Recipe for reducing XIS data taken with the P-sum/timing mode

K. Matsuta (JAXA ISAS), K. Higashi (Rikkyo Univ.), M. Tsujimoto (JAXA ISAS), and the XIS team

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1 Introduction

The Parallel-Sum (P-sum) mode is one of the clocking modes in the XIS. Events in 128 rows are summed along the Y-direction in the CCD and the sum is treated as a single row in the subsequent process. A higher timing resolution is obtained (8 s/1024 $\sim$ 7.8 ms) than the Normal mode at a sacrifice of the imaging information along the Y-axis.

This memo presents (1) the steps to generate uncleaned event files to cleaned event files, (2) the procedures to make response and spectral files, and (3) the limitations in the timing and spectral calibration for the P-sum data.

1.1 The sample data

We use Cyg X-1 observation data as an example. Cyg X-1 is a black hole candidate (Remillard & McClintock 2006), which shows random time variations of a time scale of 10 ms (Ibragimov et al. 2005). The energy dependence of the time variations is small (Negoro et al. 1994).

Cyg X-1 was observed by Suzaku for 20 ks on 2009 December 17 (OBS ID = 404075070). The XIS0 and XIS1 were operated in the Normal mode with a 1/4 window and 0.5 s burst option, while the XIS3 was operated in the P-sum mode. The source was placed at the HXD nominal position. The XIS data were distributed through the pipeline processing version 2.2 .

The light curves of the XIS and the HXD (Fig.1) and the XIS images constructed from the cleaned event files (Fig.2) are shown. A part of the segment A in the XIS0 is lost due to a putative micrometeorite hit occurred in 2009 June (Suzaku memo 2010-01). The data rate changed in the middile of the observation, which caused the telemetry saturation in the latter half of the observation. This is noticeable with a sudden decline in the count rate in figure 1. We assume that the spectrum is not affected by the telemetry saturation, and use all the data for the spectral analysis.

Unfortunately, the data suffer a pile-up at the center of the PSF both for the P-sum image (pile-up threshold $\sim$ 245 counts/sec) and the Normal mode with a 1/4 window + 0.5 s burst option ($\sim$ 192 counts/sec). We use events in the PSF wing for the timing and spectral analysis.

1.2 Coordinates

We briefly summarize various coordinates of the detector that are used throughout this recipe (Fig. 3).

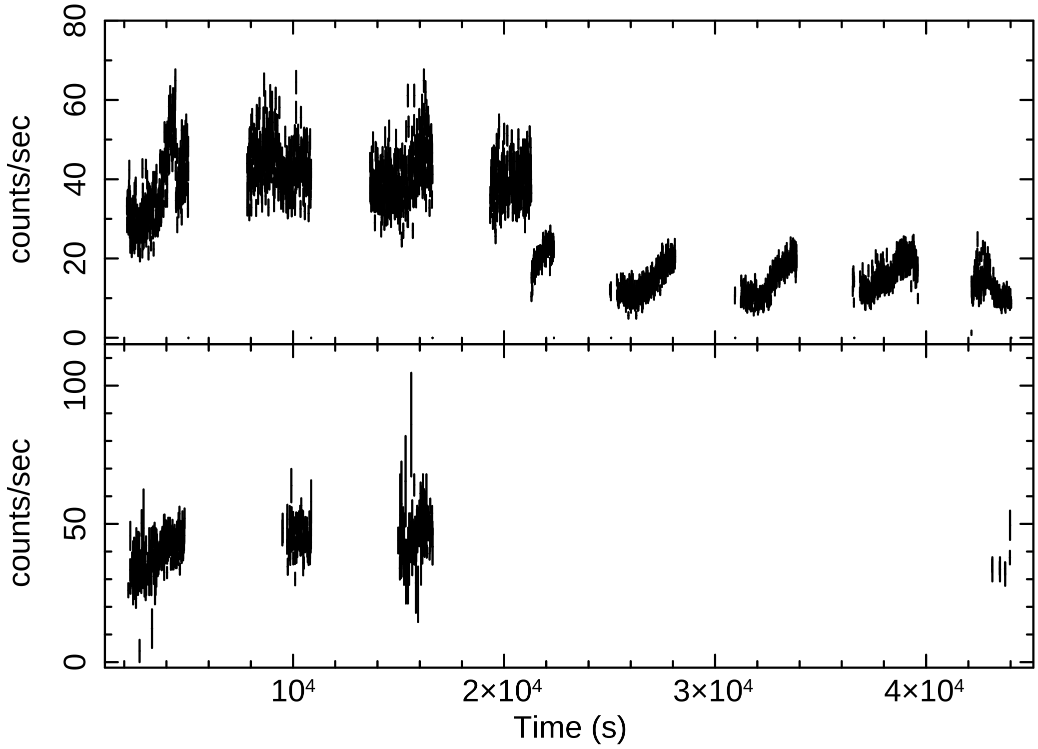

Figure 1: Light curve made by the cleaned event files of the XIS0 (top panel) and the HXD (bottom panel). Events were extracted from an annular box (see §3.1). The bin time is 8.0 s. The telemetry is saturated in the latter half of the observation.

