How to check pile up of Suzaku XIS data

From HongoWiki

This document explains how to check the significance of photon pile-up in the Suzaku XIS data, and is prepared by Shin'ya Yamada (http://www-utheal.phys.s.u-tokyo.ac.jp/~yamada/homepage/), a member of Makishima group, University of Tokyo, Hiromitsu Takahashi, a menber of Hiroshima University, and supervised by Tadayasu Dotani (http://www.astro.isas.jaxa.jp/~dotani/).

Because all the contents in this page are under development, please use the methods in this page with your own responsibility. However, of course, any comments or suggestions are welcome. Please feel free to contact us (see the URL above).

Contents

Qualitative Guidelines

Here we list qualitative methods useful to detect the photon pile-up in the XIS data. Quantitative methods are explained in the next section.

For the basic information of the photon pile-up, please see the Suzaku technical description in 7.9.1, which is available from the following URL (http://www.astro.isas.ac.jp/suzaku/doc/suzaku_td/node10.html#SECTION00109100000000000000
).

Number Density of incident photons (including NXB)

Photon pile-up is simply determined by the number of incident photons per exposure per pixel (=Photon/exposure/pixel). For example, if the number density exceeds 1 photon/exposure/pixel, it is clear that significant fraction of detected photons is piled-up. In reality, because X-ray events can extend up to 4 pixels, photon pile-up becomes significant at much lower number density of photons. Although it is not trivial to determine an appropriate threshold, if we create an image and calculate the surface density of the X-ray events, we can in principle judge the significance of the photon pile-up.

- There are several pitfalls in this method. (Some of them are generally applicable to other methods.)

1. When we estimate the number density of incident photons, we need to consider all the grades of X-ray events. However, most of the grade 7 events is screened on board. Thus the X-ray data in the telemetry is not enough to estimate the true incident photon flux.
2. Photon pile-up is determined by the number density of incident photons. However, what we can measure is the number density of X-ray events after the photon pile-up. If the photon pile-up is very significant, number of detected events becomes smaller and can mimic data with little pile-up.
3. Because the fraction of the photon pile-up is proportional to the flux squared, pile-up is sensitive to the bright phase of the source if the source is time variable. Therefore, it is important to select only the bright phase of the source to check the pile-up of the variable sources.

Point Spread Function (PSF) in the case of a point source

This method can be applied only for point sources. Because the photon pile-up generally reduce the number of X-ray events, it tends to make the point source image dull. If the source image is compared with the PSF not affected by the pile-up and significant difference is found in the image peak, it means that photon pile-up occurred at least at the image center. Since the fluctuation of the satellite attitude also smears the shape of the PSF, it is necessary to use the actual image of the point source as the template of the PSF.

Grade Branching Ratio (in particular, Grade 1 ratio)

Grade branching ratio may be useful to detect the photon pile-up as some of the grade is sensitive to the pile-up. Although the pile-up tends to increase the ratio of split events, a fraction of the split events is not a useful indicator of pile-up because of the energy dependence of the split fraction. However, Grade 1 event can be a good criterion. Grade 1 events are rarely created by X-ray photons, while photon pile-up can easily create them. This means grade 1 fraction can be a good indicator of pile-up.

Changes of the spectral shape (in particular, hard tail)

Photon pile-up generally reduce the number of detected events, while the piled-up events mimic the high energy events. This means photon pile-up distorts the observed energy spectrum; X-ray flux decreases around the peak of the energy spectrum, while the hard flux increases. The intrinsic spectral shape critically affect the appearance of the hard tail due to the pile-up. When the intrinsic spectrum is soft, even mild pile-up creates a noticeable hard tail. On the other hard, when the intrinsic spectrum is hard, a hard tail due to pile-up is difficult to observe. Because the intrinsic spectral shape is not known in most cases, it is often required to create energy spectra for several annuli with different inner/outer radii and to compare their shape in the hard band. Because the PSF of the Suzaku telescopes have little energy dependence, a hard tail prominent only in the image center indicate significant photon pile-up.

