The Suzaku Data Reduction Guide

–also known as the ABC Guide–

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Copies of this guide are available in the following formats:
HTML - `http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/abc/`
Postscript - `ftp://legacy.gsfc.nasa.gov/suzaku/doc/general/suzaku_abc_guide.ps.gz`
PDF - `ftp://legacy.gsfc.nasa.gov/suzaku/doc/general/suzaku_abc_guide.pdf`

For news on the *Suzaku* data analysis see section 4.2 "Checking for Updates" and chapter 5 "README FIRST".

More frequent updates can be found on the web:
`http://heasarc.gsfc.nasa.gov/docs/suzaku/aehp_proc.html`
`http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/watchout.html`
`http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/suzakumemos.html`
`http://www.astro.isas.jaxa.jp/suzaku/process/caveats/`
`http://www.astro.isas.jaxa.jp/suzaku/analysis/xis`

Users are encouraged to contact the *Suzaku* Guest Observer Facility via the comment webpage at `http://heasarc.gsfc.nasa.gov/cgi-bin/Feedback`.

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Chapter 1

Introduction

This document is meant as a guide and reference for scientists who are generally familiar with astronomical X-ray analysis and the *Suzaku* instruments and want to use *Suzaku* data to extract scientific results. General information on the *Suzaku* satellite may be obtained from the *Suzaku* Guest Observer Facility (GOF) page,
`http://suzaku.gsfc.nasa.gov`.

Readers who are not familiar with the *Suzaku* instruments may wish to read the technical appendix of the NASA Research Announcement (NRA), available at:
`http://heasarc.gsfc.nasa.gov/docs/suzaku/prop_tools/suzaku_td`.

This document is intended to familiarize the readers with the standard procedure for *Suzaku* data analysis. Unusual data modes, complex data reduction methods, and advanced data analysis techniques are outside its present scope but could be added as time progresses.

This version corresponds to the analysis of Version 2 processed data. Users should not use Version 1 processed data or documentation, with the sole exception of Version 1 HXD PIN background files for observations taken during a specific period, as described in section 7.5.1.

The software needed for *Suzaku* data analysis is described in chapter 2, including instructions for its downloading and installation. In chapter 3 we explain the *Suzaku* data directory structure, coordinate systems, and file names and formats. In chapter 4 we provide a broad overview of the data analysis flow. Chapter 5 points out important details of the current status of the data analysis and calibration. In chapter 6 and 7 we explain how to analyze data from the X-Ray Imaging Spectrometer (XIS) and Hard X-Ray Detector (HXD) and explain the issues of both analyses. Acronyms used in this document are described in appendix A. Useful email addresses and websites are given in appendix B.

Chapter 2

Software

Suzaku data reduction is primarily performed using the HEAsoft package, which is described in detail at: http://heasarc.gsfc.nasa.gov/docs/software/lheasoft/.

HEAsoft is a multimission collection of programs and scripts (frequently also called FTOOLS, for historical reasons), all using a similar interface which can be used both interactively and in scripts. All mission-specific software required to calibrate and analyze *Suzaku* data are written by the instrument teams and released as a part of HEAsoft and are collectively called the "*Suzaku* FTOOLS". By using the *Suzaku* FTOOLS *Suzaku* users can recalibrate their data when new calibration information is made available. HEAsoft is supported on major Unix architectures, such as Linux and OS X. HEAsoft runs on Windows in principle, but not yet as smoothly as on Unix. Therefore, *Suzaku* users are strongly advised to use one of the supported Unix systems, listed on the HEAsoft website.

Major releases of the entire HEAsoft package are currently scheduled approximately once a year. As need arises, the *Suzaku* FTOOLS may be released as patch releases on a faster timescale. This guide assumes that the users have installed *Suzaku* FTOOLS Version 16 in HEAsoft Version 6.9 or later. An up-to-date and complete listing of *Suzaku* FTOOLS can be found at:
http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/suzaku_ftools.html.

