

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

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Revision history

Revision	Description
20100724	First edition
20150326	Correction & Major revision in §4

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 ($8 \text{ s}/1024 \sim 7.8 \text{ ms}$) 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 middle 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 $\sim 245 \text{ counts/sec}$) and the Normal mode with a 1/4 window + 0.5 s burst option ($\sim 192 \text{ counts/sec}$). We use events in the PSF wing for the timing and spectral analysis.

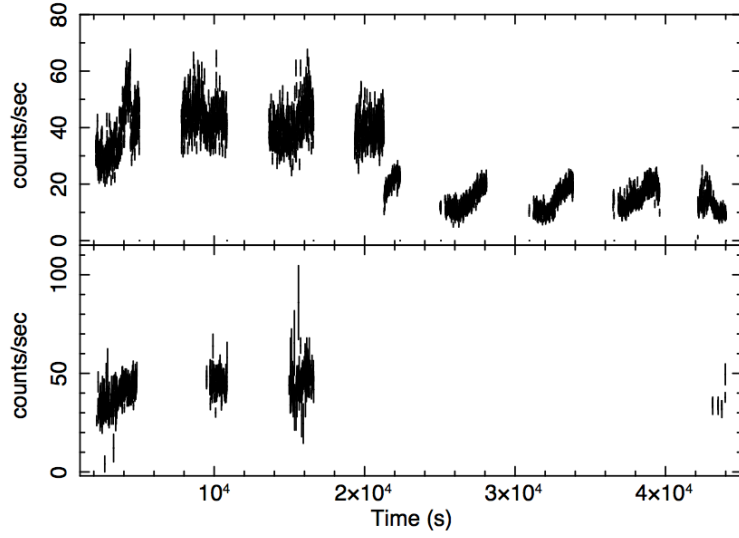


Figure 1: Light curve made by the cleaned event files of the XIS0 (top panel) and the HXD (bottom panel). Events were extracted from an annular box (see §3.1). The bin time is 8.0 s. The telemetry is saturated in the latter half of the observation.

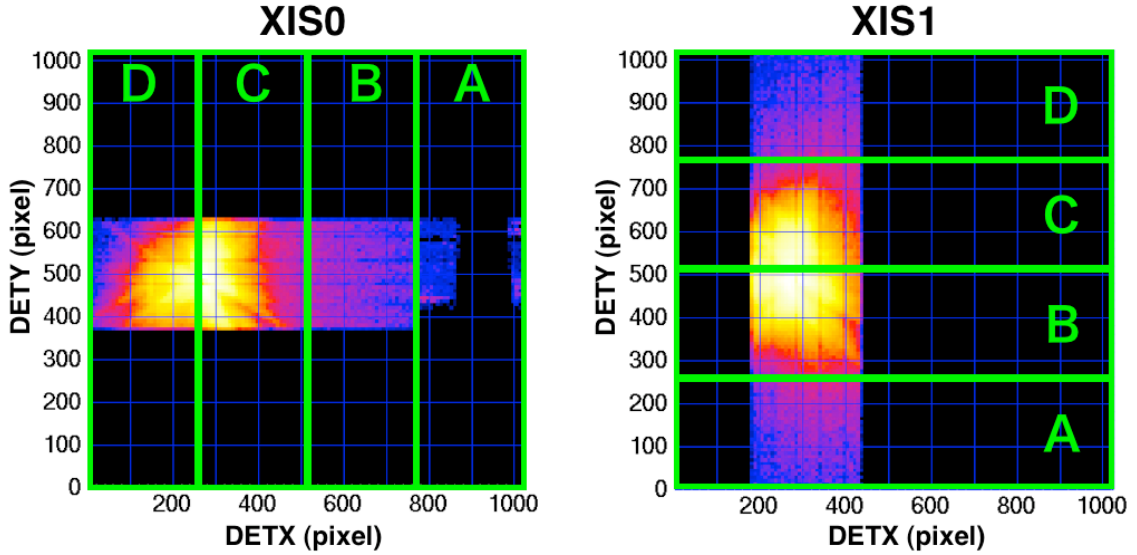


Figure 2: Images of XIS0 (left panel) and XIS1 (right panel). The four segments (A, B, C, and D) are shown in the green rectangles.

