Basics of Resolve data reduction

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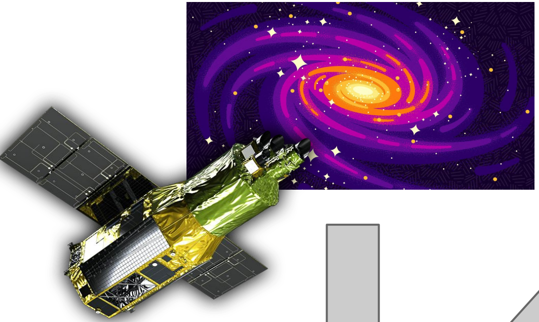
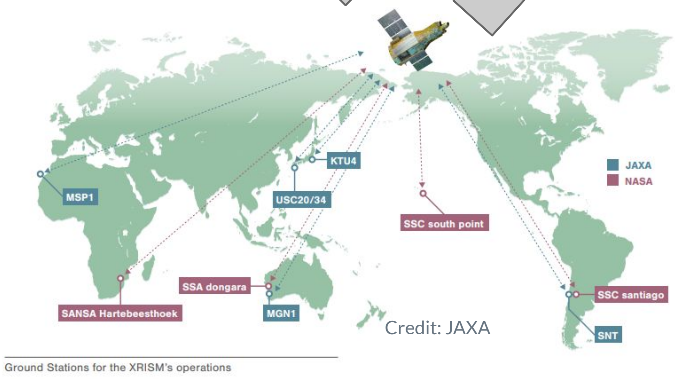
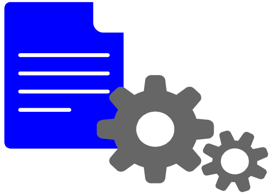
XRISM data: from satellite to your computer







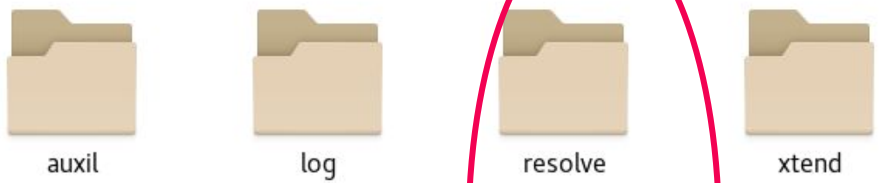
Pre-Pipeline

- not accessible to observers
- converts raw telemetry to unfiltered, unscreened event files
- calculates attitude, orbit, event times, etc
- *to make sure data is processed with the latest pre-pipeline, download data directly from archive*

Pipeline

- accessible to observers
- initial data processing: calibration, basic data screening
- done automatically before data is archived
- *observers **CAN** and often **SHOULD** re-run the pipeline (reprocess the observation)*

Inside the XRISM observation folder



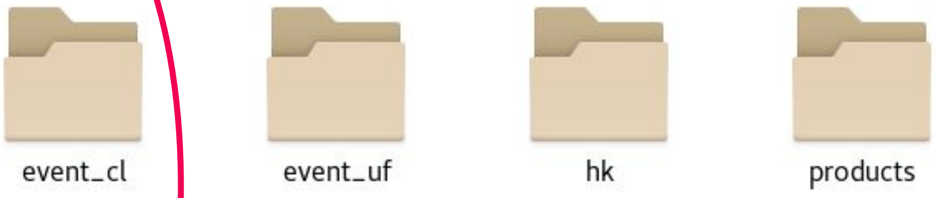
auxiliary files not associated with a particular instrument, e.g. attitude, orbit, filter, housekeeping files
some needed for Resolve data reduction

log files from the pipeline processing

Resolve data & files

Xtend data & files

Inside ‘resolve’ directory



cleaned event file: X-ray event data filtered using the standard screening criteria

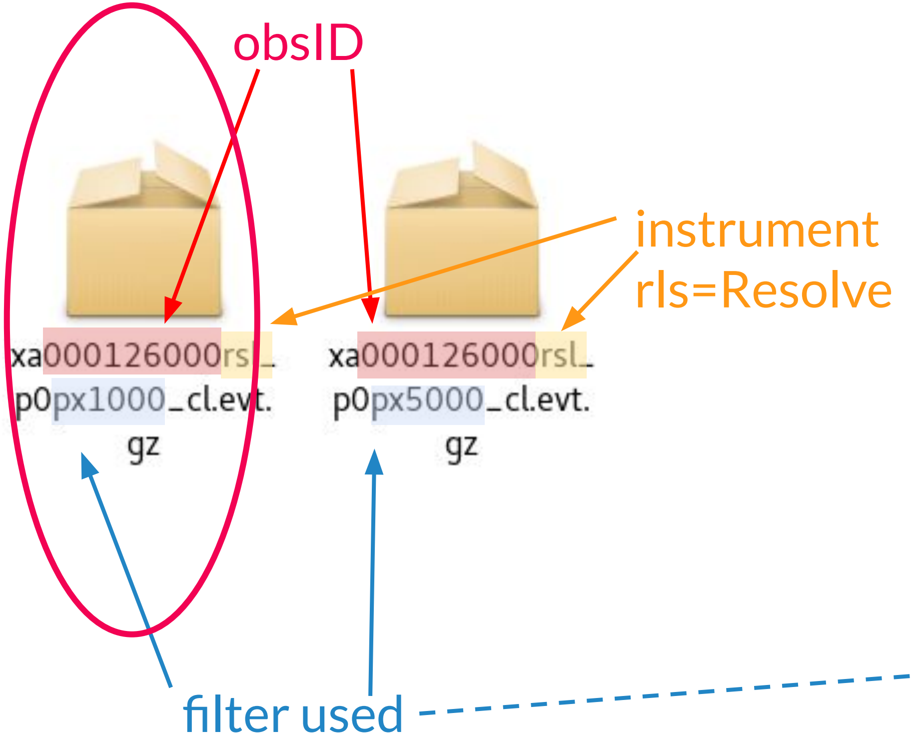
unfiltered event files: all X-ray event data

