# XRISM simulations using heasim

## (1) Where and how to retrieve files and docs

The README, responses and other supporting files, and additional guiding documents are available from

https://heasarc.gsfc.nasa.gov/FTP/xrism/prelaunch/simulation/sim3/

## (2) Spectral Simulations

This suite of available files (in specfiles_v003.tar.gz) is sufficient to assess feasibility (for a given exposure time) of meeting the spectral goals of most prospective XRISM targets (see README_XRISM_SPECFILES_v003.txt for details). The files are in-flight hitomi sxs (renamed to “resolve”) response and non-X-ray background (NXB) files, as well as pre-flight hitomi sxi (renamed to “xtend”) response and background files. The NXB is negligible for bright point sources.

Spectral simulations may be conducted in the standard way, e.g. XSPEC/fakeit (see Section B.1 of heasim_20170825.pdf, available at the website mentioned above). The table below lists and describes the available files.

The (normalized) Resolve response matrix files (RMF) include only the Gaussian core of the line spread function (LSF) and are provided for four different values of the FWHM – as are the corresponding Resolve NXB spectra. Provisionally, the 5 and 6 (7 and 8) eV files correspond to high- and mid-resolution events in the nominal (requirement-satisfying) case. The Resolve effective area (ARF) files include the quantum efficiency and the dewar filter stack optical blocking filter transmission. They range over energies 0.11-25 keV and include gate-valve open ("noGV") and closed ("withGV") versions. Note that the above ARFs were made with the new gate valve model (the CalDB file for which is to be included in the XRISM CalDB release). The gate valve for XRISM has a different structure compared to the Hitomi one, which impacts the effective area. In addition to these Filter Wheel Open files, ARFs for Beryllium filter ("BeFw") and Neutral density ("ND") filter selections are provided (the gate valve is assumed open in these cases). Resolve NXB spectra are based on Hitomi pre-launch estimates with the addition of MnK-alpha and K-beta features with fluxes estimated by the instrument team. These are consistent with in-flight Hitomi SXS NXB spectra derived using the "sxsnxbgen' ftool. The Resolve NXB, at ~0.01 ct/s over the Resolve array, is negligible in most cases of interest.

The Hitomi (Astro-H) pre-launch Xtend ARF, RMF,and  NXB spectral files were derived using a 1.8 arcminute radius circular extraction region. The NXB spectrum for the entire FoV ("full") is also included.

| FILE | NOTE |
|---|---|

| | |
|---|---|
| **Resolve** | |
| resolve_h5ev_2019a.rmf | High resolution, nominal |
| resolve_m6ev_2019a.rmf | Mid resolution, nominal |
| resolve_h7ev_2019a.rmf | High resolution, required |
| resolve_m8ev_2019a.rmf | Mid resolution, required |
| resolve_pnt_spec_noGV_20190701.arf | On-axis point source, gatevalve open |
| resolve_pnt_spec_withGV_20190701.arf | On-axis point source, gatevalve closed |
| resolve_bet_spec_noGV_20190611.arf | 5.7 arcmin radius beta-model, beta=0.57, 1.26 arcmin core centered on-axis, gatevalve open |
| resolve_bet_spec_withGV_20190611.arf | 5.7 arcmin radius beta-model, beta=0.57, 1.26 arcmin core centered on-axis, gatevalve closed |
| resolve_flt_spec_noGV_20190611.arf | 5 arcmin radius uniform circle centered on-axis, gatevalve open |
| resolve_flt_spec_withGV_20190611.arf | 5 arcmin radius uniform circle centered on-axis, gatevalve closed |
| resolve_pnt_spec_BeFw_20190701.arf | On-axis point source, Be filter |
| resolve_pnt_spec_ND_20190701.arf | On-axis point source, Neutral Density filter |
| resolve_h5ev_2019a_rslnxb.pha | Use with resolve_h5ev_2019a.rmf |
| resolve_m6ev_2019a_rslnxb.pha | Use with resolve_m6ev_2019a.rmf |
| resolve_h7ev_2019a_rslnxb.pha | Use with resolve_h7ev_2019a.rmf |
| resolve_m8ev_2019a_rslnxb.pha | Use with resolve_m8ev_2019a.rmf |
| **Xtend** | |
| ah_sxi_20120702.rmf | SXI pre-launch |
| sxt-i_140505_ts02um_int01.8r.arf | 1.8 arcminute radius circular extraction region |
| ah_sxi_pch_nxb_r1p80_20110530.pi | Use with sxt-i_140505_ts02um_int01.8r.arf |
| ah_sxi_pch_nxb_full_20110530.pi | Full field-of-view |

As a rule of thumb, even for an extended source, the point source arf should be good to ~25% in converting flux from a small (<array) region to a count rate. Do a full simulation (see below) for somewhat more accurate treatment of off-axis and extended sources.

