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Make your XRISM feasibility study with heasim

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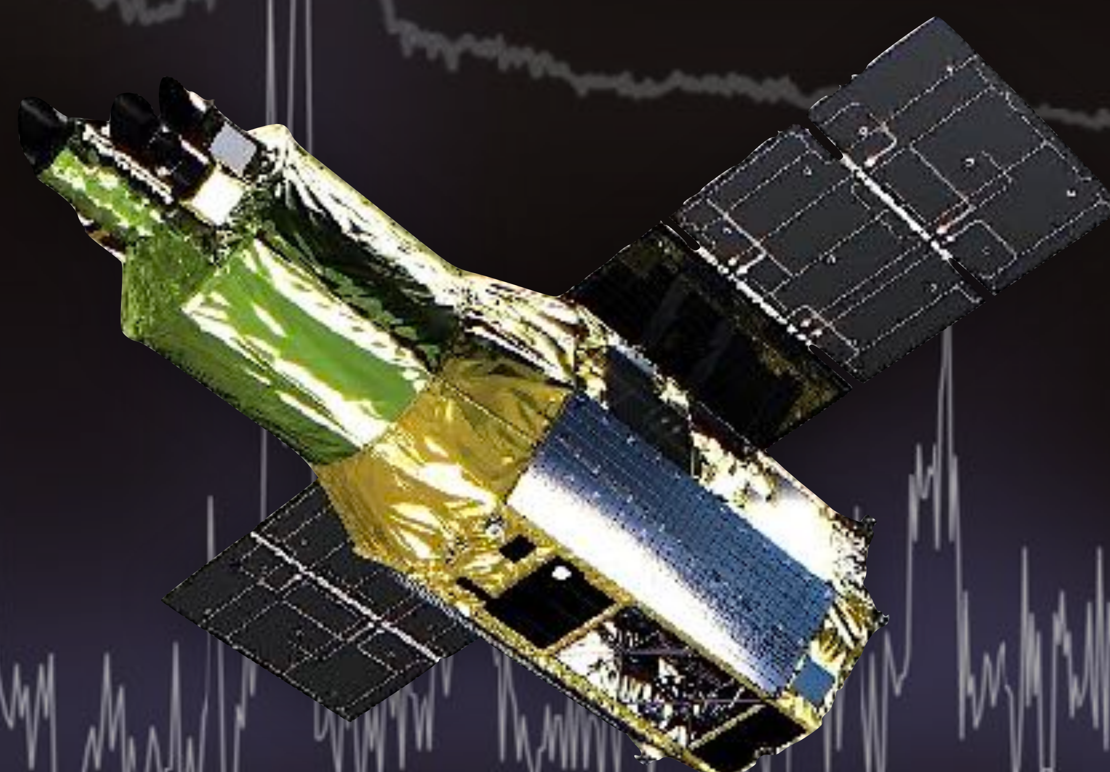


What this tutorial will cover

OUR AWESOME XRISM PROPOSAL

Abstract

This is our abstract for our awesome XRISM GO Cycle 1 proposal. Don't you think it is awesome? Personally we do. Please give us 5 Ms on my favorite source, it's worth it we promise!

1 Introduction

The science we are doing is awesome. However there are many open questions that only XRISM will be able to answer. Which is why we need XRISM data.