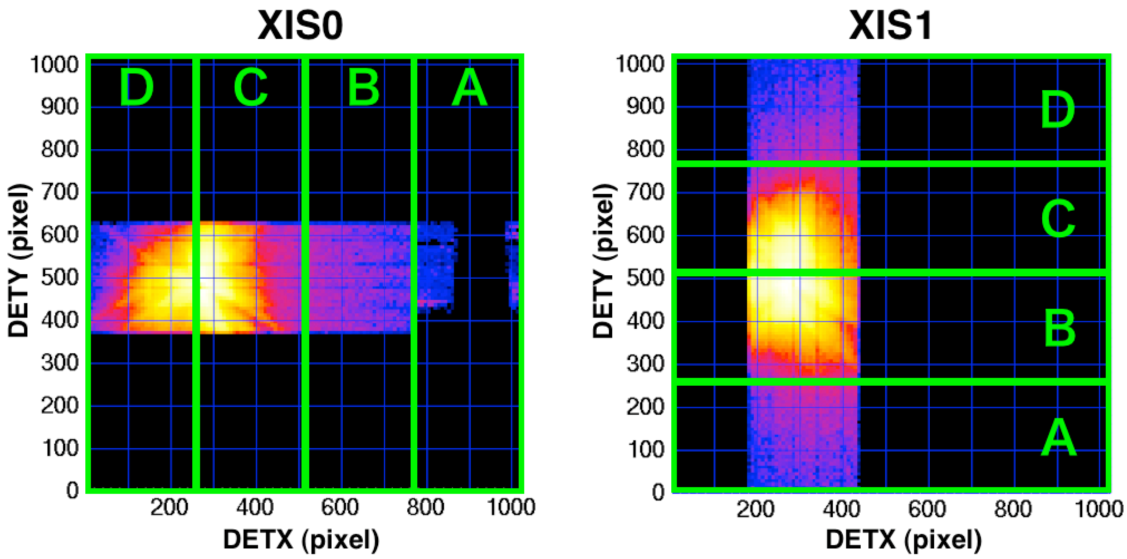

Figure 2: Images of XIS0 (left panel) and XIS1 (right panel). The four segments (A, B, C, and D) are shown in the green rectangles.

RAW coordinates

RAWX/Y is the original digitized values in the telemetry to identify the pixel of events in each segment of the sensors. This may not reflect the physical locations of the pixels on the sensors.

The XIS RAWX (RAWY) coordinate has values from 0 to 255 (1023) in each CCD segment.

ACT coordinates

ACTX/Y is defined to represent the actual pixel locations in each sensor. The value takes from 0 to 1023 to denote the 1024×1024 pixels in the chip. The orientation is defined by looking down the sensors.

DET coordinates

DETX/Y is the physical position of the pixels in each sensor. The values take from 1 to 1024. The coordinate is defined by looking up the sensor.

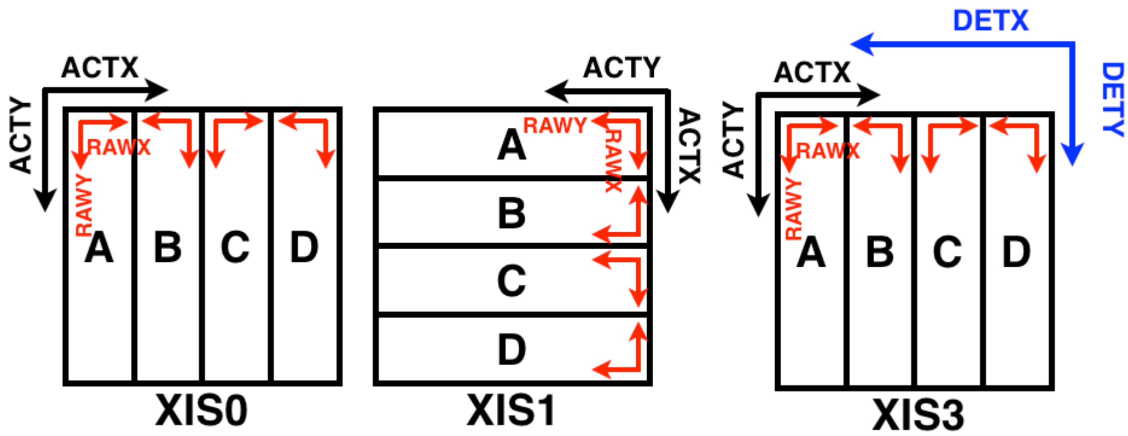

Figure 3: Layout of the RAWXY, ACTXY, and DETXY coordinates in each XIS sensor. The four segments (A, B, C, and D) are shown with black boxes.

2 Data reduction

2.1 Event reprocessing

The distributed event files (under the `event_cl` directory) do not consider the grade filtering properly for P-sum data. Users need to reprocess events from the unfiltered event files (under the `event_uf` directory) to obtain a cleaned event file.