Quantitative Guidelines

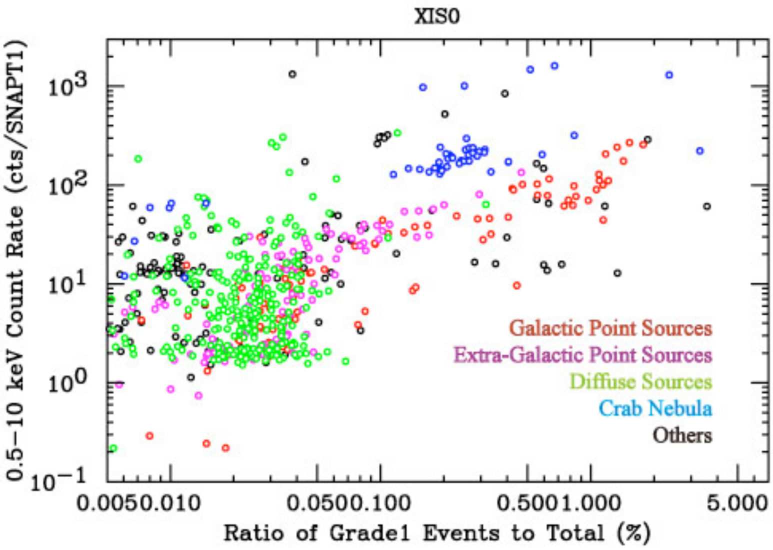
We have explained several methods useful to check the photon pile-up. However, it is difficult to select a single method good for all sources. Thus, we show several examples of the Suzaku XIS data, on which we have been working. Because analysis of photon pile-up is in progress, description in this page may subject to change in near future. Readers are encouraged to check the data by themselves, even if the same data described in this page are used.

Before checking the pile-up effect, it is essential **to reject the data which suffered from the telemetry saturation**. This can be easily done by using hk/*tel_uf.gti file.

Grade1 event

We calculated fractions of the Grade1 events for almost all the Suzaku archive data.

This graph shows a correlation between the fractions of the Grade 1 events and the average count rates in XIS0 (Counts/exposure). It can be seen from the correlation that the fraction of the Grade1 events can be a criterion for the photon pile-up.



Details of the analysis is summarized in this report,

- http://www-utheal.phys.s.u-tokyo.ac.jp/~yamada/documents/Grade1EventInSuzakXIS_Syamada_20090610.pdf

Note that energy range of the analysis should be limited above 3 keV to avoid complexity due to the Si edge (as shown in the report).

Observations with high grade1 fraction are listed below,

- http://www-utheal.phys.s.u-tokyo.ac.jp/~yamada/documents/Grade1EventInSuzakXIS_Syamada_20090610.htm