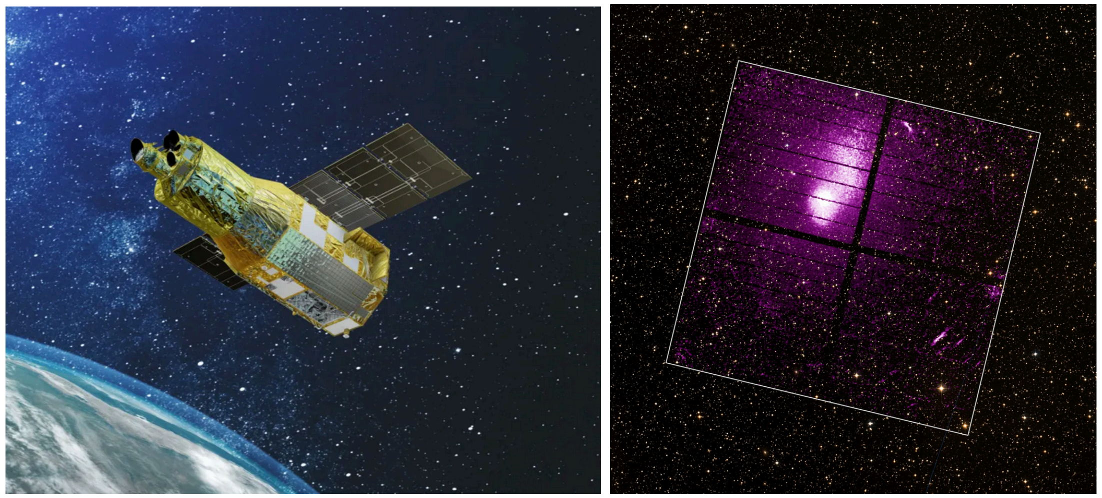


Figure 1: *Left:* This is an artistic representation of XRISM. Beautiful, isn't it? *Right:* This is the Xtend pointing as revealed publicly on Jan 5, 2024. What a fantastic dataset!

2 Scientific objectives

The science goals we propose are the following:

1. We will measure some subtle things with XRISM (spectral features with Resolve and cover a wide field of view with Xtend).
2. This will allow us to revolutionize our field of research.
3. Eventually, the proposed research will allow us to get the Nobel Prize next year. All this thanks to XRISM!

The unique capabilities of XRISM (through the exquisite spectral resolution of Resolve and the very large field of view of Xtend) are absolutely essential to fulfill our scientific goals.

3 Technical feasibility

???

What this tutorial will cover

✓ Advanced feasibility study for XRISM proposals

✓ Using **HEAsim** for Resolve simulations

✓ (Largely) based on Mike's tutorial from the 1st XRISM Community Workshop (2023) and identical to the heasim tutorial from last year's workshop

Software & support files

What you need for XRISM simulations

1. Software
   - ✓ **heasim** -- simulate an event file
   - ✓ **skyback** -- simulate sky X-ray background
   - ✓ **sxsbranch** -- calculate the spectrometer branching ratio
   - ✓ **Xspec** -- for spectra simulation
   - ✓ **Xselect** -- extract spectra from event file

   Included in HEASoft

2. CalDB
   - ✓ 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)

3. Support files (included in HEASARC)
   - ✓ https://heasarc.gsfc.nasa.gov/FTP/xrism/prelaunch/simulation/sim3/
   - ✓ (aka /FTP/xrism/prelaunch/simulation/sim3 in, e.g., SciServer)

4. Documentation (and links to support file direct downloads)
   - ✓ https://heasarc.gsfc.nasa.gov/docs/xrism/proposals/index.html

Spectral simulations: The basics

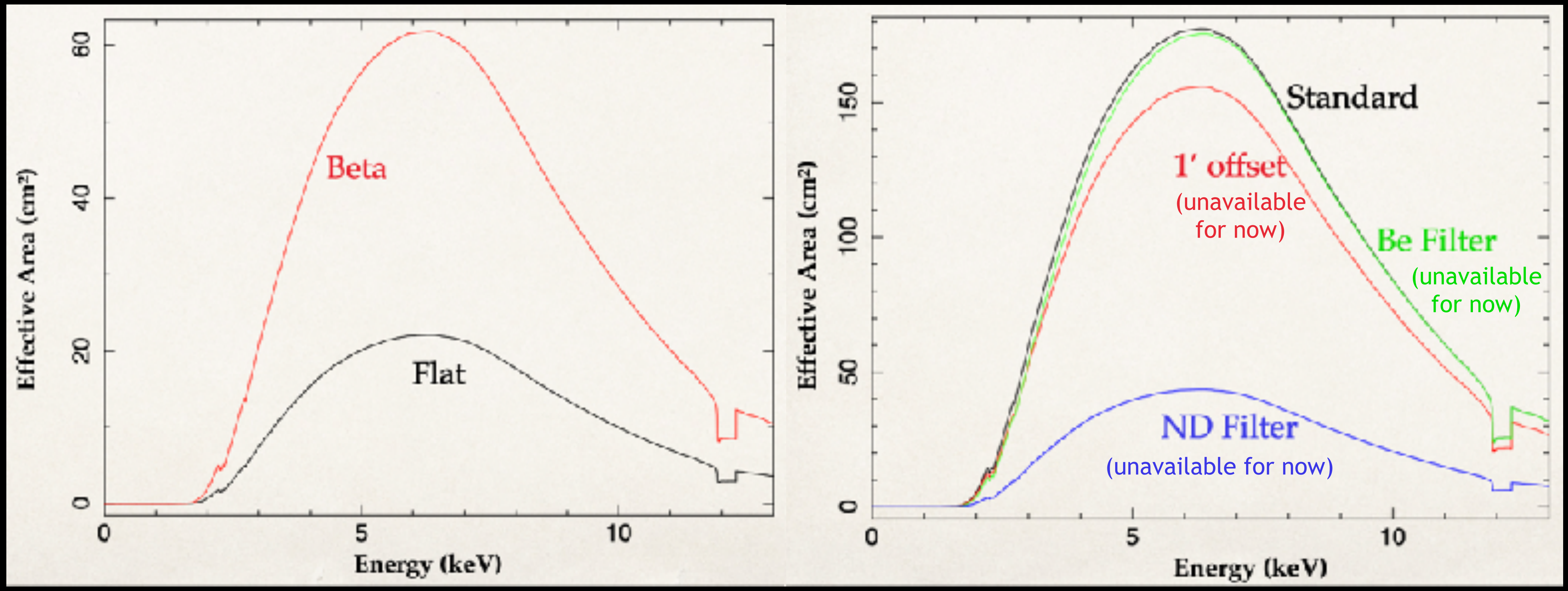
This suite of files (in `specfiles_v003.tar.gz`) is sufficient to assess feasibility (for a given exposure time) of meeting the spectral goals of many prospective XRISM targets.