1.2 Coordinates

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

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.

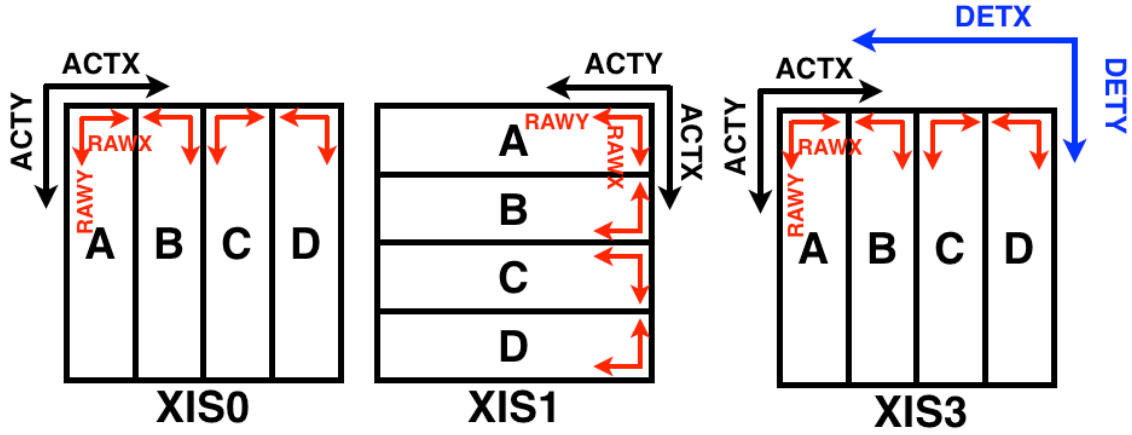


Figure 3: Layout of the RAWXY, ACTXY, and DETXY coordinates in each XIS sensor. The four segments (A, B, C, and D) are shown with black boxes.