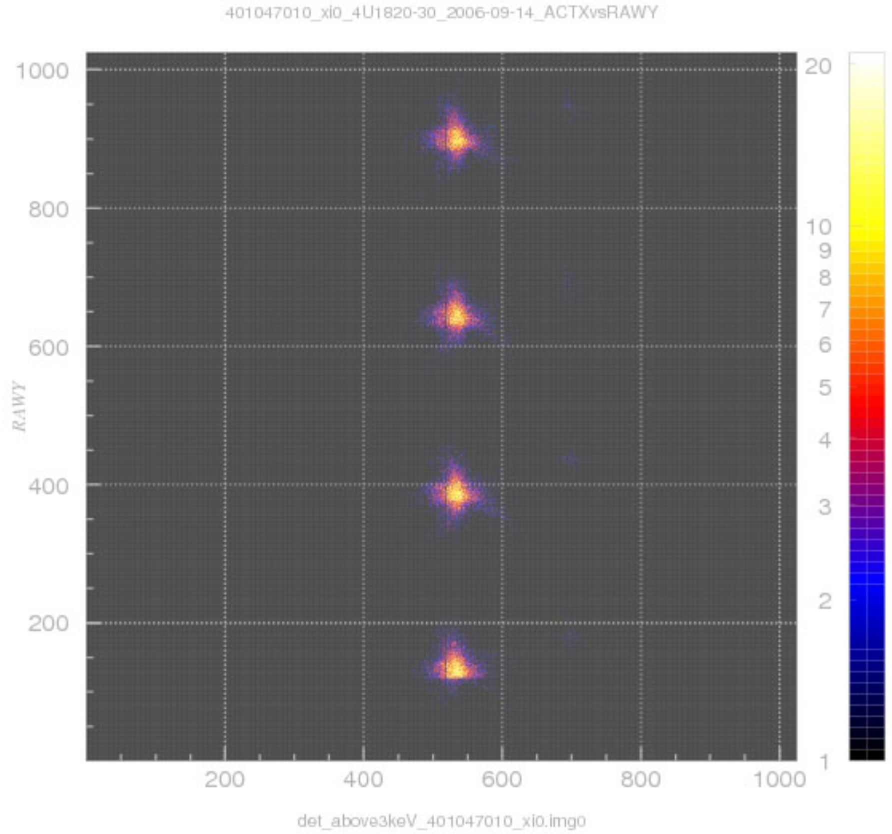
Since it is difficult to set a clear grade1 fraction which divides the pile-up affected and pile-up free data, caution should be payed when this method is applied. Grade1 image may be one of the useful methods to determine the region affected by the photon pile-up.

Grade1 images of the top 100 sources with high grade1 fraction are uploaded below,

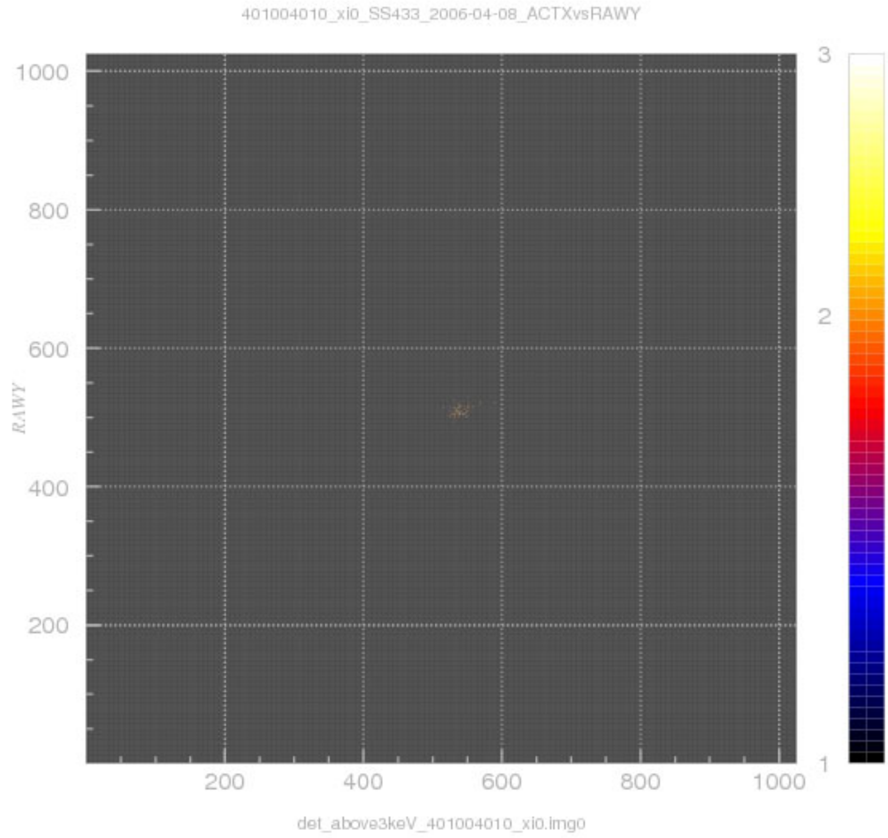
- XIS0 Grade1 image are found in http://www-utheal.phys.s.u-tokyo.ac.jp/~yamada/documents/XIS0_Grade1_Rank100.pdf
- XIS1 Grade 1 image ara found in http://www-utheal.phys.s.u-tokyo.ac.jp/~yamada/documents/XIS1_Grade1_Rank100.pdf

We show two typical examples below.