Since *Suzaku* data files are in FITS format, other analysis suites (such as CIAO) can be used with *Suzaku* files to complete certain tasks. However, due to limited resources the *Suzaku* GOF will focus support on using HEAsoft to analyze *Suzaku* data and only support other tools as time permits.

2.1 CALDB

Suzaku calibration information is provided to the users via the HEASARC "Calibration Database" (CALDB):
`http://heasarc.gsfc.nasa.gov/docs/heasarc/caldb/caldb_intro.html`. Many *Suzaku* `FTOOLS` cannot run if they cannot access CALDB files. While it is possible to run the tools by specifying the paths to individual CALDB files, this is not recommended since it puts undue burden on the users to know the paths to the correct and up-to-date calibration files for each calibration parameter of each tool. Instead, CALDB provides index files and other infrastructure so that *Suzaku* `FTOOLS` can determine the correct file to use, open it and read its contents. The users of such tools need only specify "CALDB" (or "AUTO" in some cases; these are the default values in the *Suzaku* `FTOOLS` distributions) instead of the full path name of calibration files.

As explained at the above URL, CALDB can be installed on the users' local machines or accessed remotely. The latter ensures that the most up-to-date version is used, but there may be a penalty in terms of speed of access. In the former case, it is the local CALDB manager's responsibility to ensure that the latest version is installed. Note that the *Suzaku* calibration files may be updated as frequently as once a month; the latest version are described at, and can be obtained from
`http://heasarc.gsfc.nasa.gov/docs/heasarc/caldb/suzaku/`.

To set up access to the local installation of CALDB, source the caldbinit file in the CALDB tree in the directory software/tools (either caldbinit.csh or caldbinit.sh can be used depending on the shell being used; note that these script must be edited to fit the location of the CALDB on each system). This will set up the environment variables that are necessary for the use of CALDB. The remote access method is explained at
`http://heasarc.gsfc.nasa.gov/docs/heasarc/caldb/caldb_remote_access.html`.

2.2 XSELECT

`xselect` is a multi-mission program which has been widely used to analyze data from *ASCA*, *ROSAT*, *BeppoSAX*, *Einstein*, *Chandra* and other high energy missions. After passing through standard processing, *Suzaku* event files do not require any particular analysis software, since they comply with FITS event file standards. Nonetheless, the *Suzaku* GOF recommends `xselect` as a convenient and straightforward analysis tool. Therefore, in this document it is assumed readers will use `xselect` to extract *Suzaku* data into spectra, images, and lightcurves. The primary purpose of `xselect` is to provide a "shell" that translates simple commands (such as "extract image") into more complicated mission- or instrument-dependent `FTOOLS` commands. This guide, however, will not describe all the features of `xselect`. Users unfamiliar with `xselect` should read the `xselect` manual, available at `http://heasarc.gsfc.nasa.gov/docs/software/lheasoft/ftools/xselect/xselect.html`. The most important `FTOOL` used by `xselect`, `extractor`, does the actual work of extracting images, spectra, light curves or newly filtered event files from input event files. Users wishing to create scripts based on `xselect` commands will likely want to use `extractor` directly.

2.3 XANADU

XANADU is a mission-independent data analysis software package for high energy astrophysics which is normally distributed as part of the `HEAsoft` package. Currently XANADU includes XSPEC for spectral analysis, XIMAGE for image analysis, and XRONOS for timing analysis. *Suzaku* spectral, image, and timing analysis may be carried out within XANADU. In particular, the *Suzaku* GOF will fully support spectral analysis using XSPEC, and provide spectral response files (and/or response generators) with the XSPEC standard format. This guide assumes that the user is generally familiar with the XANADU package but if not, more information can be found at:
`http://heasarc.gsfc.nasa.gov/docs/xanadu/xanadu.html`.