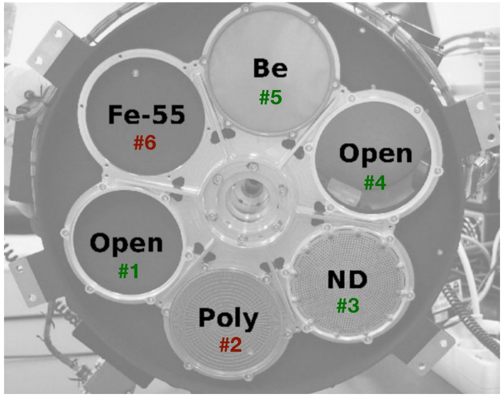
instrument housekeeping data: voltages, temperatures etc.

quick-look analysis products (images, light curves & spectra) processed with the pipeline
not suitable for science data analysis

Clean event file folder

xa - from *xarm*, the initial name for XRISM
p0 - pointing mode (as opposed to slew mode)
cl - cleaned events





px0000	Undefined
px1000	OPEN
px2000	Al/Polyimide
px3000	Neutral Density (ND)
px4000	Be
px5000	Fe 55 calibration source

Structure of the event file

#parameters #events

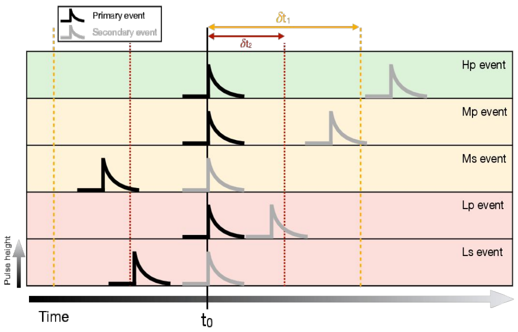
Index	Extension	Type	Dimension
0	Primary	Image	0
1	EVENTS	Binary	54 cols X 23494 rows
2	GTI	Binary	2 cols X 70 rows

File Edit Tools Help

Select	TIME	TRIGTIME	S_TIME	L32TI	CATEGORY
	1D	1D	1D	1J	1B
All	s	s	s		
Invert	Modify	Modify	Modify	Modify	Modify
1	1.553438908992E+08	1.553438908995E+08	1.553439050156E+08	2784169153	82
2	1.553438968478E+08	1.553438968480E+08	1.553439060156E+08	2784169217	82
3	1.553439038144E+08	1.553439038153E+08	1.553439090156E+08	2784169409	82
4	1.553439038183E+08	1.553439038193E+08	1.553439090156E+08	2784169409	82
5	1.553439041204E+08	1.553439041205E+08	1.553439220156E+08	2784170241	82
6	1.553439058088E+08	1.553439058089E+08	1.553439230156E+08	2784170305	82
7	1.553439094312E+08	1.553439094315E+08	1.553439259844E+08	2784170495	82
8	1.553439094315E+08	1.553439094317E+08	1.553439259844E+08	2784170495	82
9	1.553439154400E+08	1.553439154403E+08	1.553439250156E+08	2784170433	82
10	1.553439241663E+08	1.553439241664E+08	1.553439400156E+08	2784171393	82
11	1.553439248022E+08	1.553439248025E+08	1.553439420156E+08	2784171521	82
12	1.553439260332E+08	1.553439260342E+08	1.553439420156E+08	2784171521	82
13	1.553439262938E+08	1.553439262940E+08	1.553439420156E+08	2784171521	82
14	1.553439292207E+08	1.553439292216E+08	1.553439420156E+08	2784171521	82
15	1.553439292305E+08	1.553439292316E+08	1.553439420156E+08	2784171521	82
16	1.553439292325E+08	1.553439292336E+08	1.553439420156E+08	2784171521	82
17	1.553439294877E+08	1.553439294880E+08	1.553439390156E+08	2784171329	82
18	1.553439333053E+08	1.553439333054E+08	1.553439400156E+08	2784171393	82
19	1.553439361948E+08	1.553439361950E+08	1.553439420156E+08	2784171521	82
20	1.553439393918E+08	1.553439393921E+08	1.553439560156E+08	2784172417	82
21	1.553439428636E+08	1.553439428639E+08	1.553439587344E+08	2784172591	82
22	1.553439447365E+08	1.553439447367E+08	1.553439560156E+08	2784172417	82

- List of events - something triggering a pulse in a pixel
- New parameters that may not be familiar from working with CCDs, and parameters you're maybe used to

- ❖ ITYPE: Resolution grade (Hp, Mp, Ms, Lp, Ls ...)
- ❖ RISE_TIME: how long does the pulse rise
- ❖ PIXEL: which pixel the event happened at
- ❖ PI: pulse invariant
- ❖ STATUS: event flag



GTI: Good Time Interval: screening criteria for time, e.g. when the telescope is observing the source, when the detector is on, ...