- ✓ The files are (renamed) in-flight Hitomi response files. Update to XRISM response files soon!
- ✓ Spectral simulations may be conducted in the usual way, e.g. Xspec / fakeit.
- ✓ The normalized RMF files include only the Gaussian core of the line spread function (LSF), for 4 (constant) values of FWHM (see table below).

Spectral simulations: Effective areas (ARFs)

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 (made with the new gate valve model). GO users should only to use the latter (for now…).
- ✓ In addition to these Filter Wheel Open files, ARFs for Beryllium filter (“BeFw”) and Neutral density (“ND”) filter selections are provided… but for GV open only! GO users should **not** use them (for now…)



Spectral simulations: Non-X-ray Background (NXB)

- ✓ 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. Update to XRISM NXB files soon!
- ✓ These are consistent with in-flight Hitomi SXS NXB spectra derived using the `sxsnxbgen` ftool.
- ✓ This is not a precise match to the Resolve NXB, and so should only be used to assess whether the NXB might be a concern.
- ✓ However, the Resolve NXB, estimates at ~0.01 ct/s over the Resolve array, is negligible in most cases of interest.

HEAsim file summary

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

HEAsim file summary: Xtend

FILE	NOTE
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

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

A worked simulation example

Let’s simulate the Perseus cluster!

(No need to type your commands at the same time;
this session is recorded and will be publicly available)

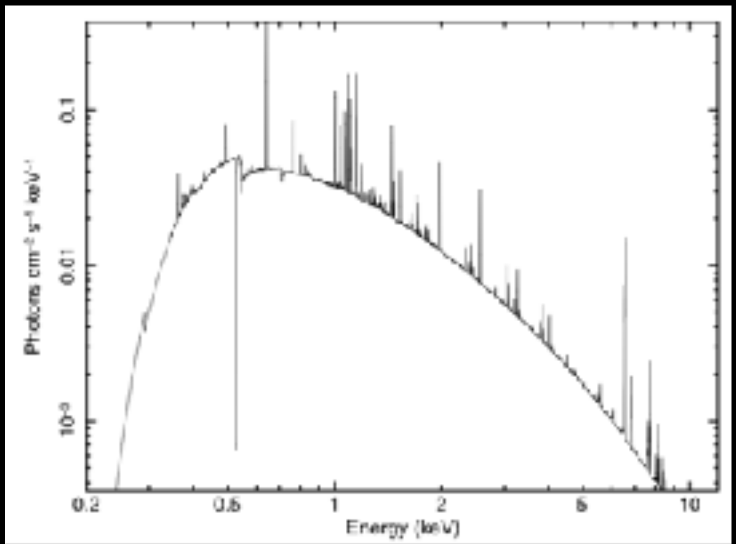
Step 1: Make Xspec qdp files

In this example "Perseus" = beta model ICM (TBabs*bvvapec)
+ point source AGN (Tbabs*plaw)