2 Data reduction

2.1 Event reprocessing

The following instruction shows how to reprocess the events from the unfiltered event file 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 xynname 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 xynname 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

```

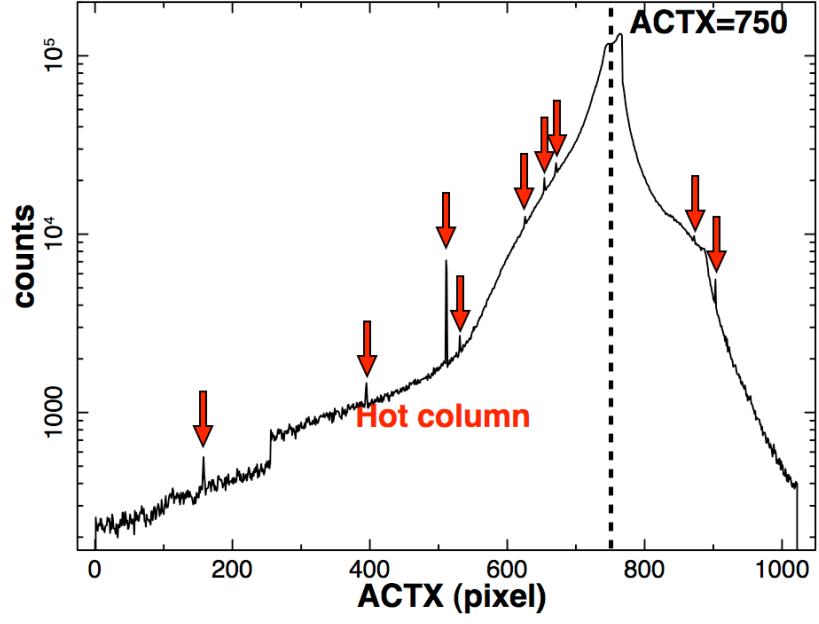


Figure 4: Histogram of ACTX versus counts of the P-sum data (XIS3). The black dashed line shows the source center. The red arrows show positions of the hot columns.

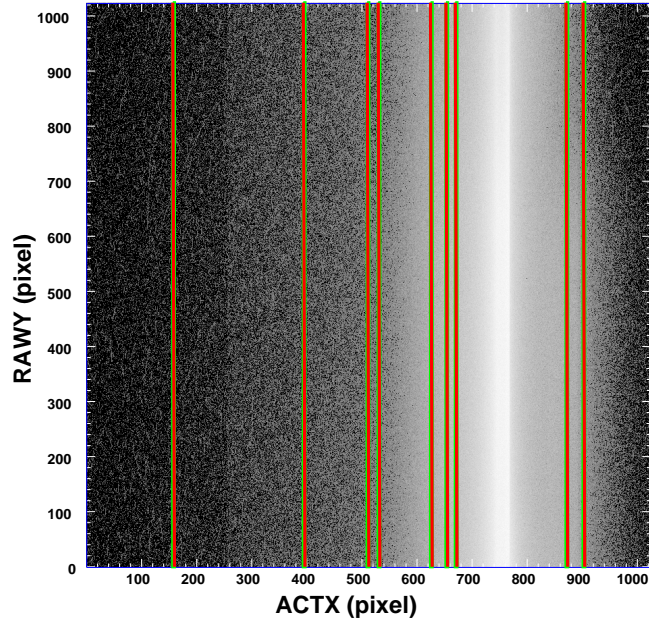


Figure 5: Image of the P-sum data (XIS3). The thin green boxes are masked regions for hot columns, which are centered at $ACTX = 158, 395, 511, 531, 626, 654, 671, 872$ and 903 with a size of 3×1024 pixels.

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.

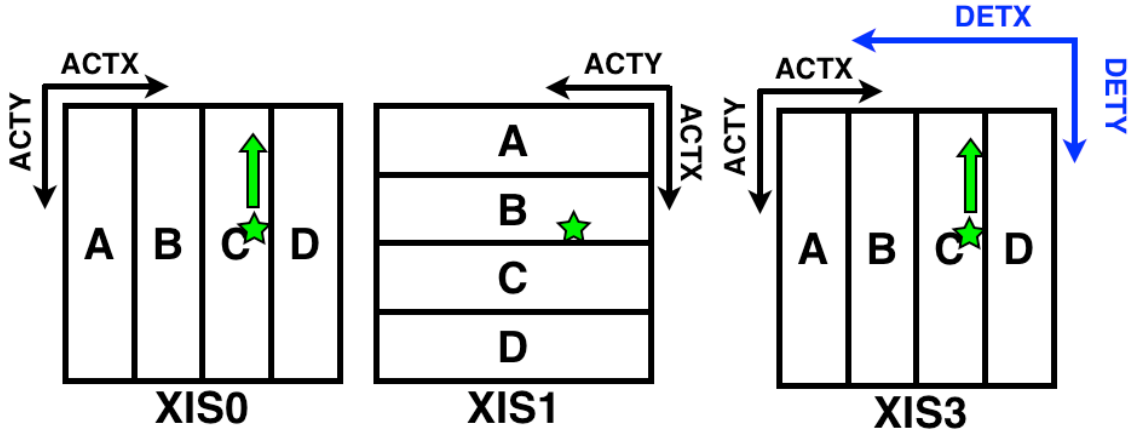


Figure 6: Layout of the ACTXY and DETXY coordinate of each sensor. The four segments (A, B, C, and D) are shown with black boxes. The green star shows the center of the source position, while the green arrows show the direction of the read out in the XIS0 and XIS3.

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