What & why does the pipeline screen

- ➔ *Event screening is performed to maximize the science signal and minimize the background*
- ➔ Some screening is common to all observations, but some will depend on the science (e.g. weak vs bright source)
- ➔ Pipeline applies the minimal set of screening, common to all observations

Example pipeline screening criteria
(for more see ABC guide)

ITYPE<5	
(SLOPE_DIFFER==b0||PI>22000)	b0: no b1: yes
QUICK_DOUBLE==b0	
STATUS[2]==b0	
STATUS[3]==b0	excl. antico events
STATUS[6]==b0	excl. e- from pix 12
RISE_TIME <127	
PIXEL!=12	excl. calibration pixel
−8 < TICK_SHIFT <7	

[1]: outside of all-pixel GTIs
[2]: outside of individual-pixel GTIs
[3]: coincidence with anti-co event
[4]: coincidence with event on any pixel except 12
[5]: coincidence with pixel 12 event
[6]: [5] & passed energy test for absorption of electron ejected from 12
[7]: candidate electrical crosstalk event or its source
[8]: [7] & largest PHA of coincident group
[9]: during pulse of MXS direct source
[10]: during afterglow of MXS direct source
[11]: during pulse of MXS indirect source
[12]: during afterglow of MXS indirect source
[13]: event likely contaminated by untriggered electrical crosstalk
[14]: [13] & largest PHA of coincident group

https://heasarc.gsfc.nasa.gov/docs/software/lheasoft/help/xapipeline.html

1. Do we re-run the pipeline/reprocess

Reprocessing may be necessary if new calibration is available or if there were major updates to the software that was used to calibrate the data. To check:

- ➢ Find the **CALDBVER** and **SOFTVER** keywords in event file headers of your data
- ➢ Check current CALDB version: https://heasarc.gsfc.nasa.gov/docs/xrism/calib/index.html
- ➢ Check current HEASoft version: https://heasarc.gsfc.nasa.gov/docs/software/lheasoft/
- ➢ If these don't match, reprocess with *xapipeline*
- ➢ *When in doubt, reprocess!*

```
SOFTVER = 'Hea_21Aug2024_V6.34_XRISM_21Aug2024_V001'
CALDBVER= 'gen20240315_xtd20240815_rsl20240815' / Ver
```

The current version of HEASoft is 6.34
(22 August 2024)

XRISM CALIBRATION DATA			
GEN Index Summary	Current Version: 20241115	Release Notes	Download
Resolve Index Summary	Current Version: 20241115	Release Notes	Download
XTEND Index Summary	Current Version: 20241115	Release Notes	Download
General Index Summary	Current Version: 20240822	Release Notes	Download

- ➢ The pre-pipeline version can be found with TLM2FITS keyword
- ➢ If there is a new pre-pipeline version, all archive will be reprocessed
- ➢ Because observers cannot run pre-pipeline themselves, data will need to be re-downloaded
- ➢ *When in doubt, re-download*

Reprocessing

xapipeline - both Resolve and Xtend are reprocessed.

```
xapipeline indir=000126000 outdir=000126000 rep
steminputs=xa000126000 stemoutputs=DEFAULT entry stage=1
exit stage=2 instrument=ALL verify input=no
```

Stages:

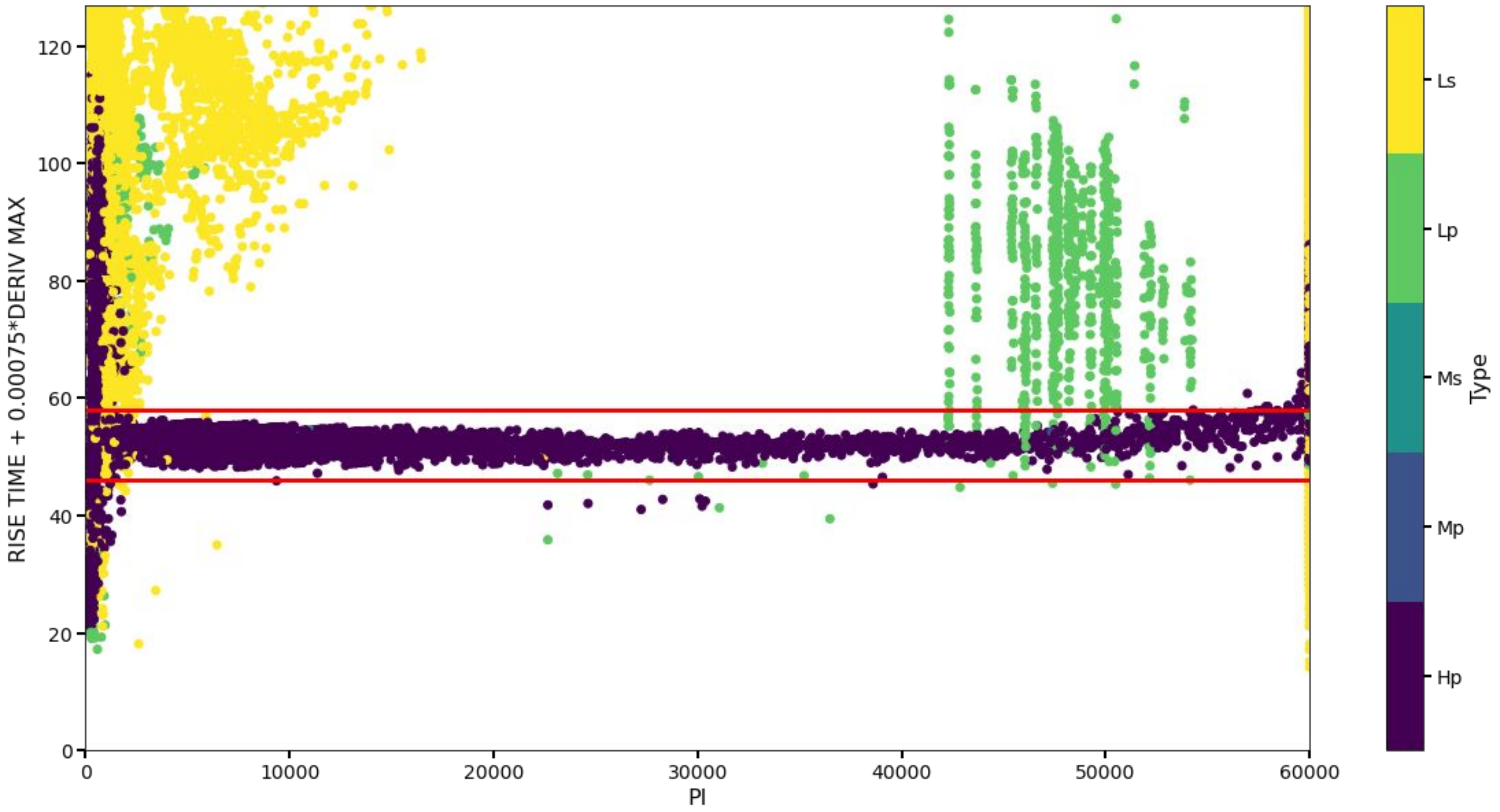
1. Applying new calibration
2. Baseline data screening
3. Quick-look product creation (can easily skip this step)

2. Additional screening

This heavily depends on the science case and the target. Here we show some that are currently recommended to consider. Make sure to check back, since these recommendations may change with time.

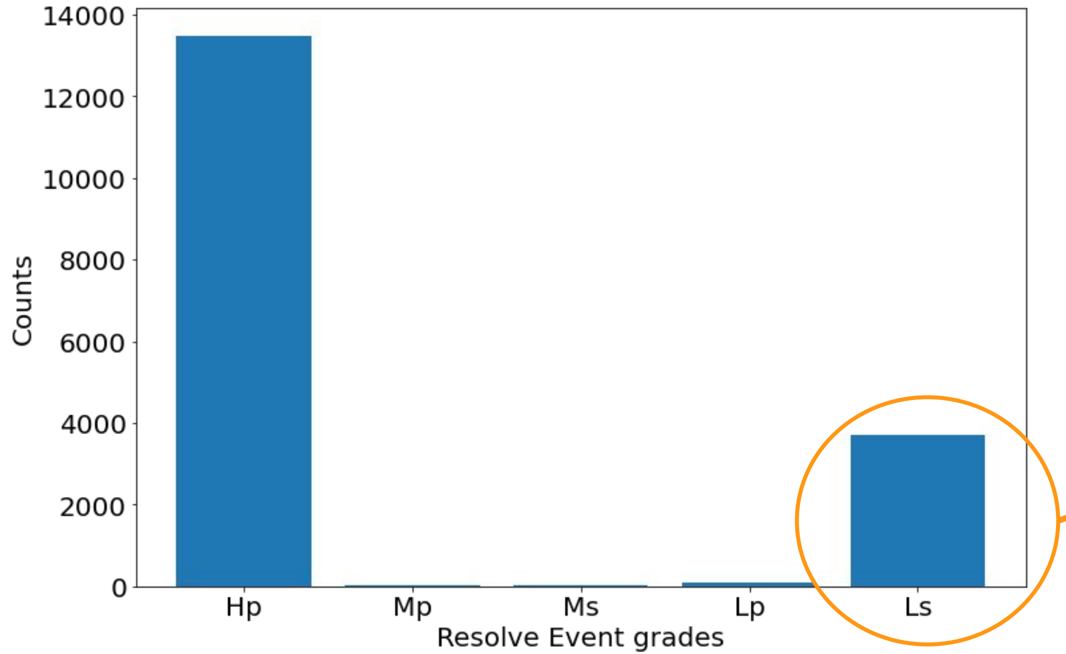
```
(PI>=600) &&(((((RISE_TIME+0.00075*DERIV_MAX)>46)&&
((RISE_TIME+0.00075*DERIV_MAX)<58))&&ITYPE<4)||(ITYPE==4))&& STATUS[4]==b0]
```