## (3) Simulating the Perseus Cluster with Heasim – A Worked Example

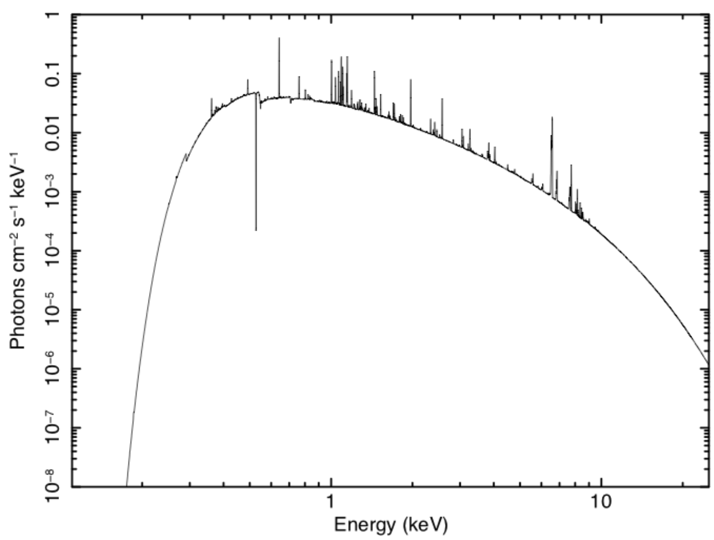
In order to run heasim, HEASoft needs to be installed and initialized. The Hitomi CalDB must also be installed and initialized if one wishes to assign pixels and grades to heasim event files using the sxsbranch ftool (see below).

### (a) Make Xspec qdp model files representing the spectrum of each spatial component

Absorbed thermal (ICM) component model "perseus_icm_abs_mod.xcm" –

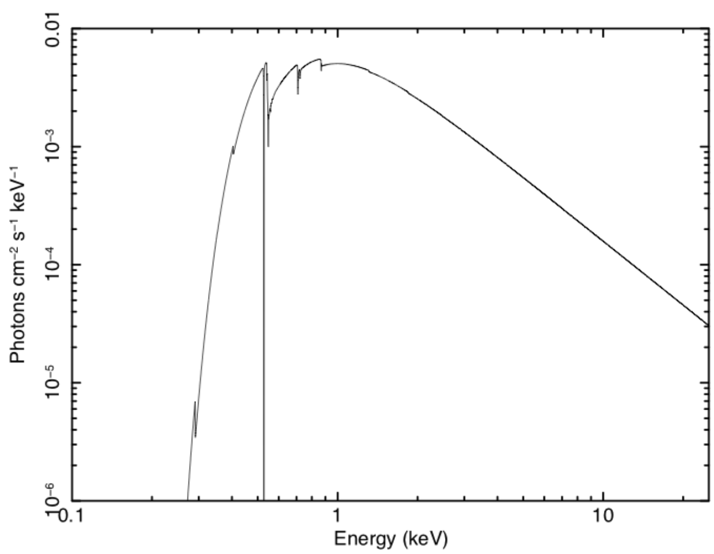
```
XSPEC12>@perseus_icm_abs_mod.xcm
XSPEC12>data none
XSPEC12>energ 0.1 27.1 27000
XSPEC12>cpd /xs
```

XSPEC12>setplot comm wdata perseus_icm_abs_mod.qdp
XSPEC12>plot model




Absorbed non-thermal (AGN) component model “perseus_brtptsrc_mod.xcm” –

XSPEC12>@perseus_brtptsrc_mod.xcm
XSPEC12>data none
XSPEC12>energ 0.1 27.1 27000
XSPEC12>cpd /xs
XSPEC12>setplot comm wdata perseus_brtptsrc_mod.qdp
XSPEC12>plot model




Tips –

- Set the energy range in the Xspec *energ* command to span the instrument bandpass.
- Set the energy bin size in the Xspec *energ* command to be smaller than the instrument resolution.
- Properly normalize the model so that it yields the correct flux over the extent of the spatial model (see below).
- Combine all components with the same spatial distribution into one spectral model, if possible.