1. Calculate PI values using `xispi`. The XIS HK files can be found in the `xis/hk` subdirectory.

```
〉 cd 404075070/xis/event_uf
〉 xispi infile=./ae404075070xi3_0_timp002z_uf.evt.gz \
outfile=ae404075070xi3_0_timp002z_uf_new.evt hkfile=../hk/ae404075070xi3_0.hk.gz
```

2. Clean events with the standard filtering criteria.

   (a) Generate the selection script for P-sum events (`xis_event.sel`).

```
〉bash
〉cat << EOF > xis_event.sel
? (GRADE==0||GRADE==1||GRADE==2)&& \
   (STATUS >=0&&STATUS <=524287)
? EOF
```

(b) Download two filtering scripts; `xisrepro.xco` and `xis_mkf.sel`.

```
〉wget http://suzaku.gsfc.nasa.gov/docs/suzaku/analysis/xisrepro.xco
〉wget http://suzaku.gsfc.nasa.gov/docs/suzaku/analysis/xis_mkf.sel
```

(c) Apply these filters using the xselect script `xisrepro.xco`.

```
〉gunzip ../../auxil/ae404075070.mkf.gz
〉xselect
Enter session name > [xsel]
    xsel:SUZAKU > read eve ae404075070xi3_0_timp002z_uf_new.evt ./
    xsel:SUZAKU-XIS3-TIMING >@xisrepro
    !xsel:SUZAKU-XIS3-TIMING > select events @xis_event.sel
    !xsel:SUZAKU-XIS3-TIMING > save events
    > Give output file name > [] xi3_timp_uf_new
```

3. Exclude hot pixels. Hot pixels are pixels that always produce unreasonably high pulse height values. For normal clocking modes, they are automatically removed during the onboard processing. For the P-sum mode, these pixels need to be removed manually. In the P-sum data, a hot pixel affects the entire column (hereafter hot columns) that it belongs to as signals of all pixels in a column are stacked.

   (a) Identify hot columns. Construct a histogram of ACTX versus counts by `ximage` in the `HEASoft` package. An example is shown in Fig. 4. In the example, the source is located at the HXD nominal position of ACTX=750. Several spikes indicate hot columns.

```
⟩ xselect
Enter session name > [xsel]
xsel:SUZAKU > read eve xi3_timp_uf_new.evt ./
xsel:SUZAKU-XIS3-TIMING > set xybinsize 1
xsel:SUZAKU-XIS3-TIMING > set xyname ACTX RAWY
xsel:SUZAKU-XIS3-TIMING > ext all
xsel:SUZAKU-XIS3-TIMING > save image xi3_timp_uf_new.fits
xsel:SUZAKU-XIS3-TIMING > exit
> Save this session? > [no]

⟩ ximage
XIMAGE > read/rebin=1/xi3_timp_uf_new.fits
XIMAGE > cpd /xw
XIMAGE > disp
XIMAGE > slice/xslice/start_pixel=0/end_pixel=1024/\
    outfile=xi3_timp_uf_new.cut/plot
PLT >
XIMAGE > q

⟩ cat xi3_timp_uf_new.cut | tail -n +20 | \
    awk '{print $1, $3 }' > xi3_timp_uf_new.qdp

⟩ qdp xi3_timp_uf_new.qdp
PGPLOT file/type: /xw
```

(b) Exclude hot columns. Generate a source extraction region based on the ACTX vs counts plot (Fig. 4). We show the DS9 image with the regions to exclude the identified hot columns (Fig. 5).

```
⟩ xselect
Enter session name > [xsel]
xsel:SUZAKU > read eve xi3_timp_uf_new.evt ./
xsel:SUZAKU-XIS0-TIMING > set xyname ACTX RAWY
xsel:SUZAKU-XIS0-TIMING > ext image
xsel:SUZAKU-XIS0-TIMING > sao

(Generate regions for hot columns in the DS9 and save the region file;
hotpixels.reg.)

xsel:SUZAKU-XIS3-TIMING > filter region hotpixels.reg
xsel:SUZAKU-XIS3-TIMING > ext event
xsel:SUZAKU-XIS3-TIMING > save eve xi3_timp_uf_new_reduction.evt
```

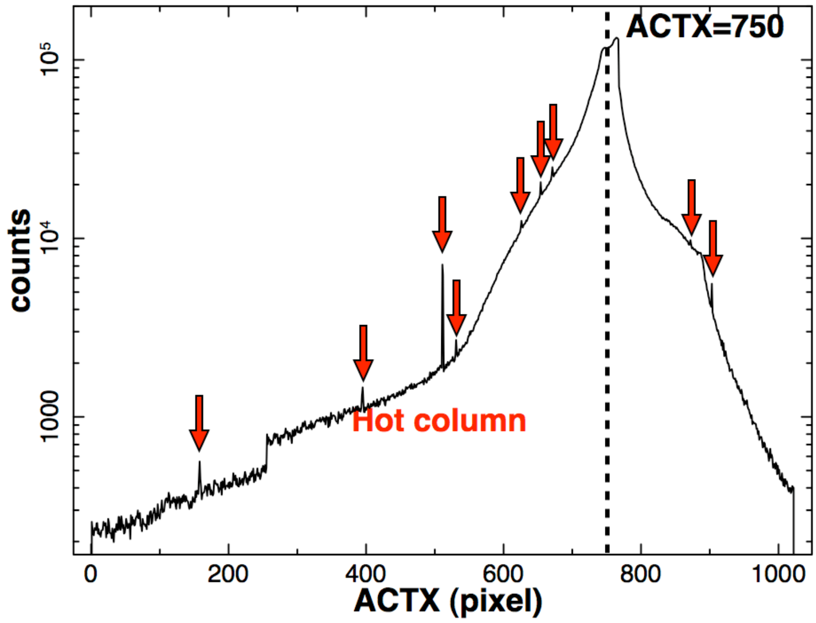

Figure 4: Histogram of ACTX versus counts of the P-sum data (XIS3). The black dashed line shows the source center. The red arrows show positions of the the hot columns.