2.4 Profit

Profit is a spectral analysis tool with a graphical user interface, designed generally for high-resolution spectroscopy but with *Suzaku* in mind. *Profit* is in active development and the reader is directed to
`http://heasarc.gsfc.nasa.gov/docs/software/profit/` for downloading instructions and details of its current functionality. In its initial release, *Profit* can display *Suzaku* spectra, focusing in and out as desired. Emission lines in the spectrum can be labelled using atomic data from either the ATOMDB or XSTAR line lists. The user can also select individual emission lines and redisplay the data in velocity space to search for line broadening or a Doppler shift. *Profit* has some ability to fit spectra, although this is rudimentary compared to XSPEC which is recommended when performing measurements for publication. Despite this limitation, *Profit* may be useful as a “first-look” tool when examining *Suzaku* data, especially for users not familiar with X-ray spectroscopy.

Chapter 3

Suzaku Data Specifics and Conventions

This chapter describes the contents of *Suzaku* observation data sets, including the directory structure, data files, and the format of those files. The *Suzaku* data structure is similar to previous X-ray missions, with small variations.

3.1 Directory and Data File Structure

3.1.1 Retrieving the Data

Public Data Access

Public *Suzaku* data sets can be accessed through the `HEASARC Browse` interface at GSFC which can be found at `http://heasarc.gsfc.nasa.gov/cgi-bin/W3Browse/w3browse.pl`. They can also be retrieved using `wget` or FTP.

For more details also see the *Suzaku* Archive GOF web page at `http://heasarc.gsfc.nasa.gov/docs/suzaku/aehp_archive.html`. The `wget` or public FTP download works identical to the proprietary data access (see next section), without the need for decrypting the downloaded files.

In addition users can access the data at the ISAS DARTS site (mainly intended for Japanese and European-based observers).

Proprietary Data Access – US PI Case

When the data are processed, the PI of the observation will receive an e-mail from the *Suzaku* GOF at GSFC giving the FTP location to access and download the data. For more information on the format of the location (presently ftp://legacy.gsfc.nasa.gov/suzaku/data/obs/M/NNNNNNNNN where M is a number indicating the type of target and NNNNNNNNN the sequence number of the data), please access the guide to the *Suzaku* archive at `http://heasarc.gsfc.nasa.gov/docs/suzaku/aehp_archive.html`.

We recommend to use `wget` to retrieve the data[1]:

```
wget --passive-ftp -q -nH --cut-dirs=5 -r 10 -c -N -np \
--retr-symlinks ftp_address_received
```

where the `ftp_address_received` is the location mentioned above:
ftp://legacy.gsfc.nasa.gov/suzaku/data/obs/M/NNNNNNNNN/
Note that the "/" at the end of the command is required.

Alternatively, this can be done using the following FTP commands:

```
ftp legacy.gsfc.nasa.gov
login:  anonymous
password : your_email_address@your_domain_address
ftp> cd suzaku/data/obs/M
ftp> binary
ftp> get NNNNNNNNN.tar.gz
ftp> quit
```

Once retrieved, they need to be decrypted using either PGP or GPG software and a perl script available at the website `http://heasarc.gsfc.nasa.gov/docs/cookbook/decrypt_data.pl`. General information on how to decrypt the data is available at: `http://heasarc.gsfc.nasa.gov/docs/cookbook/decrypt.html`.

The decryption keys for *Suzaku* data are 32 or 34 characters long and sometimes include special characters. We therefore recommend against specifying the key on the command line. Also, with gpg, this process will leave both the encrypted and decrypted versions of the files in your data directory. You therefore need to make sure you have adequate (original $\times 2$) disk space. Finally, glitches during download can prevent decryption. If an initial attempt fails, re-downloading the data set may be all that is required to successfully decrypt the data.

[1] `wget` is available at: `http://www.gnu.org/software/wget/wget.html`

3.1.2 Data Organization

All *Suzaku* data (including ground calibration and test data) have unique 9-digit sequence numbers (*e.g.* 900000450) which is used as the name of the top level directory. Under this directory are a series of sub-directories, each of which carries a particular kind of data file, as explained below. All the data files are in the standard FITS format, although some output products are in Postscript, HTML, GIF or simple ASCII. The subdirectories are:

auxil Auxiliary files not associated with a particular instrument, such as the spacecraft attitude (file named aeNNNNNNNNN.att – see Section 3.2 for an explanation of the name structure) and the orbit file (file named aeNNNNNNNNN.orb). The most important of these is the "filter file" (with the suffix "mkf"), in which various satellite and instrumental parameters to be used for data screening are recorded as a function of time.

log Log files from the pipeline processing.

hxd Data from the Hard X-ray Detector (HXD).

xis Data from the X-ray Imaging Spectrometers (XIS).