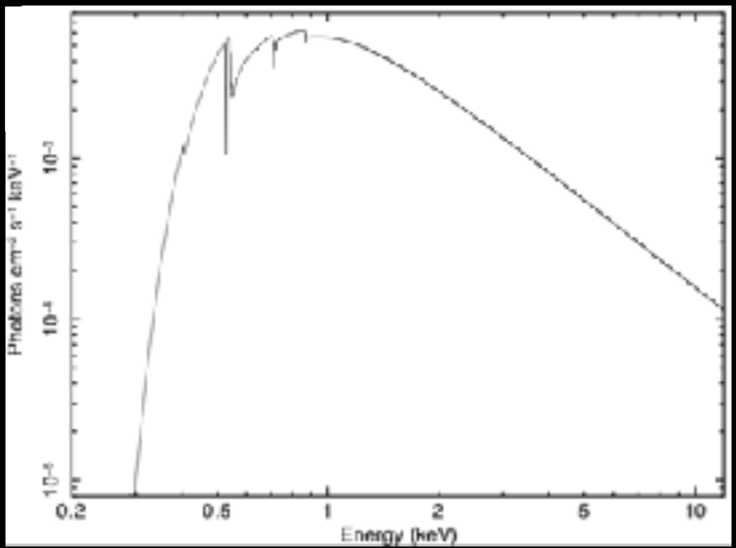
Model should be properly normalized (i.e. give the correct flux)

Energy bin smaller than the instrument resolution

```
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
```




```
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
```



+ Combine all components with the same spatial resolution into 1 model

Step 2: Make source definition files

Heasim requires a source definition file ("sdf") as input to specify the source position in the sky, and source characteristics (consult the heasim guide for details). 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	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.

Step 2: Make source definition files

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

nH

Spectrum (Here "user" follows QDP model)

Specpar (0 if "user")

Flux (0 if "user")

Bandpass

Specfile (i.e. spectral model in QDP format)

Specunits

Specformat

Step 3: Setup HEAsim

Download and unpack support files `heasimfiles_20201012.tar.gz`, placing them in some directory <heasimfilesdir>

Set the `HEASIM_SUPPORT` environment variable:

`setenv HEASIM_SUPPORT <heasimfilesdir>` (C-shell) or

`export HEASIM_SUPPORT=<heasimfilesdir>` (Bash)

Step 4: Run HEAsim

- ✓ 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`"). For extended sources, we currently recommend using the point source arf and including vignetting – rather than using the extended source ARFs (which would require doing two simulations and combining the simulated output event files).
- ✓ As mentioned above, the NXB may be neglected in most cases ("`intbackfile=none`") but is included here for demonstration purposes.

```
$ 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_withGV_20190701.arf
  intbackfile=$HEASIM_SUPPORT/xrism/resolve/background
  resolve_h5ev_2019a_rslnxb.pha flagsubex=no seed=1234567890 clobber=yes
```