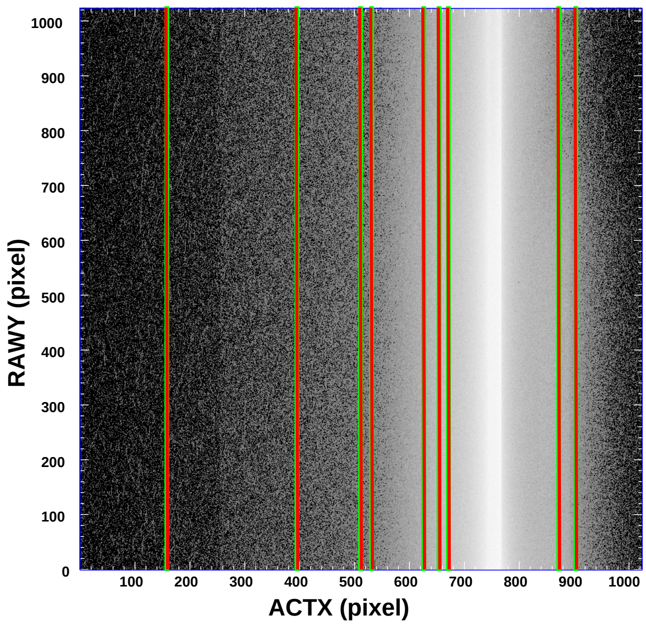

Figure 5: Image of the P-sum data (XIS3). The thin green boxes are masked regions for hot columns, which are centered at ACTX = 158, 395, 511, 531, 626, 654, 671, 872 and 903 with a size of 3 $\times$ 1024 pixels.

2.2 Absolute time Correction.

The absolute arrival time of events needs to be corrected in the P-sum mode. Users who are not concerned about the absolute time of a 10 ms order can skip this procedure.

The correction depends on where the source is observed along the ACTY axis. The layout of DETXY and ACTXY is shown in Fig. 6. The ACTY direction is the same with the read out direction. The source position along ACTY can be derived from another sensor operated in a non-P-sum mode. At least, the P-sum mode is unavailable for the XIS1, so users can use the XIS1 data for this purpose (Fig. 6).

1. Determine the location of the source along the ACTY axis.

```
〉cd 404075070/xis/event_cl
〉xselect
> Enter session name > [xsel]
xsel:SUZAKU > read eve ae404075070xi1_0_3x3b105b_cl.evt.gz ./
xsel:SUZAKU-XIS1-STANDARD > set xyname ACTX ACTY
xsel:SUZAKU-XIS1-STANDARD > ext image
xsel:SUZAKU-XIS1-STANDARD > sao
```

In the P-sum mode, 128 rows are stacked in the ACTY-direction. Each stacked row is read out in 7.8 ms. Therefore, for a source at the ACTY position y, a time of $[y/128]\times 7.8$ ms needs to be subtracted, where $[y/128]$ indicates the integer closest to $y/128$. In Fig. 7, the source is at ACTX = 507 in the XIS1, which corresponds to ACTY = 507 in the XIS3. The time required for readout is thus $[507/128]\times 7.8$ msec = 31.2 msec.

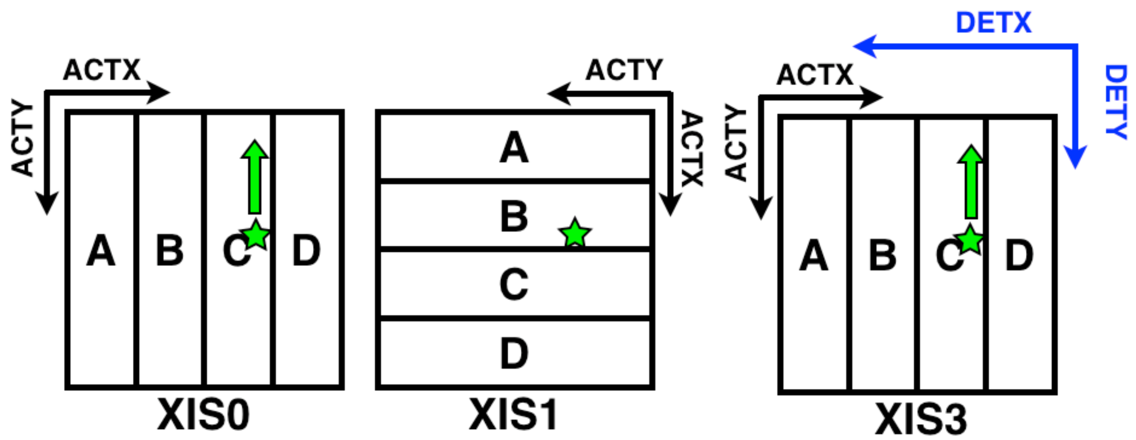

Figure 6: Layout of the ACTXY and DETXY coordinate of each sensor. The four segments (A, B, C, and D) are shown with black boxes. The green star shows the center of the source position, while the green arrows show the direction of the read out in the XIS0 and XIS3.