Within each of the two instrumental directories (`hxd, xis`) there are four subdirectories:

hk Instrumental housekeeping files containing information such as voltages, temperatures and other detector-specific data.

event_uf Second FITS Files (SFF); these are unfiltered events files derived from the First FITS Files (FFF). FFF are effectively the telemetry data converted into FITS format.

event_cl Cleaned events in this directory have gone through the standard cuts (grades, SAA and such) and they are in principle directly useful for analysis. However, users can re-run these cleaning processes (see chapters 6 and 7 for more on the standard cuts applied).

products Output products from the pipeline, such as GIF images of the data and automatically generated lightcurves.

The filename conventions in each of these directories are instrument dependent, as described in the next section.

3.2 Filenames

The filenames (except for some log files) use the following general convention:

```
aeNNNNNNNNNiii_n_mmmmmmmm_ll.ext.gz
```

where

ae is short for *Astro-E2*, the initial name of *Suzaku*.

NNNNNNNNN is the observation sequence number and is identical to the directory name.

iii is the instrument specification. This string is set as follows: hxd=HXD, xi[0-3]=XIS-[0-3]. xis is used for files common to all the XIS units. This string can be omitted in files under the `auxil` and `log` directories.

n ranges from 0 to 9 and indicates the RPT file number. The original telemetry file is divided into RPT files and more than one RPT can contribute to one observation. The value of 0 is used when the science file combines data from different RPT or if there is only one RPT file that contributes to that sequence. This number can be omitted in files under the `auxil` and `log` directories.

mmmmmmmm is the file identifier. The string distinguishes between files from the same instrument.

ll indicates the file level. For event files, the string can be "uf" or "cl" to indicate "unfiltered" or "cleaned" event files. It also can be "bg," "sk," "sr," "gso," "pin," "wel" (`products` directory for both the XIS and HXD) or "wam" (`hk` directory for the HXD). The string can be omitted.

ext is the file extension. Currently it can take the values: "evt" (event files), "gti" (good time interval), "hk" (house keeping), "ghf" (gain history file), "ght" (gain history table), "lc" (light curve), "pi" (pulse invariant), "html," "log," "com," "att" (attitude file), "cat," "ehk," "mkf," "orb," "tim," "img," and "gif."

For more information on file names of the products of the pipeline processing, please refer to the documentation that can be found at
`http://heasarc.gsfc.nasa.gov/docs/suzaku/aehp_data_analysis.html`.

3.3 *Suzaku* Coordinates

The XIS is an imaging instrument (unlike the HXD), and the coordinate values in XIS files indicate the pixel center positions. The XIS coordinate systems are described below:

Sky coordinates "X" and "Y" are used to describe the sky positions of the events relative to a celestial reference point. The tangential projection is used, and north is defined up (increasing Y), and east is left (decreasing X). "X" and "Y" columns are computed using attitude information.

Focal plane coordinates These are the event locations on the focal plane, which is common to the four (there are four XIS detectors) imaging instruments. "FOCX" and "FOCY" event file columns are used. The FOC coordinates differ from the Sky images in that the satellite attitude is not considered in the former. FOC images of the four instruments should match, as instrument misalignments are already taken into account.

Detector coordinates These give the physical positions of the pixels within each sensor. Misalignments between the sensors are not taken into account. The DET X and Y values take 1 to 1024 for XIS. The XIS DETX/Y pixels correspond to the actual 1024x1024 CCD pixels, and the DETX/Y pixel size is the same as the CCD physical pixel size. The DET images will give correct sky images of the objects (not mirrored images), except that attitude wobbling is not taken into account. Note that X-ray images focused by the mirrors and detected by the focal plane instruments will be the mirror images, which have to be flipped to be the actual images of celestial objects. Thus, the original look-down images are flipped (and rotated if necessary) so that the satellite +Y-axis direction will be the DETY direction.