sdf

Step 5: Extract spectrum & analyze it

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_withGV_20190611.arf
XSPEC12> arf 2:1 resolve_pnt_spec_withGV_20190701.arf
XSPEC12> model TBabs*bvvapec
XSPEC12> ... specify params
XSPEC12> model 2:agn constant*TBabs*powerlaw
XSPEC12> ... specify params
XSPEC12> … fit, derive errors, etc.
```

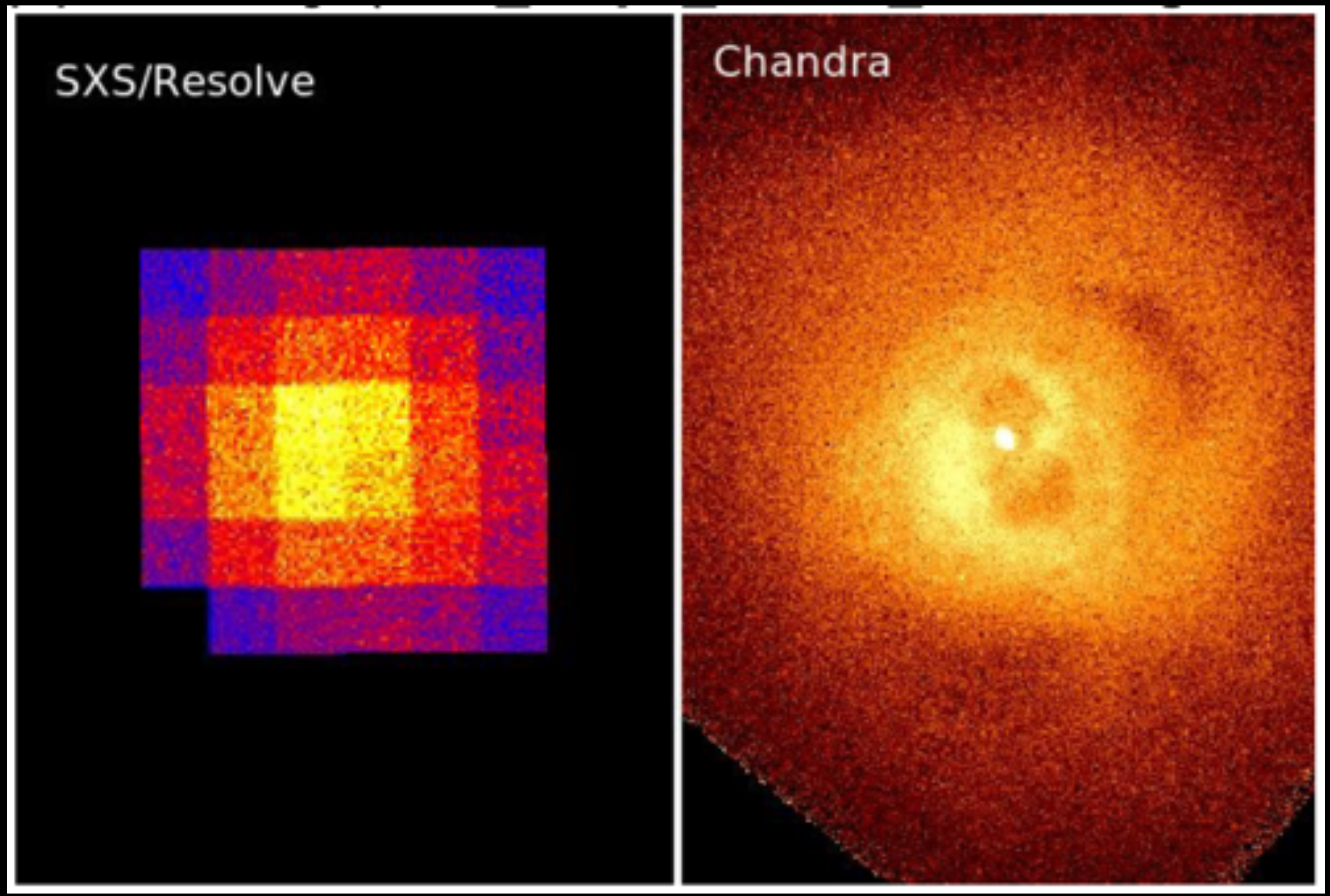
ARFs different than for input sim!
(Because we had to account for all photons also outside the detector)

Alternative: Define sdf from image

For our Perseus simulation, the sdf can also be defined from a real image:

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)
```




```
$ heasim mission=hitomi instrume=sxs
  rapoint=49.95 decpoint=41.51 roll=0.00
  exposure=200000.
  insrcdeffile=perseus_imageicm.dat
  outfile=perseus_imageicm.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_withGV_20190701.arf
  intbackfile=$HEASIM_SUPPORT/xrism/resolve
  background
  resolve_h5ev_2019a_rslnxb.pha flagsubex=no
  seed=1234567890 clobber=yes
```