2. Apply the arrival time correction with the following command.

```
〉fcalc xi0_timp_uf_new_reduction.evt TIME " TIME - 0.0312 "
```

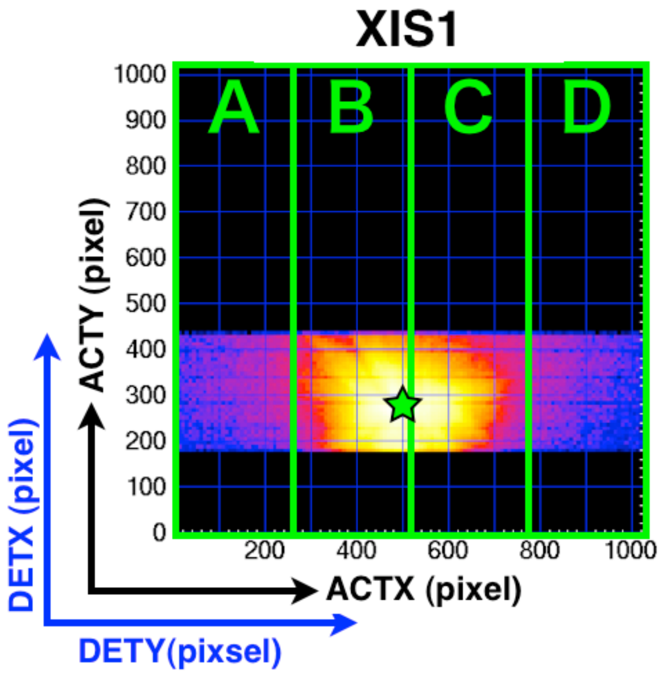

Figure 7: XIS1 image in the ACTXY coordinate. The four segments (A, B, C, and D) are shown with green boxes. The green star shows the center of the source position.

3 Prepartion for the spectral fits

3.1 Making the region files

Region files need to be made in two different coordinates.

3.1.1 For spectral and RMF files

The region files in the ACTX-RAWY coordinate are used for source PHA, background PHA, and RMF files.

```
⟩ xselect
> Enter session name > [xsel]
xsel:SUZAKU > read eve xi3_timp_uf_new_reduction.evt ./
xsel:SUZAKU-XIS3-TIMING > set xybinsize 1
xsel:SUZAKU-XIS3-TIMING > set xyname ACTX RAWY
xsel:SUZAKU-XIS3-TIMING > ext image
```

In the example (Fig.8 left panel), the source is centered at ACTX = 750. Considering the pile-up, we extract the source events from a box annulus region of 200×1024 − 60×1024. On the other hand, we set the background extraction region centered at ACT = 300 with the same size with 200×1024. Save the regions in the DS9 (`src-ACTX-RAWY.reg` and `bgd-ACTX-RAWY.reg`).

3.1.2 For ARF file

Make another source extraction region file for an ARF file. This time, the region should be in the DETX-DETY coordinate.

```
⟩ xselect
> Enter session name > [xsel]
xsel:SUZAKU > read eve xi3_timp_uf_new_reduction.evt ./
xsel:SUZAKU-XIS3-TIMING > set xyname DETX DETY
xsel:SUZAKU-XIS3-TIMING > ext image
xsel:SUZAKU-XIS3-TIMING > sao
```

An example is shown in Fig.8 (left panel). The source is centered at DETX = 274 (In XIS3, DETX = 1024 − ACTX). We use the same region size to (200×1024 − 60×1024) pixel with the source region in the ACTX-ACTY coordinate. Save the regions in the DS9 (`src-DETX-DETY.reg`).

