...
initialize: Approximate # of source counts : 742246
generate_events: Progress: |.....|
read_PSF_image: Number of PSF image in file: 1
read_PSF_image: Reading HDU 1
...
generate_events: Adding background events: 111093
generate_events: Actual number of events : 848814
...
...

```

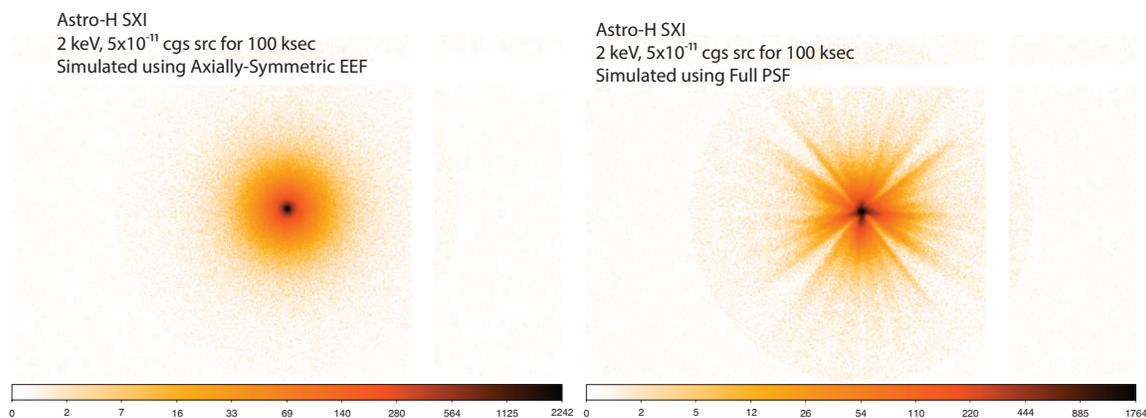


Figure 6.1: Left: Simulated SXI image using the simple EEF model. Right: Same, using the full 2-D PSF approach.

```
generate_events: Vignetted or otherwise lost events: 4525
generate_events: Pileup calculation not available for this detector
```

Next, redo this using the base SXI rather than the SXIPSF model. The only change is

```
Output Event file stem[AH_SXI_point_2kev]
unix%pset simx InstrumentName=SXI
```

The immediate output should be similar, with just a few differences:

```
t initialize: Approximate # of source counts : 742246
... generate_events: Adding background events: 110397
generate_events: Actual number of events : 849294
...
generate_events: Vignetted or otherwise lost events: 3349
```

The only differences between these two simulations is the PSF choice. They can be analyzed with XSELECT using the same approach as any other SIMX data. Figure ?? shows the differences between the two simulated datasets.

The spectrum can be viewed and analyzed using `xspec`. As mentioned in Section 1, *SIMX is not an ARF generator*. Therefore ideally, something like `xissimarfgen` should be used to create an ARF file for each specific case. However, some representative ARF files are already provided by the instrument team¹, and SIMX contains them in the `inputs` directory.

¹<http://www.astro.isas.jaxa.jp/next/astroh-sct/wiki/>

Chapter 7

Brief Overview of “SIMX” Calculations

SIMX is designed to simulate an X-ray observatory or, more generally, any event-counting detector and optics combination. The emphasis of the code is on a quick but useful calculation, with enough fidelity to assist potential observers evaluating the impact of statistical fluctuations, calibration uncertainties, blurring due to mirror PSF, or other related variables. However, SIMX is not designed to model aspects of a mission studied by engineers or instrumentalists – for example simulating an optics system via a full ray-trace or modeling the full electronics involved in a detector system.

This chapter provides a brief overview of how the code works, as an aid to those who might want or need to enhance SIMX. It is not intended for users, except those users interested in how SIMX works “under the hood.” It should first be noted that SIMX is based on an earlier code, `quicksim`, written by Steve Snowden in Fortran-90 to simulate XMM-Newton observations. SIMX is a complete re-write in C, done in a manner that enables easy reconfiguration to simulate arbitrary missions, so there are many differences in practice between SIMX and `quicksim`. However, `quicksim` does have some features not present in SIMX, such as built-in modeling of many more sources than the three types supported by SIMX (point, flat, and image). Stubs of these features still exist in places in the code (for example in `initialize.c`) in case someone is interested in adding more features.

7.1 Code Overview

The primary code used by SIMX is in the `src/` directory. The `libsrc/` directory includes off-the-shelf libraries used by SIMX, such as `cfitsio` (the HEASARC standard library for reading and writing FITS files) and `ape` (the HEASARC standard library for reading parameter, or `.par`, files). As of this writing, SIMX uses CFITSIO version 3.03 and `ape` version 2.1.1 by default, although more recent versions would likely work.

In the `src/` directory, the primary code loop is in the `simx.c` file, which calls, in this order, the following four routines:

`get_input_data` Uses `ape` to read the `simx.par` inputs as well as the mission database file `xselect.mdb`

`initialize` Reads the mission & detector response, PSF, and other calibration files as well as any input spectral files and source images. SIMX also pre-calculates the effective-area-weighted spectrum of the source at this step.

generate_events Uses the source information and weighted spectrum as generators for a Monte Carlo creation of input photons. These are then distributed on the detector according to the PSF (in position) and RMF (in energy channel). Vignetting and any impact from missing or inactive pixels is then applied as well by eliminating some photons. By default, all detectors in SIMX are assumed to be rectangular; the impact of a mask or of ccd boundaries can be applied here. This is done in a hard-coded fashion, based on the mission and detector names¹ Background events are then generated as well; these are always assumed to be distributed randomly over the field of view. Note that SIMX assumes that ‘background events’ are all from a non-x-ray background; any cosmic X-ray background can be modeled by the user as an separate term. Finally, the event list is processed to determine any pileup effects

fits_output This code shows the most significant heritage from quicksim, and consists of a number of straightforward cfitsio calls that generate an OGIP-complied EVENT file.

7.2 Data Structures Overview

SIMX contains a few data structures, with some set up as linked lists. These structures are described in `simx.h`, and include the following:

Event_Type A linked list of events, including information such as the event time, position, and energy and whether or not the event was generated from the source or the background. This list is created during the call to `generate_events`.

Response_Type A complex structure designed to store the data from both RMF and ARF files. The RMF file format, in particular, is quite involved and the reader is directed to the OGIP standards for more information about them.

Source_Type The source spectrum, position, and (if needed) image information.

PSF_EEF_Type A linked list that contains PSF EEF data

PSF_IMAGE_Type A linked list that contains PSF image data, in the case where the PSF is provided as a series of images at different energies and on- or off-axis positions.

Vig_Type A linked list that contains vignetting information

PARAMETERS A catch-all structure that contains all the values read during the `get_input_data` and `initialize` calls.

In addition to these structures, there is also an **Xselect_Entry** linked list structure stored in the `xselect_mdb.h` file. This structure holds the information in the `xselect_mdb` file, and is used by the `xselect_mdb.c` file. The code for this aspect of SIMX was kept separate from the main code because it was potentially useful to other codes (specifically, `xselect`), and so was not integrated into SIMX more tightly. The author does not know if this code is being used, but it has been offered to the `xselect` developers.

¹This is the only place in the code where mission or detector information is hard-coded, and the code would be improved if this information could be removed from the code itself and put into an input file.

Chapter 8

Remarks

Important notes

(1) In order to analyze SIMX output event files with `xselect`, you need to use the specially-modified version of `xselect.mdb`. Do not forget set the following environment variable:

```
unix% setenv XSELECT_MDB /path/to/simx/inputs/xselect.mdb  (csh)
unix% export XSELECT_MDB=/path/to/simx/inputs/xselect.mdb  (bash)
```

(2) To derive an appropriate simulation result, the input spectrum should have smaller energy bin size than that of the detector's RMF used in the SIMX running.

(3) SIMX read only the shape of the spectrum from the input qdp data, while the flux is set by the command directly. In other words, SIMX always removes any normalization present in the input spectrum file, and renormalize using the requested total flux.

(4) SIMX does not have an option to limit the range of the flux input, but assumes the flux given as input matches the spectrum file. This means if the input spectrum covers 0.1–12.0 keV, the flux value is assumed to cover that range as well.

(5) The output from SIMX does not include any CXB component, which should be created by users separately. See chapter 5 for details.

Current limitation that users should notice

(1) The NXB data of the SXS and SXI do not include fluorescence-line components.

(2) SIMX includes only the on-axis PSF information, except in one case, the SXSPSF option where there is some off-axis PSF image data available. However, in all other cases the on-axis PSF will be used even if you simulate an off-axis source. In addition, unless the SXIPSF or SXSPSF instruments are used, the PSF shape is simply given with a 1-dimensional profile.

(3) The correct vignetting profile for the SXI is available only in the $r < 20$ arcmin region. If the source image is larger than this, you will see a warning.

(4) The SXI pile-up estimation is not available currently.

(5) Stray lights from out of the FoV cannot be estimated.

(6) Out-of-time events cannot be estimated.