- Pile-up affected case : Grade1 ratio = 1.53 %, 4U 1820.



- Pile-up free case: Grade1 ratio = 0.17%, SS433.



PSF method

This may be the most reliable method to determine the pile-up free region of point sources. This section is summarized by Hiromitsu Takahashi in Hiroshima University. To estimate the region where pile up effects, it is useful to draw the point-spread function (PSF) of your data and to check the count rate per one CCD exposure at the image peak.

Below, I show you three examples: Crab, a pile-up free case, and a moderately piled-up case, and the concrete methods when using "ximage".

1. Crab (Obs Id: 101004020)
2. Case of no pile up: Aql X-1 (402053020)
3. Case of moderately pile up: Serpens X-1 (401048010)

Crab observations with the Full-window mode and 0.1-s burst option were used for XIS calibration, and we here assume the Crab data are free from the pile-up effect. Since Crab is the extended source (not the point source), please do not use the Crab PSF for the comparison of the PSF "shapes" with other sources. When you analyze much brighter sources, please see the Cygnus X-1 (100036010) analysis by Makishima et al. (2008) in detail.

Case (1): Crab (Full-window, 0.1-s burst)

In the directory, 101004020/xis/event_cl,

- Check the window mode and the burst option

```
%> fkeyprint ae101004020xi1_0_3x3b008b_cl.evt SNAPTI1
SNAPTI1 =             0.100000 / Exposure of Window 1 in Normal and Burst clock
fkeyprint ae101004020xi1_0_3x3b008b_cl.evt DELAY1
DELAY1  =             7.900000 / Time lag of Window 1 start
```

This results means Full window, 0.1-s burst.

```
If the sum of the SNAPTI1 + DELAY1 is
8 s -> Full window
2 s -> 1/4 window
1 s -> 1/8 window
```

The SNAPTI1 corresponds to the exposure of the burst option.