## (b) Create the source definition file

Heasim requires a source definition file ("sdf") as input to specify the source position in the sky, and source characteristics (consult heasim_20170825.pdf for additional details, and other examples such as off-axis / multiple point sources). Each line represents a single source, or single component of a multi-component source. The comma-separated elements of the sdf are as follows:

RA,DEC,NH,spectrum,flux,bandpass,specfile,specunits,specformat,source_specifications

For our Perseus simulation, the sdf representing the extended thermal, and point-like non-thermal, components is as follows:

```
perseus_betaicm_brptsrc.dat ==
49.95,41.51,0.0,user,0.,0.,0.-0.,perseus_icm_abs_mod.qdp,2,2,extmod(beta,0.53,1.26,1.0,0.0,0.0,5.7)
49.95,41.51,0.0,user,0.,0.,0.-0.,perseus_brtptsrc_mod.qdp,2,2
```

| | |
|---|---|
| RA,DEC | Source coordinates. |
| NH | Column density: set to 0 if absorption is included in the input spectrum. |
| spectrum | Set to "user" if using input spectrum. |
| flux | Source flux in erg/sec/cm2: set to 0 if using an input spectrum (flux will be calculated from that). |
| bandpass | Bandpass within which flux is calculated: set to 0.0-0.0 if using an input spectrum. |
| specfile | File name of input spectrum (qdp) file name: see guide for other formats. |
| specunits | 2 for specfile derived as shown: see guide for other options tied to specfile. |
| specformat | 2 for specfile derived as shown: see guide for other options tied to specfile. |
| source_specifications | Extended spatial distribution, or time variation, specifier (if any). Here, a beta=0.53, core radius =1.26 arcmin beta-model extending to 5.7 arcmin is adopted for the Perseus ICM. The specified flux corresponds to this distribution. |

## (c) Simulation setup

The heasim support files may be installed as follows:

1) Download and unpack support files heasimfiles_20201012.tar.gz, placing them in some directory <heasimfilesdir>
2) Set the HEASIM_SUPPORT environment variable:

setenv HEASIM_SUPPORT <heasimfilesdir> (C-shell) or
export HEASIM_SUPPORT=<heasimfilesdir> (Bash)

## (d) Run the simulation

The heasim command to run the Perseus Cluster simulation (200 ks exposure) is given below. Since the pointing RA and DEC are the same as those for the source, an on-axis simulation is conducted. For point sources, the vignetting function may be ignored ("vigfile=none"). As mentioned above, the NXB may be neglected in most cases ("intbackfile=none"), but is included here for demonstration purposes. Note that the input ARF file is not the same as that used for spectral simulations, since heasim must account for photons originating outside of the field-of-view. In the simulation below, the psffile is specified as an eef and thus results in an axisymmetric X-ray distribution. The image file sxs_psfimage_20140618.fits may instead be used to include the effects of PSF asymmetries.

```
heasim mission=hitomi instrume=sxs rapoint=49.95 decpoint=41.51 roll=0.00 exposure=200000.
insrcdeffile=perseus_betaicm_brptsrc.dat outfile=perseus_betaicm_brptsrc.fits
psffile=$HEASIM_SUPPORT/xrism/resolve/psf/eef_from_sxs_psfimage_20140618.fits
vigfile=$HEASIM_SUPPORT/xrism/resolve/vignette/SXT_VIG_140618.txt
rmffile=$HEASIM_SUPPORT/xrism/resolve/response/resolve_h5ev_2019a.rmf
arffile=$HEASIM_SUPPORT/xrism/resolve/response/resolve_pnt_heasim_noGV_20190701.arf
intbackfile=$HEASIM_SUPPORT/xrism/resolve/background/resolve_h5ev_2019a_rslnxb.pha
flagsubex=no seed=1234567890 clobber=yes
```

## (e) Extract and analyze the Resolve spectrum

1) Set the XSELECT_MDB environment variable to run xselect on your output:

   setenv XSELECT_MDB $HEASIM_SUPPORT/xrism/auxiliary/xselect.mdb.heasim (C-shell) or
   export XSELECT_MDB=$HEASIM_SUPPORT/xrism/auxiliary/xselect.mdb.heasim (Bash)

2) Extract the spectrum from the heasim output file using xselect:

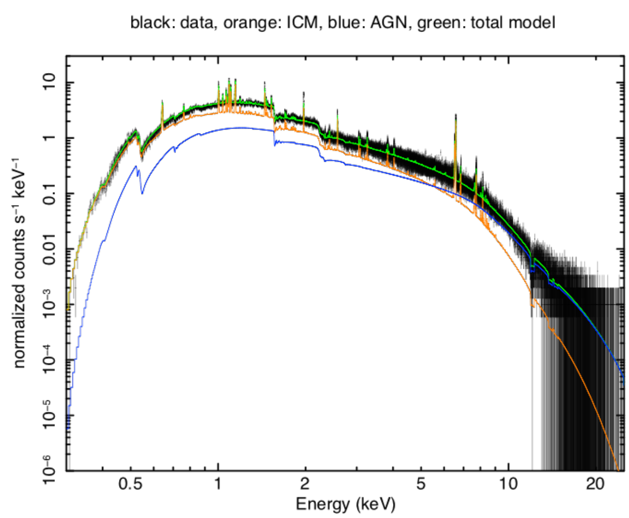
```
xsel:HITOMI-SXS-PX_NORMAL > read events perseus_betaicm_brptsrc.fits
xsel:HITOMI-SXS-PX_NORMAL > extract spectrum
xsel:HITOMI-SXS-PX_NORMAL > save spectrum perseus_betaicm_brptsrc.pi
```

3) Analyze the spectrum.

```
XSPEC12>data 1:1 perseus_betaicm_brptsrc.pi
XSPEC12>response  1:1 resolve_h5ev_2019a.rmf
XSPEC12>response  2:1 resolve_h5ev_2019a.rmf
XSPEC12>arf 1:1 resolve_bet_spec_noGV_20190611.arf
XSPEC12>arf 2:1 resolve_pnt_spec_noGV_20190701.arf
```

XSPEC12>model  TBabs*bvvapec
XSPEC12>... specify params
XSPEC12>model  2:agn constant*TBabs*powerlaw
XSPEC12>... specify params
XSPEC12>... fit, derive errors, etc.

The above spectrum is compared to its generating model, and its components, below. Note that different ARFs from that used as heasim input are applied in spectral fitting. The extended source ARF, resolve_bet_spec_noGV_20190611.arf, is exclusively appropriate to the simulation at hand. More generally, one may use the point source ARF for both components to recover the spectral parameters and uncertainties, however the flux of the extended component will not be correct (expert users may generate the appropriate extended source ARF to recover input flux).



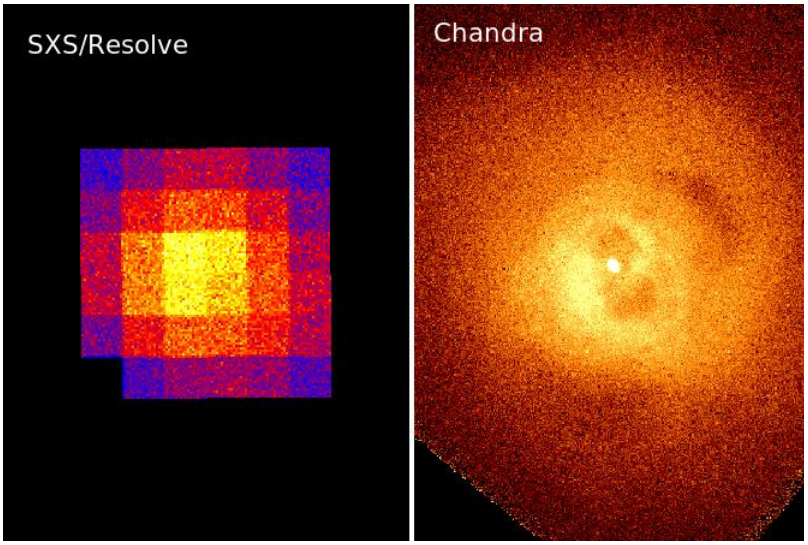

# (4) Simulating The Perseus Cluster with heasim – variations

## (a) Use an input image, rather than a spatial model

In this case the source definition file is

insrcdeffile=perseus_imageicm.dat ==
49.95,41.51,0.0,user,0.,0.,0.-0.,perseus_icm_abs_mod.qdp,2,2,image(acis_chip0_band1_norm.img,0,0,0,0)

and, otherwise, the command may be issued as before. The output and input images are shown below.