ACT and RAW coordinates The ACT coordinates are used to tell actual pixel locations on the chip. Each XIS chip is composed of the four segments, and the RAW coordinates are the pixel locations on each segment. Note that the XIS-0 and XIS-3 installations on the baseplate are aligned, whereas XIS-1 and XIS-2 are 90 degrees rotated relative to them, in opposite directions respectively. Therefore the relation between ACT and DET coordinates is dependent on each XIS sensor.[2]

3.4 Photon Energies and Pulse Heights

All *Suzaku* instruments are energy-sensitive, and each event has a measured "Pulse Height Amplitude" (PHA). The PHA may be both position- and time-varying, depending upon the instrument. Therefore, a calculated "PHA Invariant" (PI) value is also determined using the PHA in combination with the instrumental calibration and gain drift. In all cases, the PI columns should be used to extract energy spectra, or to produce energy-band selected images or light curves. For reference, the approximate relationship between "true" X-ray energy E and the event PI is shown below for each instrument. The exact relationship

[2]Conversion from the RAW to ACT coordinates is not straightforward, because of the particular order of the pixel read-out and possible use of the Window option.

Type		Type	Minimum	Maximum	Origin	Unit
Sky	X/Y	Integer	1	1536	768.5	$0.0174'$
	ROLL	Real	0.0	360.0	–	degree
FOC	X/Y	Integer	1	1536	768.5	$0.0174'$
DET(XIS)		Integer	1	1024	512.5	0.024 mm
ACT	X/Y	Integer	0	1023	–	–
SEGMENT		Integer	0	3	–	–
RAWX(XIS)		Integer	0	255	–	–
RAWY(XIS)		Integer	0	1023	–	–

Table 3.1: Types of coordinates and coordinate related variables and their possible values.

between energy and PI is given in the second extension of the instrument response matrix file, or "RMF."

XIS The PI column name is "PI", which takes values from 0 to 4095. The PI vs. energy relationship is the following: E [eV] = 3.65×PI [channel].

HXD The "PI_SLOW" column (as opposed to "PI_FAST"), which takes values from 0 to 511, should be used for GSO spectral analysis. The PI vs. energy relationship is the following: E [keV] =2×(PI_SLOW + 1.0), where E is the center of the bin. For PIN spectral analysis, the "PI_PIN" column which takes values from 0 to 255, should be used. The value in this column is copied from the PI column of the triggered PIN, which is one of the PI_PIN0, PI_PIN1, PI_PIN2 or PI_PIN3. The PI vs. energy relationship is the following: E [keV] =0.375×(PI_PIN + 1.0), again E is the center of the bin.

3.5 Timing Information

The *Suzaku* event arrival time is represented by the "*Suzaku* time", which is defined as the elapsed time in seconds from the beginning of the year 2000 (January 1st, 00:00:00.000) in UTC (when TAI is 32 seconds ahead). There will always be a constant offset between TT and *Suzaku* time, and this is reflected in the time-related keywords. These and other systems of time are documented at:
`http://heasarc.gsfc.nasa.gov/docs/xte/abc/time_tutorial.html`.

The event time resolution of each detector as follows:

XIS In the Normal observation modes (5x5, 3x3, or 2x2) without a Window option, the time resolution is 8 sec, corresponding to a single frame exposure. The event time assigned is the midpoint of the exposure frame. When the Window option is used, depending on its size, the time resolution will be 2 s (1/4 Window), or 1 s (1/8 Window). In Timing mode, the time resolution is 7.8125 ms, regardless of the number of lines to be combined (either 64, 128, or 256). Users should note that when combining a small number of lines, there could be a noticeable amount of cross-talk between one time bin and the next, due to the wings of the PSF. For example, 64 lines is only about 1.2 arcmin, so a fraction of the source counts will fall on the neighboring groups of 64 lines, and so be mis-time-tagged by +/-N times 7.8125 ms. For this reason, it may be safer to always use a grouping of 256 lines.