Alternative: Add an emission line to the source

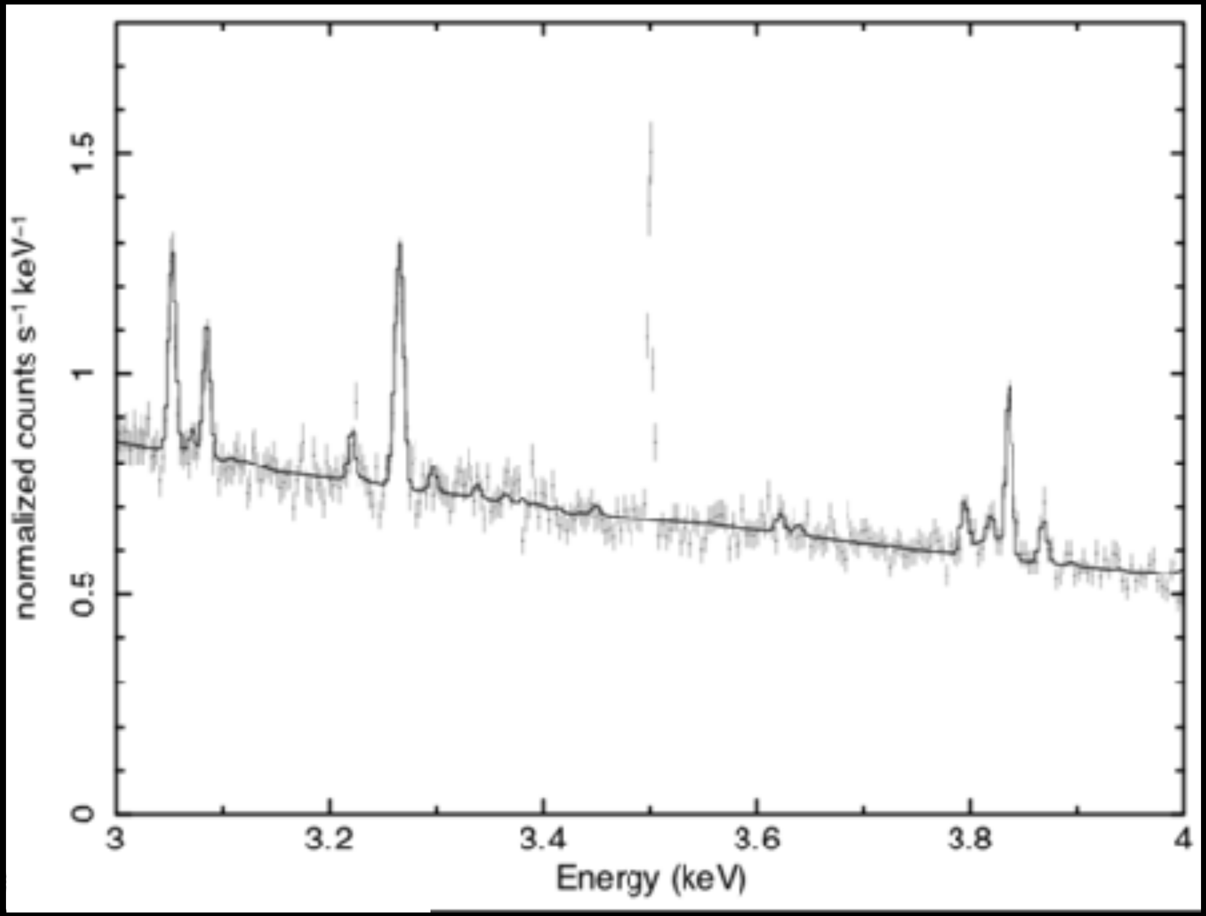
For our Perseus simulation, one can also add one extra line:

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)
```

mono = narrow Gaussian line for finite width use user model

```
$ heasim mission=hitomi instrume=sxs
  rapoint=49.95 decpoint=41.51 roll=0.00
  exposure=200000.
  insrcdeffile=perseus_betaicm_brptsrc_line.dat
  outfile=perseus_betaicm_brptsrc_line.fits
  psffile=$HEASIM_SUPPORT/xrism/resolve/psf
  eef_from_sxs_psfimage_20140618.fits(…)
```



Calculate branching ratios

- Use Hp and Mp for high-resolution spectroscopy.
- Rule of thumb: check branching if **>1 ct/sec/pixel** (see Edmund's talk yesterday).

sxsbranch (rslbranch)

✓ computes branching ratios for each event resolution grade – for each pixel, and over the entire array
✓ statistically estimates these quantities using Poisson statistics, based on some count distribution in pixels
✓ produces a more realistic version of the event file by populating the PIXEL, and ITYPE columns with the grade (`ITYPE = 0:HP, 1:MP, 2:MS, 3:LP, 4:LS`)

```
$ 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
```

For example, in Xselect...

corner of the array

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

Hp only (1:Mp, 2:Ms, 3:Lp, 4:Ls)

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.