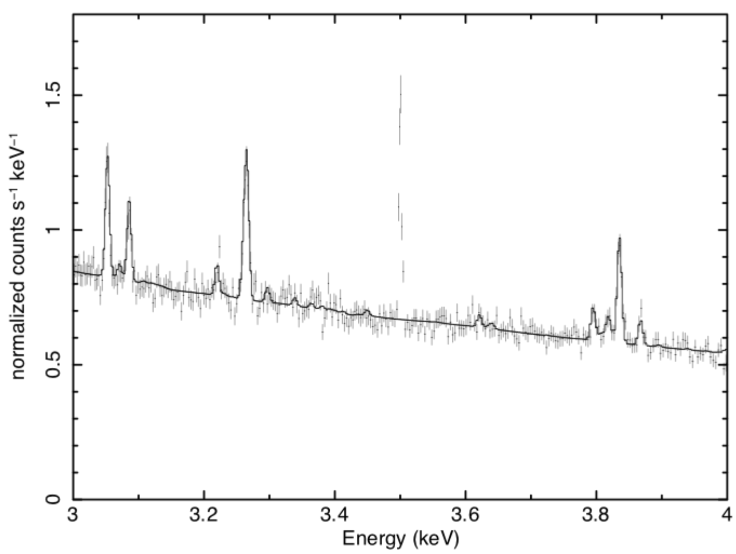



## (b) Include an additional component - in this case a narrow 3.5 keV emission line

In this case the source definition file is

insrcdeffile=perseus_betaicm_brptsrc_line.dat ==
49.95,41.51,0.0,user,0.,0.,0.-0.,perseus_icm_abs_mod.qdp,2,2,extmod(beta,0.53,1.26,1.0,0.0,0.0,5.7)
49.95,41.51,0.0,user,0.,0.,0.-0.,perseus_brtptsrc_mod.qdp,2,2
49.95,41.51,0.0,mono,3.5,1.0e-13,2.5-4.5,none,2,2,extmod(beta,0.66,0.1,1.0,0.0,0.0,5.7)

and, otherwise, the command may be issued as before. The spectrum and original (without the extra line) model are shown below. The "mono" model corresponds to a zero-width gaussian line; for finite width use user model.




## (c) Simulate a source observed using one of the filter wheel filters

For the Be filter that preferentially reduces the low energy through, set

arffile=$HEASIM_SUPPORT/xrism/resolve/response/resolve_pnt_heasim_BeFw_20190701.arf

and, otherwise, issue the command as before. In analyzing the spectrum extracted from the simulated event file, use resolve_pnt_spec_BeFw_20190701.arf.

Similarly, for the neutral density filter, set

arffile=$HEASIM_SUPPORT/xrism/resolve/response/resolve_pnt_heasim_ND_20190701.arf

and, otherwise, issue the command as before. In analyzing the spectrum extracted from the simulated event file, use resolve_pnt_spec_ND_20190701.arf.

### (d) Filter the simulated event file on, e.g., pixel or resolution grade

For the highest quality spectroscopy, only Resolve high- and mid-resolution grade events are most useful. The sxsbranch ftool calculates the grade branching ratios for each pixel, and over the entire array, and creates an enhanced simulation event file with PIXEL and IYTPE (grade; ITYPE = 0:HP, 1:MP, 2:MS, 3:LP, 4:LS) columns. As a rule of thumb, one ought to check the branching ration is cases where the count rate per pixel exceeds 1 ct/sec/pixel. An example or the sxsbranch command is

```
sxsbranch infile=perseus_betaicm_brptsrc.fits filetype=sim sxsbranch
infile=perseus_betaicm_brptsrc.fits filetype=sim
outfile=perseus_betaicm_brptsrc_branch.out
pixfrac=$HEASIM_SUPPORT/xrism/resolve/sxsbranch/pixfrac.txt pixmask=none
ctelpixfile=$HEASIM_SUPPORT/xrism/resolve/sxsbranch/pixmap.fits ctphafrac1=0.0
ctphafrac2=0.0 dtprimary=70.72 dtmidhigh=70.72 dtlowmid=18.32
```

An example of the subsequent xselect commands that selects only HP events in one corner of the array is

```
xsel:HITOMI-SXS-PX_NORMAL > read events perseus_betaicm_brptsrc.fits.out
xsel:HITOMI-SXS-PX_NORMAL > filter column "PIXEL=27:35"
xsel:HITOMI-SXS-PX_NORMAL > filter GRADE 0-0
xsel:HITOMI-SXS-PX_NORMAL > extract spectrum
xsel:HITOMI-SXS-PX_NORMAL > save spectrum perseus_betaicm_brptsrc_HPsub.pi
```

Please see Section 4 of the Hitomi Coordinate Definition CalDB document

https://heasarc.gsfc.nasa.gov/docs/hitomi/calib/caldb_doc/astroh_sct_020_20170925.pdf

for the SXS (Resolve) detector array pixel map.