```
> fcalc xi0_timp_uf_new_reduction.evt xi0_timp_uf_new_reduction_fcalc.evt TIME "TIME
- 0.0312"
```

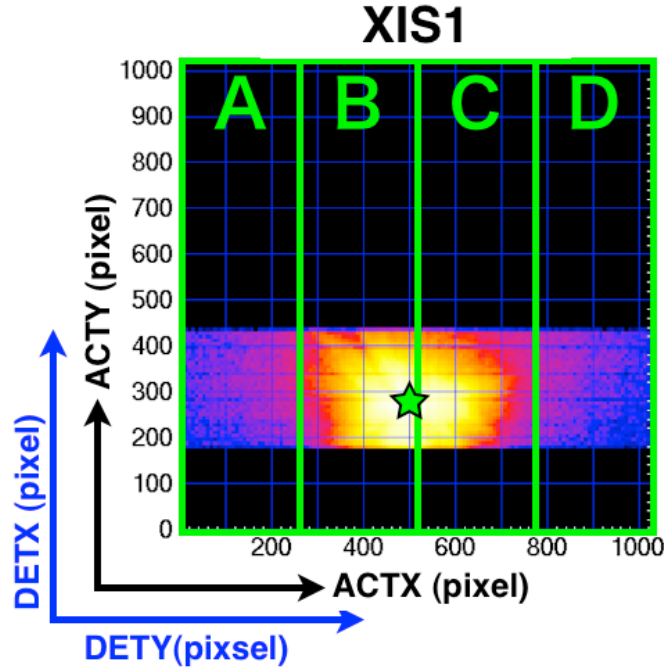


Figure 7: XIS1 image in the ACTXY coordinate. The four segments (A, B, C, and D) are shown with green boxes. The green star shows the center of the source position.

3 Preparation 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 $200 \times 1024 - 60 \times 1024$. 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 `bkg-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 xynome 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`).

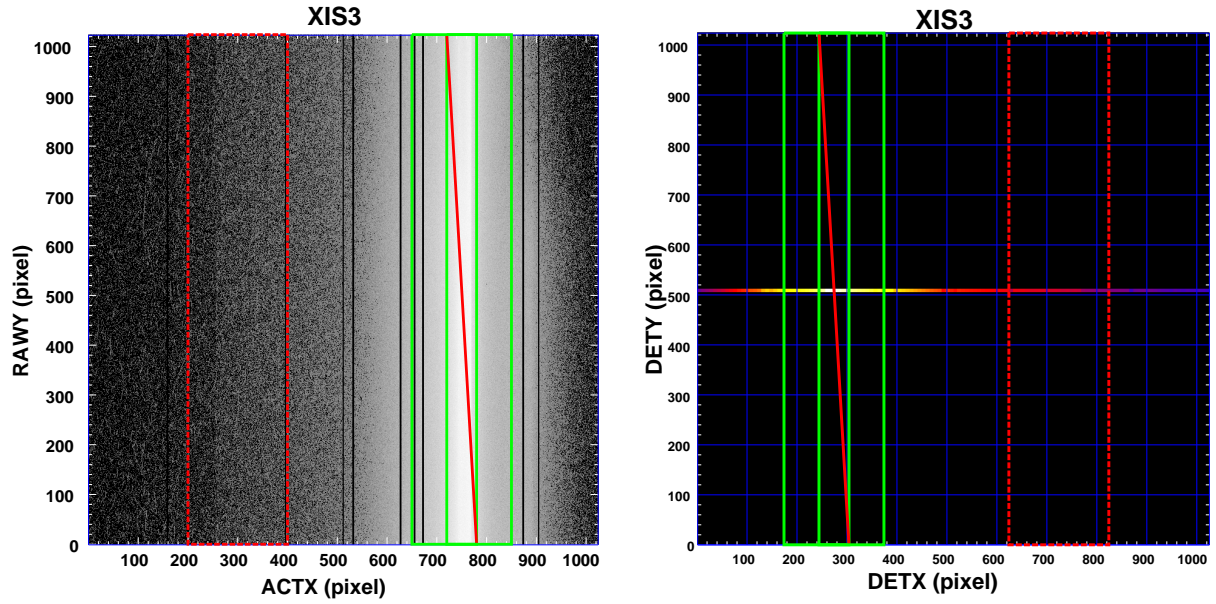


Figure 8: Images in the ACTX-RAWY coordinate (left panel) and in the DETX-DETY coordinate (right panel) on ds9 image. In the image, the green solid box annulus is the source region, while the red dashed box is the background region.

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 xynome 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.

1. Make the RMF file.

```

> xisrmfgen
xisrmfgen version 2012-04-21
Name of input PI or IMAGE file or NONE[] src.pha
Name of output RMF[] xis3.rmf

```

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 2010-11-05
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[] 100000
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[] full

```

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 Calibration

The calibration for P-sum data were primitive until June 2014. It was improved greatly by the release of new CALDB files on July 2014¹. In this section, we describe the current status of the P-sum mode calibration.