- PI>=600 : E<0.3 keV, removes mostly cross-talk events
- ((((RISE_TIME+0.00075*DERIV_MAX)>46)&& ((RISE_TIME+0.00075*DERIV_MAX)<58))&&ITYPE<4) : rise time cut off based on what pulse rise time real events should have
- STATUS[4]==b0 : flags pixel-to-pixel coincidence, removes frame events. However, for high count rate sources, this will introduce a lot of false-positives. Thus, determine carefully if applicable.
- Anomalous Ls events and energy gain examination-> see Mike's talk



RISE TIME + 0.00075*DERIV MAX
PI
Type
Ls
Lp
Ms
Mp
Hp
0
20
40
60
80
100
120
0
10000
20000
30000
40000
50000
60000

3. Examining the branching ratios

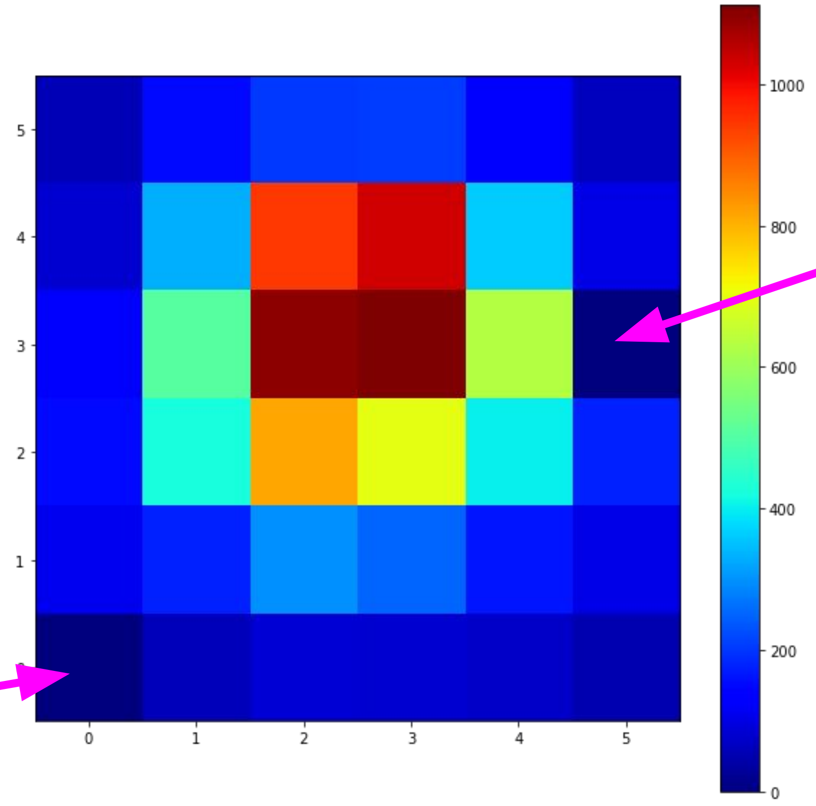


- Histogram of event grades = branching ratios
- Depending on the count rate of the source, this will vary a lot
- Help to decide which spectra to extract since **each grade spectrum should be extracted separately**

Important: currently we are dealing with anomalous Ls events, which are not from the source. See next talk for details.

4. Creating an image

read eve
xa000126000rsl_p0px1000_n
o27_cl2.evt .
set image DET
filter pha_cutoff 4000 20000
extr image

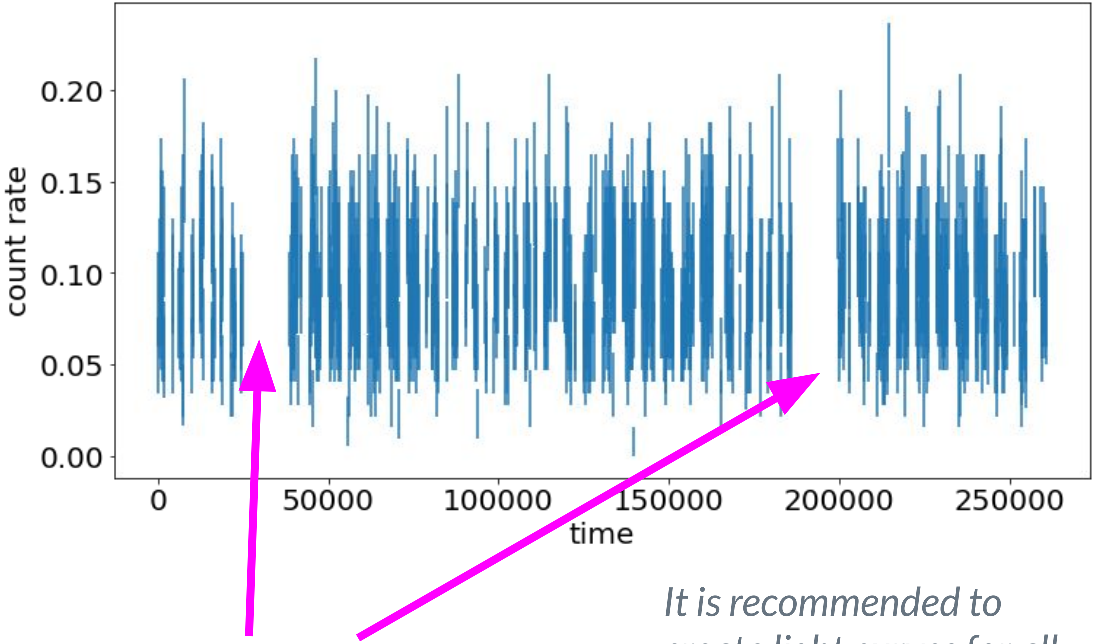


Pixel 27 - currently recommended to not include due to gain tracking issues (see next talk)