### (e) Extract the branching ratios, and rates, from the header keywords

fkeyprint "perseus_betaicm_brptsrc_branch.out[BRANCHCALC]" BRANCHHP
…
BRANCHHP=    0.956693713669771 / Good events fraction grade HP

fkeyprint "perseus_betaicm_brptsrc_branch.out[BRANCHCALC]" BRANCHMP
…
BRANCHMP=   0.0157619813996684 / Good events fraction grade MP

fkeyprint "perseus_betaicm_brptsrc_branch.out[BRANCHCALC]" BRANCHMS
… (note typo)
BRANCHMS=   0.0161088494238448 / Good events fraction grade LP

fkeyprint "perseus_betaicm_brptsrc_branch.out[BRANCHCALC]" BRANCHLP
… (note typo)
BRANCHLP=  0.00557972649642782 / Good events fraction grade MS

fkeyprint "perseus_betaicm_brptsrc_branch.out[BRANCHCALC]" BRANCHLS
…
BRANCHLS=  0.00585572901028855 / Good events fraction grade LS

fkeyprint "perseus_betaicm_brptsrc_branch.out[BRANCHCALC]" RATEHP
…
RATEHP  =             7.695075 / Good events rate grade HP

fkeyprint "perseus_betaicm_brptsrc_branch.out[BRANCHCALC]" RATEMP
…
RATEMP  =              0.12678 / Good events rate grade MP

fkeyprint "perseus_betaicm_brptsrc_branch.out[BRANCHCALC]" RATEMS
…
RATEMS  =              0.12957 / Good events rate grade MS

fkeyprint "perseus_betaicm_brptsrc_branch.out[BRANCHCALC]" RATELP
…
RATELP  =              0.04488 / Good events rate grade LP

fkeyprint "perseus_betaicm_brptsrc_branch.out[BRANCHCALC]" RATELS
…
RATELS  =               0.0471 / Good events rate grade LS

Note that the BRANCHCALC extension tabulates the branching ratios in the input event file, while the BRANCHEST extension tabulates estimates based on the distribution in the file specified by the pixfrac file for comparison (generally most useful when the input file is based on an actual observation rather than a simulation).

## (5) Xtend simulations

An example of an Xtend simulation of the Perseus Cluster corresponding to the worked example described above is

```
heasim mission=hitomi instrume=sxi rapoint=49.95 decpoint=41.51 roll=0.00 exposure=200000.
insrcdeffile=perseus_betaicm_brptsrc.dat outfile=perseus_betaicm_brptsrc_xtd.fits
psffile=$HEASIM_SUPPORT/xrism/xtend/psf/eef_from_sxi_psfimage_20140618.fits
vigfile=$HEASIM_SUPPORT/xrism/xtend/vignette/SXT_VIG_140618.txt
rmffile=$HEASIM_SUPPORT/xrism/xtend/response/ah_sxi_20120702.rmf
arffile=$HEASIM_SUPPORT/xrism/xtend/response/sxt-i_140505_ts02um_int01.8r_intall_140618psf.arf
intbackfile=$HEASIM_SUPPORT/xrism/xtend/background/ah_sxi_pch_nxb_full_20110530.pi
flagsubex=no seed=1234567890 clobber=yes
```

The spectrum may be extracted using xselect as previously described, and should be fit using the sxt-i_140505_ts02um_int01.8r.arf ARF file, and the ah_sxi_pch_nxb_r1p80_20110530.pi NXB file.

## (6) Final Remarks - DOs, DON'Ts and Takeaways

- For isolated point sources, a spectral simulation may be sufficient – but DO run sxsbranch if the source is bright.
- DO use Xspec to create input spectra for your simulation.
- DO take advantage of the multi-component source capabilities of heasim and Xspec.
- For Resolve, one DOESN'T need the source to extend beyond ~6 arcmin.
- DO use the point source ARF with vignetting for extended sources to get the most accurate count rate. But...
- DO be mindful of norms for extended sources (must use the correct ARF in Xspec to get a precisely correct flux).
- For Resolve, the NXB is negligible in most cases.
- Please consult the more complete guides for more detailed information.
- DO direct all questions, concerns, requests, etc. to XRISM-SDC-help@lists.nasa.gov.