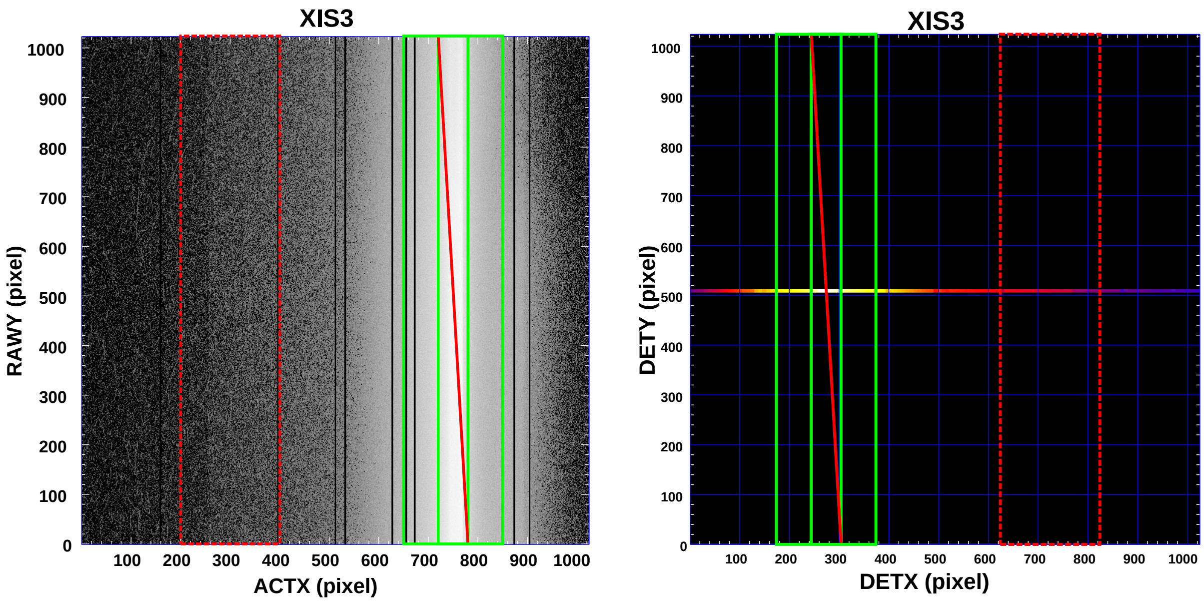

Figure 8: Images in the ACTX-RAWY coordinate (left panel) and in the DETX-DETY coordinate (right panel) on ds9 image. In the image, the green solid box annulus is the source region, while the red dashed box is the background region.

3.2 Making the PHA files

3.2.1 Extract PHA files

Extract a source and a background PHA files using the region files in §3.1.1.

```
⟩ xselect
> Enter session name > [xsel]
xsel:SUZAKU > read eve xi3_timp_uf_new_reduction.evt ./
xsel:SUZAKU-XIS3-TIMING > set xyname ACTX RAWY
xsel:SUZAKU-XIS3-TIMING > filter region src-ACTX-RAWY.reg
xsel:SUZAKU-XIS3-TIMING > ext spec
xsel:SUZAKU-XIS3-TIMING > save spec src.pha
The data will be rebinned using xsl_suzaku_xis_rebinspec
> Group ( or rebin ) the spectra before outputting?> [no]
Wrote spectrum to src.pha

xsel:SUZAKU-XIS3-TIMING > clear region
xsel:SUZAKU-XIS3-TIMING > filter region bgd-ACTX-RAWY.reg
xsel:SUZAKU-XIS3-TIMING > ext spec
xsel:SUZAKU-XIS3-TIMING > save spec bgd.pha
The data will be rebinned using xsl_suzaku_xis_rebinspec
> Group ( or rebin ) the spectra before outputting? > [no]
Wrote spectrum to bgd.pha
```

3.2.2 Edit the exposure time information

The exposure time for the P-sum data should be edited manually by users. The value can be found by the following command.

```
⟩ fkeyprint src.pha ONTIME

# FILE: src.pha
# KEYNAME: ONTIME

# EXTENSION: 0
ONTIME = 2.366402239912748E+04 / On-source time
# EXTENSION: 1
ONTIME = 2.366402239912748E+04 / On-source time
# EXTENSION: 2
ONTIME = 2.366402239912748E+04 / On-source time
# EXTENSION: 3
ONTIME = 2.366402239912748E+04 / On-source time
```

The value should be inserted in the header to the PHA files.

```
〉fparkey
Keyword value[] 2.366402239912748E+04
Name of FITS file and [ext#][] src.pha+0
Keyword name[] EXPOSURE

〉fparkey
Keyword value[2.366402239912748E+04]
Name of FITS file and [ext#][] bgd.pha+0
Keyword name[EXPOSURE]
```

3.3 Making the RMF and ARF files

The follow instruction shows how to generate the RMF and ARF files. At the moment, the `xisrmfgen` does not support to the P-sum data.

1. Make the RMF file. Select the Normal clocking mode, the 3×3 editing mode, and the change injection off, and use the region file in §3.1.1.

```
〉xisrmfgen
xisrmfgen version 2009-02-28
Name of input PI or IMAGE file or NONE[none]
Name of output RMF[] xis3.rmf
Instrument Name (XIS0,XIS1,XIS2,XIS3)[XIS3]
Date of observation (yyyy-mm-ddThh:mm:ss.sss or Suzaku time)[]\
    2009-12-17T01:29:11.000
CCD clock mode (normal,burst,psum)[normal]
Edit mode of telemetry (5x5,3x3,2x2,timing)[3x3]
Window option (0:off 1:1/4 2:1/8 3:1/16).[0]
Charge Injection (0:none 1:diagn 2:SCI-54 3:SCI-108)[0]
```

2. Make the ARF file. Select the DETXY source mode and use the region file in §3.1.2. Note that the XIS attitude file can be found in the `auxil` directory.

```
⟩ xissimarfgen
xissimarfgen version 2009-01-08
Written by Y.ISHISAKI (TMU)
Instrument Name (XIS0,XIS1,XIS2,XIS3)[] XIS3
source mode (SKYFITS,DETFITS,J2000,SKYXY,DETXY,UNIFORM)[DETXY]
source position x (pixel)[274]
source position y (pixel)[512]
number of ARF regions[1]
region mode (SKYFITS,DETFITS,SKYREG,DETREG,etc)[DETREG]
region file #1[]src-DETX-DETY.reg
output arf file #1[] xis3.arf
limit mode (ACCURACY,NUM_PHOTON)[NUM_PHOTON]
number of photons for each energy bin[1000000]
input PHA or EVENT file to get observation mode[src.pha]
XIS det-coordinates mask image file[none]
input GTI file[src.pha]
input attitude file[../../auxil/ae404075070.att.gz]
input rmf file[] xis3.rmf
energy step file[sparse]
```

3. Merge RMF and ARF files.

```
⟩ marfrmf
I/p RMF filename[] xis3.rmf
I/p ARF filename[] xis3.arf
O/p RMF filename[] xis3.rsp
* marfrmf 3.2.6
... HDUCLAS3 in o/p RSP_MATRIX set to FULL
keyword not found in header
RDARF1 1.1.0 WARNING: reading FILTER
keyword not found in header
RDARF1 1.1.0 WARNING: reading DETNAM
* marfrmf 3.2.6 completed successfully
```

4 Validation

The calibration and data processing for P-sum data remain primitive. We show timing and spectral analyses of the sample data as an evaluation to the current level of maturity.