Calibration pixel

It is recommended to create images for all event grades combined

5. Creating a light curve



Detector cooling cycles

It is recommended to create light curves for all event grades combined

- Resolve light curve will not show periods of solar flares or high background
- Recommended to inspect Xtend light curve and apply any additional GTI screening to data (see later tutorial)

set binsize 128.0
extr curve exposure=0.8

6. Extracting spectra

```
filter column "PIXEL=0:11,13:26,28:35"
filter GRADE "0:0"
extr spectrum
```

Which event grade?

Which pixels are we extracting spectrum from?

0/Hp: High-resolution Primary
1/Mp: Mid-resolution Primary
2/Ms: Mid-resolution Secondary
3/Lp: Low-resolution Primary
4/Ls: Low-resolution Secondary

**Current recommendation is to always exclude pixel 27*
**For now, energy scale accuracy may only be assured for Hp events, so it is recommended to only use Hp spectra*

Important choices:

- Which event grades and which pixels
- Response files need to be created separately for different event grade choices and different pixel choices!
- High-res resolution is 4.5~eV, and mid-res is 4.8~eV, low-res is still much better than CCDs!

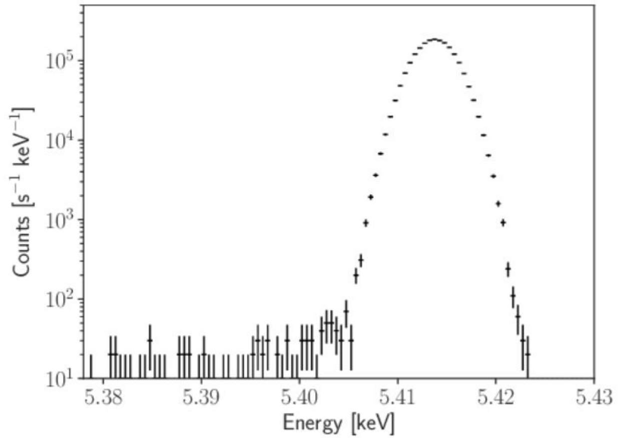
Important caveats:

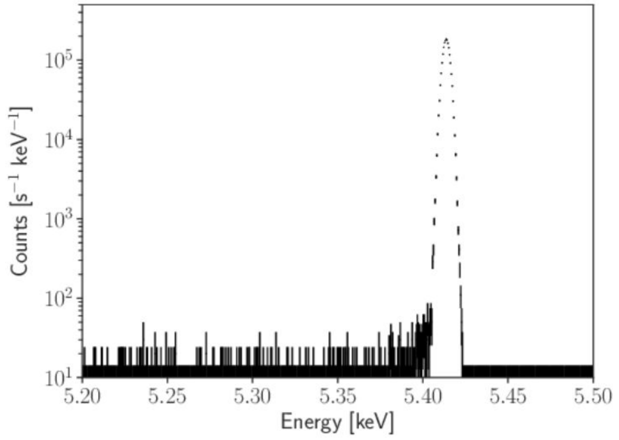
- Sub-array spectra need careful consideration of best ARF (see extended sources tutorial)
- Different event grade spectra are not all well calibrated yet (see bright sources tutorial and advanced data reduction lecture)

7. Creating RMF

Elements of Line Spread Function:

1. Gaussian core
2. low-energy exponential tail due to energy loss at the surface of the absorbers
3. extended low-energy electron loss continuum
4. discrete escape peaks from M-shell fluorescence of Hg or Te in the absorber
5. Si K alpha emission lines

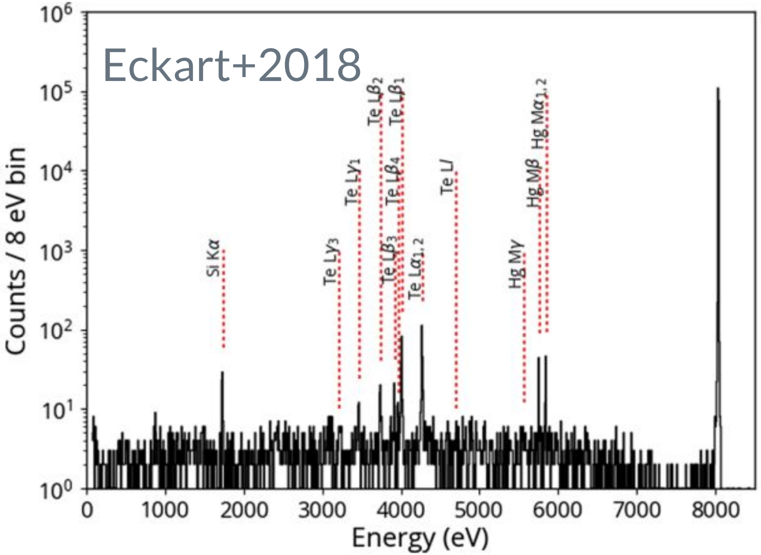




RMF sizes

Resolve RMF comes in 4 sizes:

- Small (S): only Gaussian core
- Medium (M): S+ exponential tail and Si Kalpha emission line
- Large (L): M + escape peaks
- eXtra Large (XL): L+extended electron loss continuum




```
352M  xa000126000rsl_Hp_L.rmf
 26M  xa000126000rsl_Hp_M.rmf
 15M  xa000126000rsl_Hp_S.rmf
782M  xa000126000rsl_Hp_XL_comb.rmf
430M  xa000126000rsl_Hp_XL_elc.rmf
352M  xa000126000rsl_Hp_XL.rmf
```

Which RMF should I use?