4.1 Spectrum

P-sum is available only for FI chips (XIS0,1,3). After the micrometeorite hits, we stopped supporting the P-sum operation of the XIS2 and XIS0. Therefore, the calibration is guaranteed only for XIS3 (all times as of writing) and XIS0 (until around the end of 2009).

Unlike the Normal mode, the difference of the response among different segments is quite large due mainly to the non-use of the spaced-row charge injection technique. Therefore, the ^{55}Fe sources illuminating the segment A and D cannot be applied to the segments B and C, in which basically all P-sum targets are positioned. The calibration of the segments A and D is not guaranteed.

We used celestial objects SNR E0102–72 and Perseus cluster for calibration. Table 1 shows the datasets.

Table 1: An observation list for P-sum mode calibration

Object	ID	Date	XIS
E0102–72	101005050	2006.8.25	XIS0, 3
	102022010	2008.2.14	XIS0, 3
	104005010	2009.4.23	XIS0, 3
	104008010	2009.10.11	XIS0*, 3
	104014010	2009.12.1	XIS0 [†] , 3
	105006010	2010.6.20	XIS3*
	105006030	2010.8.29	XIS3
	105006020	2010.12.7	XIS3
	105004050	2010.12.9	XIS3*
Perseus cluster	106005010	2011.07.27	XIS 3

* These data cannot be used because the exposure time is too short.

[†] This data cannot be used because of a micro-meteorite hit in 2009.

Figure 9 shows the spectral model fit of P-sum mode data both before and after the calibration. It is clear that the gain calibration has greatly improved. The spectral model of E0102–72 follows Plucinsky et al. (2008). Figure 10 shows the energy offsets between the data and the model. Although the uncertainty is large, the data are consistent with the model. Please note that this calibration only covers the data taken before 2011. We will continue updating the response when new calibration data arrive.

4.2 Timing

We evaluate the timing accuracy of the P-sum mode using two pulsars, PSR 1509–58 and Crab, which we assume to have no intrinsic energy dependence. Figure 11 shows the lightcurve folded by their periods. In both sources, the clock of the XIS is several ms ahead of that of the HXD. Table 2

¹see http://www.astro.isas.ac.jp/suzaku/caldb/doc/xis/caldb_update_20140624_README.pdf