4.1 Timing

We evaluate the timing accuracy of the P-sum mode. Because the timing in Cyg X-1 may have an intrinsic energy dependence, we constructed several band-limited lightcurves and derived the delay from the 2–3 keV curve by cross-correlation. The relative shifts thus obtained are plotted as a function of energy in Fig. 9. The possible jump of the shifts between the XIS and the HXD/PIN data is considered to be the XIS time assignment error with respect to the HXD. In the sample data, the value was constrained to be 36 ± 22 ms, assuming a linear energy dependence.

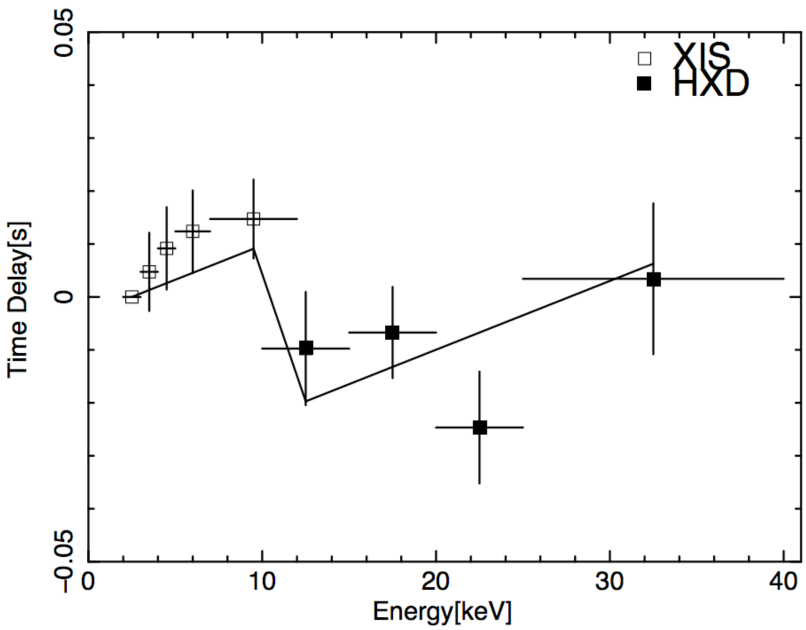

Figure 9: Time delay as a function of energy bands derived by correlating band-limited light curves. The offset from the 2–3 keV curve is plotted. The white and black boxes show the XIS and HXD data, respectively. The monotonic increase is considered to be an intrinsic feature of the object, while the discontinuous jump at 10 keV is attributable to an instrumental reason that the XIS time is not correct with respect to the HXD.

4.2 Spectrum

We compare the result of spectral fitting of the Normal mode and the P-sum mode data. We use the same model for both data; const×wabs×(deskbb+powerlaw+gauss) (Makishima et al. 2008). The const correction is introduced to account for the possible normalization difference between the Normal and Psum modes (const=1 for the Normal and is a free parameter for the P-sum). We set the same region size to (200×1024 – 60×1024) pixel with the source region in the ACTX-ACTY coordinate for doth data (§3.1).

It is known that the gain and energy offset is time-dependent for the P-sum response. Users need to find these values from their trend and incorporate into the spectral fitting using the gain correction in the `XSpec`.

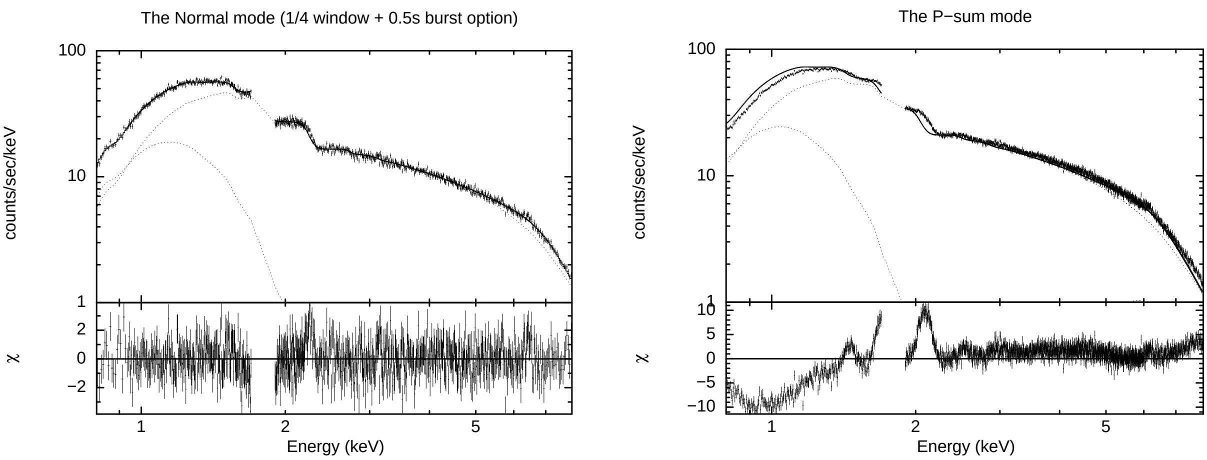

Figure 10: Result of the spectral fitting of the Normal mode with 1/4 window and 0.5 s burst option (left panel) and the P-sum mode (right panel). The best-fit model was derived from the Normal mode data, which was applied to the P-sum data only by thawing the normalization value.