- Science case dependent:
    - *read XRISM Collaboration papers!*
- L/XL are likely to be most appropriate for majority of science cases
- If using data below 3 keV, XL is very likely required for final scientific analysis, but L/M/S can be used for preliminary parameter space exploration

What can go wrong? Lots…

- Wrong line widths, artificial "soft excess", wrong continuum, lines that come from the instrument and not the source…

Creating S/M/L RMF

```
rslmkrmf infile=xa000126000rsl_p0px1000_allpix_cl3.evt
outfileroot=xa000126000rsl_Hp_L regmode=DET whichrmf=L resolist=0
regionfile=NONE pixlist=0-11,13-26,28-35 eminin=0.0 dein=0.5 nchanin=60000
useingrd=no eminout=0.0 deout=0.5 nchanout=60000
```

- *Currently need to use the event file with artificial Ls events screened out*
- Separate RMF for each grade (resolist=0 means Hp events)
- Specify which pixels via pixlist. This must match your spectrum extraction choice. No pixel 12 (it’s the calibration pixel)
- Dein - energy channel width in eV, nchainin - number of energy channels

Creating XL RMF

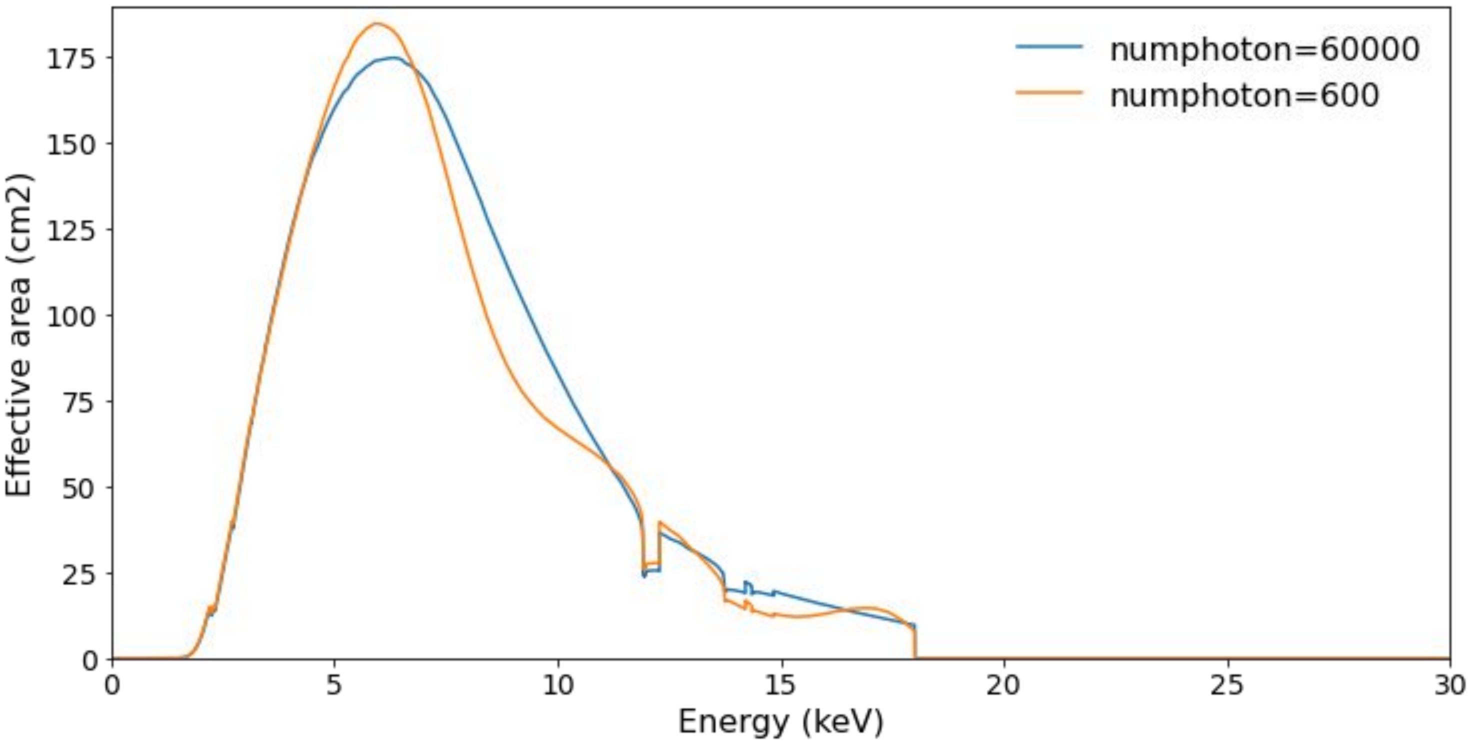
rslmkrmf infile=xa000126000rsl_p0px1000_allpix_cl3.evt outfileroot=xa000126000rsl_Hp_XL regmode=DET whichrmf=X resolist=0 regionfile=NONE splitrmf=yes elcbinfac=16 splitcomb=yes pixlist=0-11,13-26,28-35 eminin=0.0 dein=0.5 nchanin=60000 useingrd=no eminout=0.0 deout=0.5 nchanout=60000

- Important to use splitrmf=yes
- This way two extensions are created and filesize is vastly reduced from many GB to under 1 GB
- See Keith's talk on how XSPEC handles this tomorrow morning!