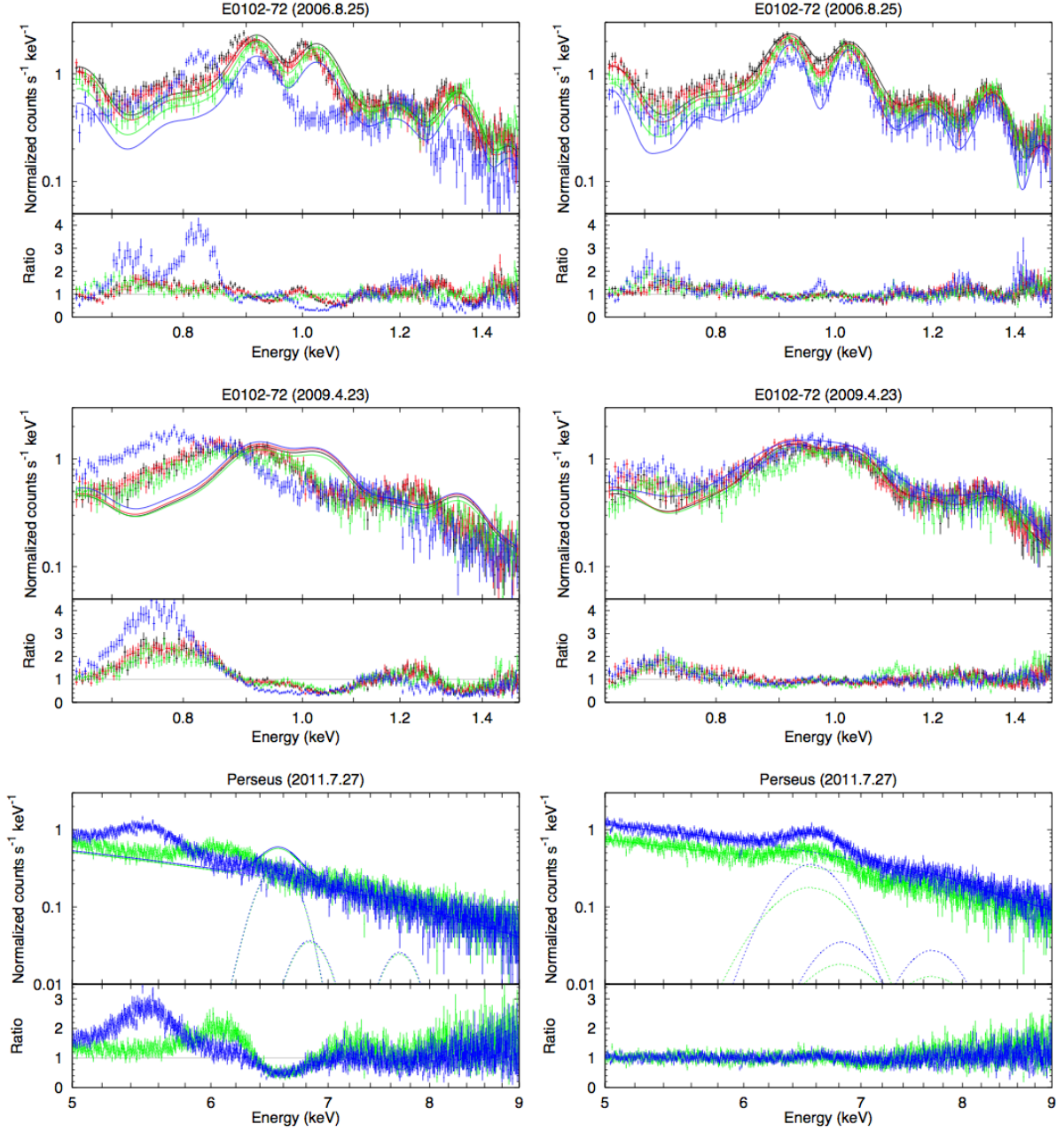


Figure 9: Comparison of spectra before (left) and after (right) calibration. Black, red, green, and blue respectively indicate XIS0 Segment B, XIS0 Segment C, XIS3 Segment B, and XIS3 Segment C. The top and middle panels show E0102–72, while the bottom panel shows Perseus cluster result.

shows the results of the cross-correlation calculation. We find that the XIS clock is about 24 ms ahead. If you are interested in the relative time between XIS and HXD in the order of 10 ms, you should adjust the XIS clock with the following command.

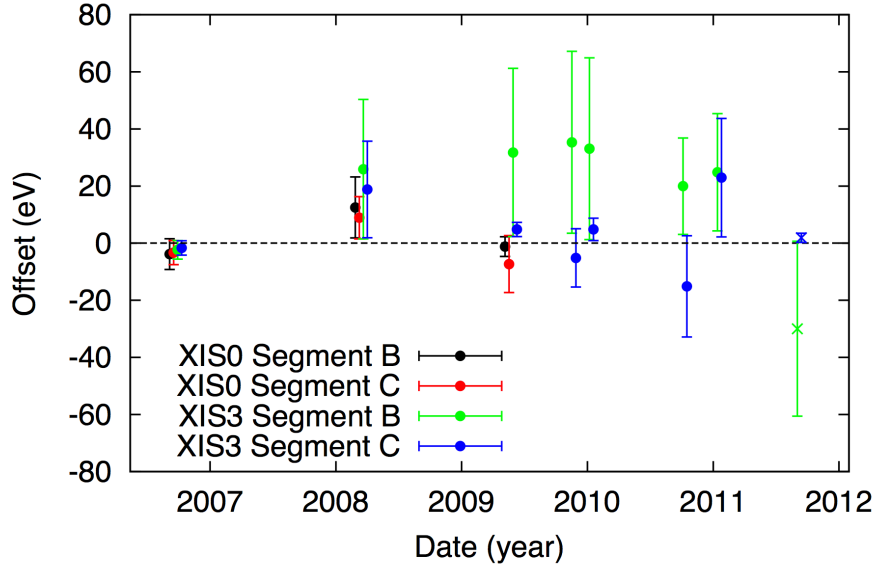


Figure 10: Energy offsets after calibrations. The values are calculated with `gain fit` command in `xspec`. When a value is positive, the photon energy is larger than the true value, and vice versa. Circle points show E0102–72, and the cross ones show Perseus cluster.

```
> fcalc xi0_timp_uf_new_reduction.fcalc.evt xi0_timp_uf_new_reduction.fcalc_offset.evt TIME
"TIME - 0.024"
```