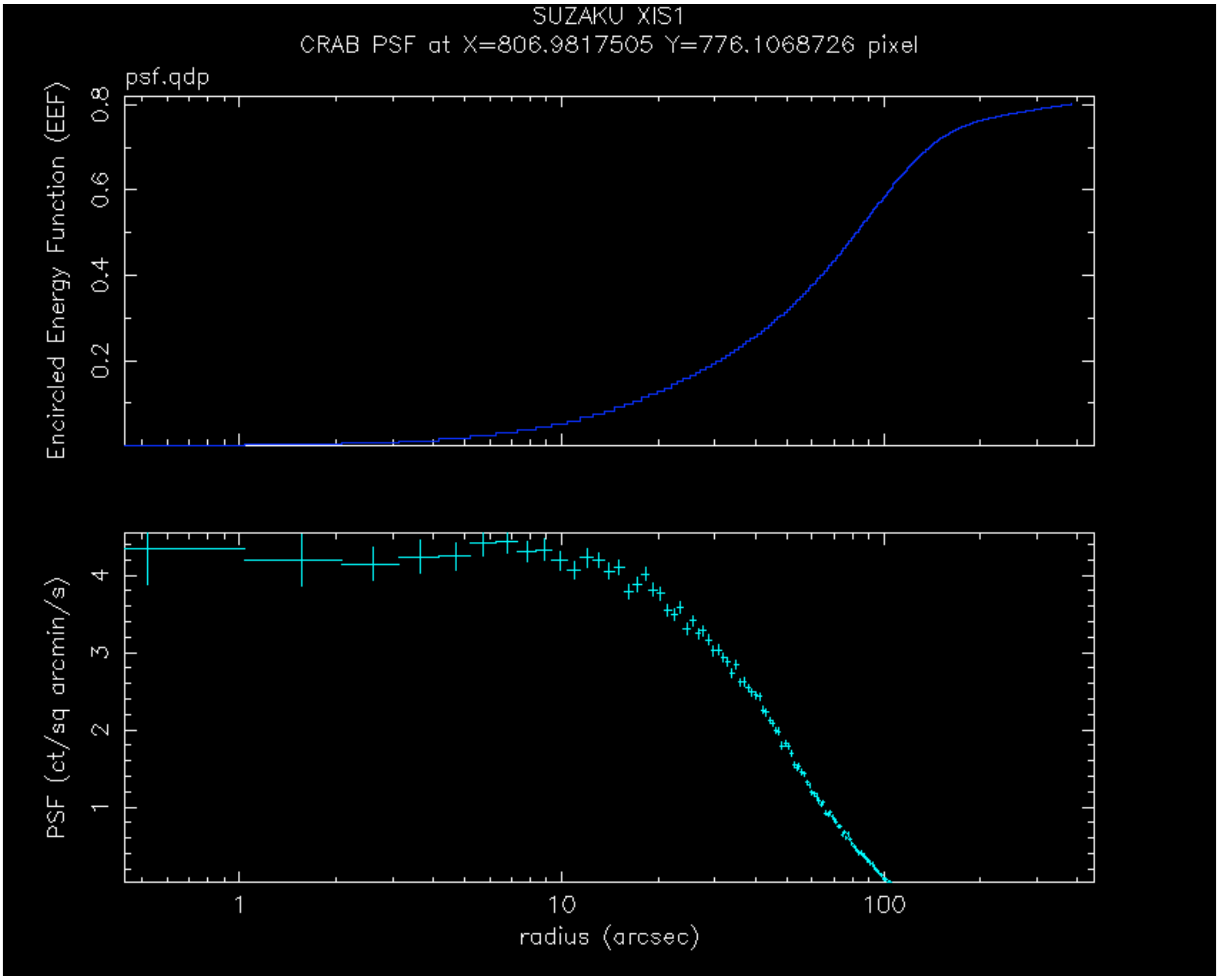
- Create the PSF

```
%> ximage
sss ae101004020xi1_0_3x3b008b_cl.evt
disp
psf/cur

# Left-click (1) the image center and (2) the outer region to calculate the PSF

log y off
plot
we psf_ximage.qdp
quit
exit
```

-> From the PSF (the bottom panel of the second window), we can obtain the count rate at the image peak (R-OBS) of ~4.5 ct/sq arcmin/s. N.B. The unit of the PSF (ct/sq arcmin/s) is divided by the exposure without taking account for efficiency of the burst option.



Since the current observation mode is the full-window mode (8-s CCD exposure) and the 0.1-s burst option, the effective exposure is 0.1/8 = 0.0125 times shorter (the actual count rate is 8/0.1 = 80 times higher).

Therefore, the peak count rate per one CCD exposure (R-CCD) can be obtained in the following way, namely we need to obtain the actual source rate [(R-OBS) * (SNAPTI1+DELAY1)/(SNAPTI1)] and then multiply the CCD exposure [* SNAPTI1];

```
(R-CCD) = (R-OBS) * (SNAPTI1+DELAY1)/(SNAPTI1) * SNAPTI1
        = 4.5 * (0.1 + 7.9)/0.1 * 0.1
        = 36 ct/sq arcmin/s (CCD exposure)
```

Case (2) No pile up : Aql X-1 (402053020)

In the directory 402053020/xis/event_cl

```
### Check the window mode and the burst option ###
fkeyprint ae402053020xi1_0_3x3n091b_cl.evt SNAPTI1
SNAPTI1 =             2.000000 / Exposure of Window 1 in Normal and Burst clock
fkeyprint ae402053020xi0_0_2x2n090a_cl.evt DELAY1
DELAY1  =             0.000000 / Time lag of Window 1 start
```