Table 1: Best-fit parameters of the spectral fits.

Component	Parameter	Normal (1/4 win+0.5s bst)	P-sum
const	–	1	$0.753 \pm (4.717 \times 10^{-4})$
diskbb	$T_{\rm in}$(keV)	0.195 ± 0.006	0.195 (fixed)
	Norm	$(6.365 \pm 1.744) \times 10^5$	6.365×10^5 (fixed)
powerlaw	Γ	$1.9 \pm (2.2 \times 10^{-2})$	1.9 (fixed)
	Norm	2.976 ± 0.084	2.976 (fixed)
wabs	$N_{\rm H}$ (10^{22} cm^{-2})	0.657 ± 0.002	0.657 (fixed)
gain	gain	N/A	0.9125
	offset (keV)	N/A	0.0003

We show the history of the gain and offset since the Suzaku launch (Fig. 11). First, find the days from the launch for your observation as follows. In the example, the observation start time is 3.14×10^8 s in the mission time, which corresponds to 1621 days from launch.

```
⟩ fkeyprint src.pha TSTART

# FILE: src-ACTX-RAWY.pha
# KEYNAME: TSTART

# EXTENSION: 0
TSTART = 3.143286210000000E+08 / time start
# EXTENSION: 1
TSTART = 3.143286210000000E+08 / time start
# EXTENSION: 2
TSTART = 3.143286210000000E+08 / time start
# EXTENSION: 3
TSTART = 3.143286210000000E+08 / time start

⟩ aetimecalc
aetimecalc version 2007-05-14
Written by Y.ISHISAKI (TMU)
Built on ANL HEADAS converter 1.81 for ANL version 1.81
any of prompt/mission/date/date_tt/mjd/mjd_tt/yday[] mission
mission time, i.e. accumulative seconds from date0[] 3.1432862100000E+08
Y+1621.063 (dy)
```

In Fig. 11, the gain value is about 4 eV/ch and the offset is about 0.3 eV at the time of the observation. The energy per channel is 3.65 eV, thus the gain value per 1 eV is 3.65/4 = 0.9125. The average offset value is 0.0433 and 0.0003 keV for each the XIS0 and XIS3.

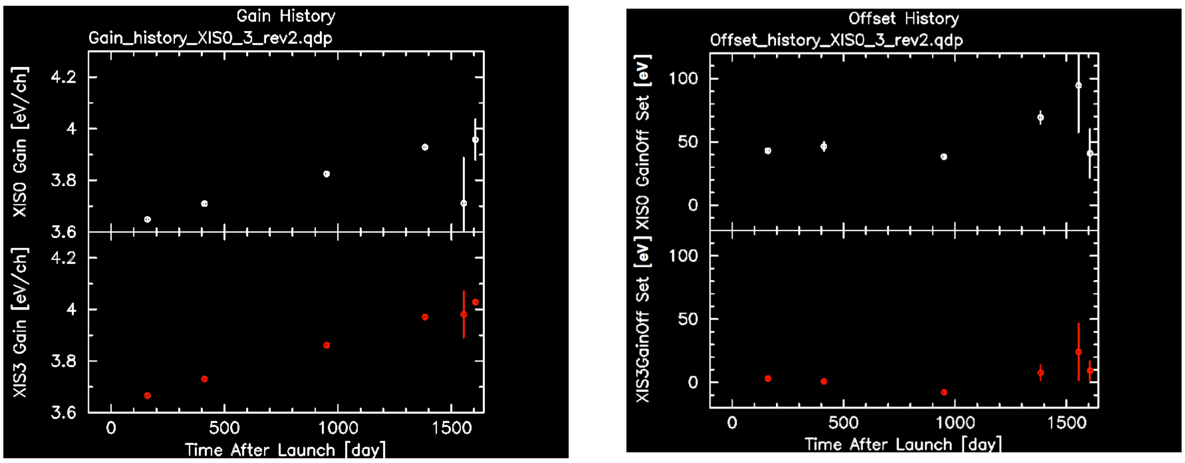

Figure 11: History of the gain (left panel) and the offset of gain (right panel) from the Suzaku launch. The top and bottom panels show the gain and the offset information of the XIS0 and XIS3, the respectively.

Adjust the gain parameters in `XSpec` for your fitting.

```
XSPEC12 > gain 1:1 0.9125 0.0003
```

Fig. 10 and Table 1 show the results of spectral fitting of the Normal and P-sum data. The best-fit spectral parameters were derived from the Normal data, which were applied to the P-sum data thawing only the normalization values.

References

Ibragimov et al. 2005, MNRAS, 362, 1435
Makishima et al. 2008, PASJ, 60, 585
Negoro et al. 1994, ApJ, 423, L127
Remillard & McClintock, 2006, Annu. Rev., 44, 1, 49