Table 2: Timing Offsets

Object	Period	Timing offset
PSR 1509–58	151.358 ms	24.46 ± 0.11 ms
Crab	33.628 ms	23.19 ± 0.03 ms

References

- Ibragimov et al. 2005, MNRAS, 362, 1435
Ishisaki et al. 2007, PASJ, 59, S113
Negoro et al. 1994, ApJ, 423, L127
Plusinsky et al. 2008, SPIE Conf., 7011, 2
Remillard & McClintock, 2006, Annu. Rev., 44, 1, 49

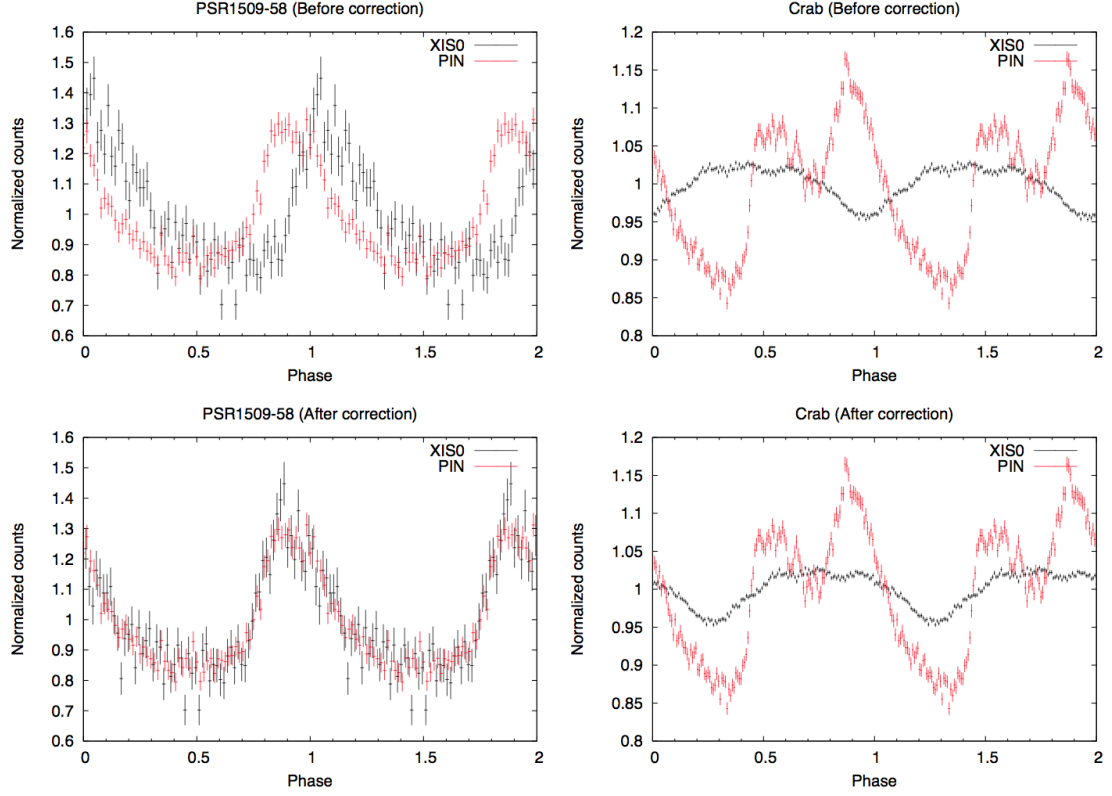


Figure 11: Light curves folded by the period of the pulsars. Only the XIS0 and HXD-PIN data are shown for clarity. The left panels show PSR 1509–58, and the right ones show Crab. The upper panels show the result without offset corrections, while the lower panels show with the correction. For the Crab, the timing resolution of the XIS does not fully resolve the profile.