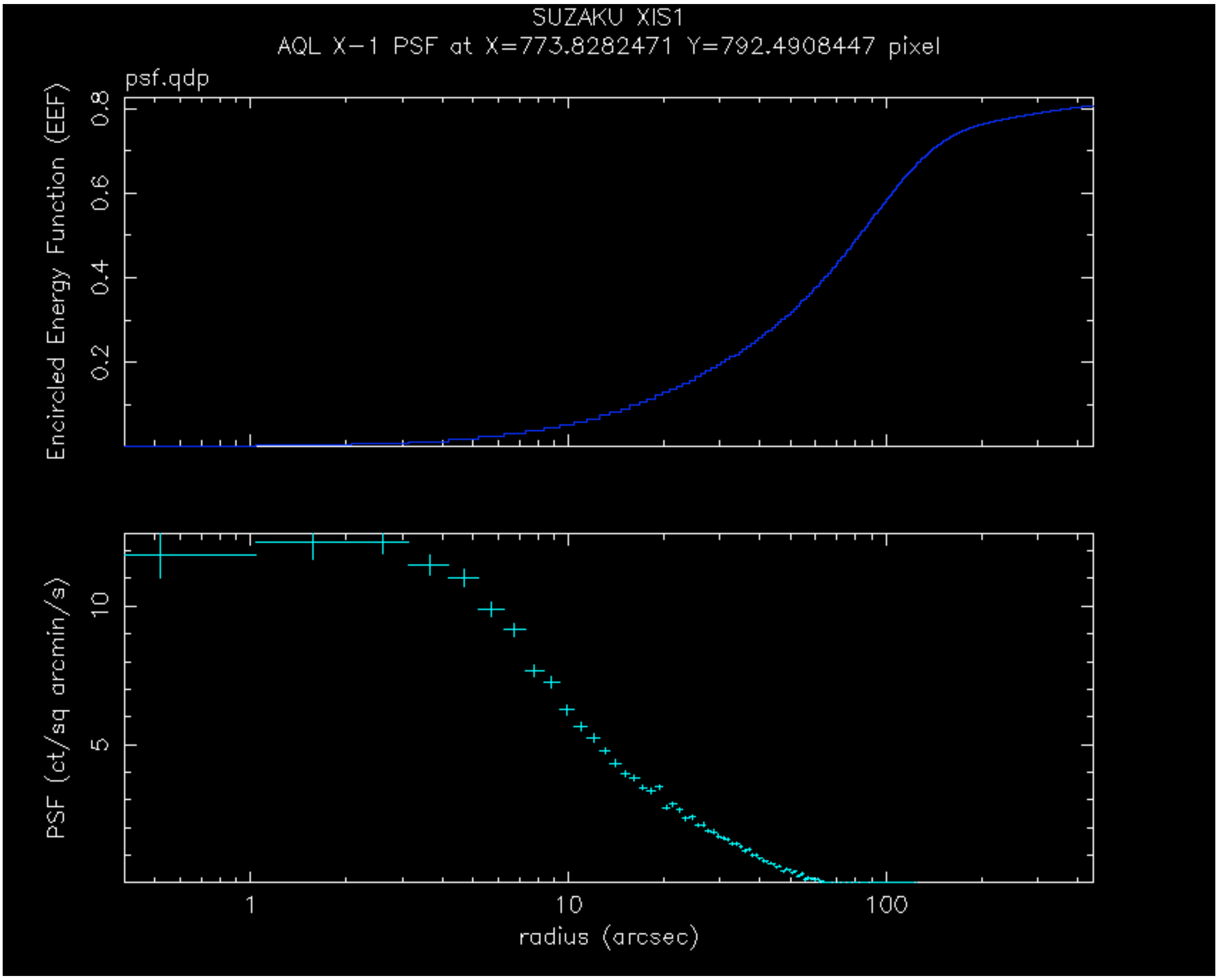
-> 1/4 window, no burst

```
### Create the PSF ###
ximage
read/size=1024/rebin=1 ae402053020xi1_0_3x3n091b_cl.evt
disp
psf/cur

# Left-click (1) the image center and (2) the outer region to calculate the PSF

log y off
plot
we psf_ximage.qdp
quit
exit
```