8. Creating ARF

xaarfgen xrtevtfile=raytrace_xa000126000rsl_ptsrc.fits source_ra=81.25849396 source_dec=-69.64122312 telescop=XRISM instrume=RESOLVE emapfile=xa000126000rsl_p0px1000.expo regmode=DET regionfile=no27.reg sourcetype=POINT rmffile=xa000126000rsl_Hp_S.rmf erange="0.5 18.0 0.0 0.0" outfile=xa000126000rsl_ptsrc.arf numphoton=600000 minphoton=100 [.........]

- regionfile=no27.reg: region file in detector coordinates that matches the region that spectrum was extracted from
- sourcetype=POINT: source shape that illuminates the array. Here we assume point source, but we should use an IMAGE in case of extended source, see Francois' talk tomorrow
- Xrtevtfile is the raytrace file - you can keep it to generate different ARFs from different regions (see Francois' demo tomorrow)
- erange="0.5 18.0 0.0 0.0" which energy range should be used for the output ARF. If narrow energy range is required, the ARF generation will take less time. The last two numbers are important for IMAGE mode (see Francois' demo)
- numphoton=600000 minphoton=100 : minimum number of photons in raytrace at the outset and reaching the focal plane after raytrace, needs to be high enough to have robust ARF estimation


numphoton=60000
numphoton=600
Effective area (cm2)
Energy (keV)
0
25
50
75
100
125
150
175
0
5
10
15
20
25
30

9. Do your science!

Where to find more information?

https://heasarc.gsfc.nasa.gov/docs/xrism/analysis/index.html

-> Data Reduction Guide (a.k.a. ABC Guide

-> Quick-Start Guide

-> Things to Watch Out For Page (see Mike's talk)

-> *XRISM Collaboration papers!*

Where to get help?

fhelp *yourcommand*

```
PARAMETERS

   infile [filename]
          Name of input event file used to calculate the grade and pixel
          weighting factors.

   outfileroot = response [filename]
          Output root name for all output files.

   (splitrmf = no) [boolean yes|no]
          If 'splitrmf=yes', split the RMF/RSP into core and ELC
          responses.

   (elcbinfac = 32) [integer]
          If 'splitrmf=yes', 'elcbinfac' is the rebinning factor for the
          ELC component of the RMF/RSP, which must be an exact divisor of
          'nchanin'. If 'splitrmf=no', 'elcbinfac' is ignored.

   (splitcomb = no) [boolean yes|no]
          If 'splitrmf=yes' and 'splitcomb=yes', the two response matrices
```

```
amogorza@gs66-lem:~/.../resolve/analysis/ARF$ fhelp rslmkrmf
NAME

   rslmkrmf - Create a XRISM Resolve redistribution matrix file (RMF)
   and/or a response (RSP) file for selected Resolve pixel and grade
   combinations, with weighting factors derived from an input event file
   and region

USAGE

   rslmkrmf infile outfileroot resolist regmode regionfile

DESCRIPTION

   The rslmkrmf task is a script that calculates a Resolve redistribution
   matrix file (RMF) for selected grade and pixel combinations, weighted
   according to relative counts. After a file containing the weights is
   calculated based on the pixel and grade distributions in the input
   event file, the RMFs for single pixels and grades are individually
   calculated and then combined accordingly using the rslrmf task. If an
   ARF is provided, rslmkrmf can output a total response (RSP) file upon
   request.

   The required inputs to rslmkrmf are: (1) a cleaned Resolve event file
   ('infile') that should be the same as that used to extract the spectrum
   to which the RMF is to be applied; (2) a list of resolution grades
   ('resolist'); and (3) a list of pixels. The selected grades and pixels
   should match the lists that were used to extract the spectrum and to
   create the ARF.

   The following two options for specifying the list of pixels are
   supported. (1) The user may input a DS9-format region file in either
   DET or SKY coordinates by setting the 'regmode' and 'regionfile'
   parameters. The task 'coordpnt' is then used to convert the region into
   a pixel list using the teldef CalDB file specified by the 'teldeffile'
   parameter. If 'regmode=SKY', by default the conversion from SKY
   coordinates uses the pointing recorded in the RA_NOM, DEC_NOM, and
   PA_NOM keywords of the input event file. However, these may be
   overridden using the 'rapoint', 'decpoint', and 'roll' parameters. The
   'pixeltest' parameter determines the criteria for including pixels in
   the region. If 'regionfile=ALLPIX', all pixels are included. (2) If
   'regionfile=NONE', the pixel selection is executed by entering the
   pixel numbers in the 'pixlist' parameter.
```