-> The count rate at the image center (R-OBS) ~ 11 ct/sq arcmin/s.




```
(R-CCD) = (R-OBS) * (SNAPTI1+DELAY1)/(SNAPTI1) * SNAPTI1
        = 11 * (2 + 0)/2 * 2
        = 22 ct/sq arcmin/s (CCD exposure)
```

This value is smaller than that obtained at Case (1) : Crab of 36 ct/sq arcmin/s (CCD exposure), and this dataset is thought to be free from the pile up.

Case (3) moderately pile up : Serpens X-1 (401048010)

In the directory 401048010/xis/event_cl

```
### Check the window mode and the burst option ###
%> fkeyprint ae401048010xi1_0_3x3b062b_cl.evt SNAPTI1
SNAPTI1 =             0.998000 / Exposure of Window 1 in Normal and Burst clock
fkeyprint ae401048010xi1_0_3x3b062b_cl.evt DELAY1
DELAY1  =             1.002000 / Time lag of Window 1 start
```

-> 1/4 window, 1 s burst

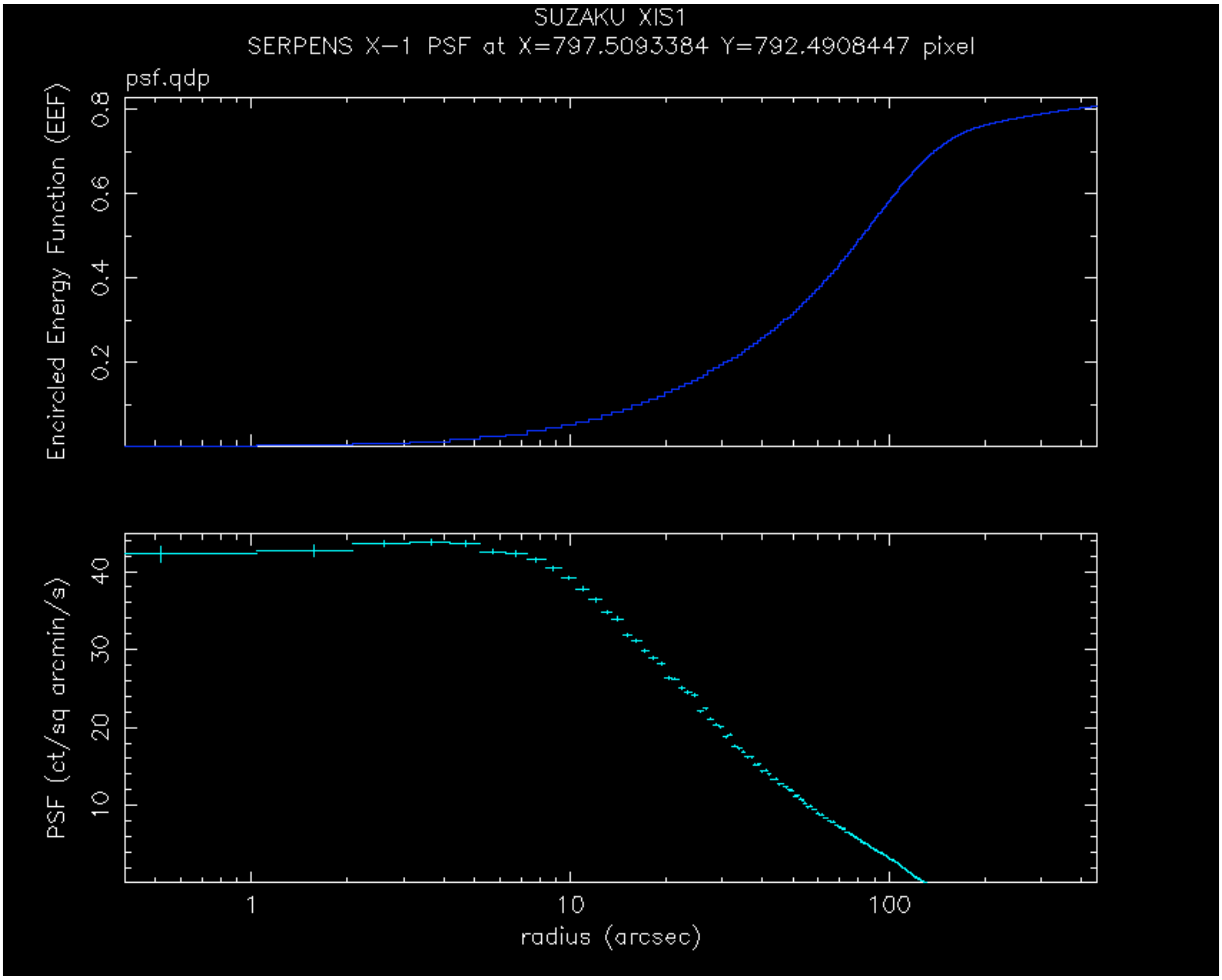
```
### Create the PSF ###
%> ximage
read/size=1024/rebin=1 ae401048010xi1_0_3x3b062b_cl.evt
disp
psf/cur

# Left-click (1) the image center and (2) the outer region to calculate the PSF

log y off
plot
we psf_ximage.qdp
quit
exit
```

-> The count rate at the image center (R-OBS) ~ 44 ct/sq arcmin/s.

```
(R-CCD) = (R-OBS) * (SNAPTI1+DELAY1)/(SNAPTI1) * SNAPTI1
        = 44 * (0.998000 + 1.002000)/0.998000 * 0.998000
        = 88 ct/sq arcmin/s (CCD exposure)
```



This value is larger than that obtained at Case (1) : Crab of 36 ct/sq arcmin/s (CCD exposure), and some pile-up effect is expected in the image center.

In the current case, the radius where (R-CCD) becomes 36 in the PSF is about 30-40 arcsec, and it is better to exclude the region within the radius of 30-40 pixel to eliminate the pile up effect (XIS CCD pixel size: 1 pixel = 1.04 arcsec).

From the top figure (Encircled Energy Function) of the ximage output, you can estimate about 20-25 % of events are excluded, when the radius of 30-40 arcsec is not used.

Future methods

There is a method to correct the pile-up by using a model. (http://space.mit.edu/ASC/software/suzaku/). We have not calibrated the software yet, which will be done soon.

Frequently Asked Questions

My XIS image has a hole at the center

There are two possibilities.

- severely affected by pile-up

When the source is too bright, photon pile-up alters most of the X-ray events to grade 7, which are discarded on board. If this happens, you will see a hole at the image center. If you want to analyze such data, you need to exclude all the data affected by pile-up.

- malfunction of xisclean (sisclean)

When the source is too bright, xisclean sometimes does not work properly. It may misclassify the healthy pixels as hot/flickering ones, and remove all the events of such pixels. If this happens, you will see a region deficient of X-ray events in the image (not necessarily at the image center.). To avoid such malfunction, it is required to manually adjust the threshold parameter in xisclean. Most of the hot-pixel-affected events are discarded on board. Thus the remaining hot pixels are not so much.

Why my XIS image is elongated ?

This is not caused by pile-up. Details of this phenomenon are described in Figure 9 of the Suzaku XRT paper, taking the Crab nebula as an example (http://www.astro.isas.ac.jp/suzaku/doc/suzakumemo/suzakumemo-2006-34.pdf).

Do the PSFs of the XISs have a dependency on energy ?

No. Within the systematic error they do not show the energy dependency (see the paper on XRT in detail, http://ads.nao.ac.jp/abs/2007PASJ...59S...9S).