HXD The nominal time resolution is 61 μs, which corresponds to the HXD_WPU_CLK_RATE_HK parameter = 1 (Fine). A higher time resolution, 30.5 μs is possible within the requirements of satellite operations, in which case HXD_WPU_CLK_RATE_HK will be 2 (Super-Fine), although this is not user-selectable at this time.

3.6 *Suzaku* Telemetry

3.6.1 Data Rates

The telemetry rate determines the data transfer rate from the onboard instruments to the Data Recorder. Being limited by the data storage and downlink capacity, the highest data rates may not be used all the time[3]. Basically, a combination of the following three telemetry rates will be used for observations: High rate (261 kbps), Medium rate (131 kbps), or Low rate (33 kbps) [4]. Among the 10 Gbit raw data per day, 4 Gbits will be taken between the contacts (contact passes) with High and Medium bitrates, and 6 Gbits will be taken after the contacts (remote pass) using Medium and Low bitrates.

3.6.2 Allocations

Although the maximum Data Recorder recording rate is limited by the telemetry rate for each bitrate, allocation of the telemetry to various instruments is variable. The XIS and HXD telemetry limits depend on the bitrates.

[3] The amount of the data taken per day is mainly limited by the capacity of the Data Recorder (6 Gbits) and the downlink rate at Uchinoura Space Center (2 Gbits/ground contact). There will be 5 ground contacts per day separated by 90 minutes, so not more than 10 Gbits/day raw data can be taken, with typical daily sizes being considerably smaller than this.

[4] In addition, there is a Super-High rate (524 kbps) which is not used for general observations.

	Telem. limit [kbps/XIS]	5x5 s^{-1}	3x3 s^{-1}	FI 2x2 / BI 3x3 s^{-1}/s^{-1}	Timing s^{-1}
Super-High	144	138.24	291.03	341.33/485.05	1382.40
High	144	138.24	291.03	341.33/485.05	1382.40
Medium (weekday)	60	57.60	121.26	142.22/202.11	576.00
Medium (weekend)	25	24.00	50.53	59.26/84.21	240.00
Low (weekday)	15	14.40	30.32	35.56/50.53	144.00
Low (weekend)	1	0.96	2.02	2.37/0.76	9.60

Table 3.2: Telemetry limits (in events/s per XIS unit) – *as in use since the loss of XIS2 in 2006 November* – for different XIS editing modes.

These numbers do not include overheads (telemetry header and HK) and background event rates (FI∼10/s/sensor; BI∼20/s/sensor). Allow for a 10% margin.
Modification of telemetry saturation limit by window/burst options:
1. No window $+m$ s burst option – telemetry limit increases $8/m$ times.
2. $1/n$ window $+m$ s burst option – telemetry limit increases $8/m/n$ times.
3. Area discrimination will further increase the telemetry limit.

3.6.3 Telemetry Limits

XIS The approximate XIS telemetry limits (events/s per XIS unit) – *as in use since the loss of XIS2 in 2006 November* – for different bitrates and editing modes is given in Table 3.2.

XIS events are compressed on-board and actual telemetry limits may vary within $\sim \pm 40\%$ depending on the PHA values. Note that different XIS sensors may be operated using different modes and telemetry allocations.

HXD The approximate HXD Well telemetry limits will be the following (in counts/s): Super-High=1150, High=550, Medium=250, and Low=30. This is based on the assumption that HXD will take 30% of the telemetry. Note that the Crab rate in the HXD is ~ 200 cts/s.

3.7 XSELECT Default Parameters

The `XSELECT` behavior for each mission is determined by the mission database file, usually located at $FTOOLS/bin/xselect.mdb[5]. The *Suzaku* entries in the mission database files enable the following:

[5]Users may specify their own mission database file with an environmental parameter XSELECT_MDB.

- Common for all the instruments:
  - Default light curve bin size is 16 sec.
  - "extractor" is used to extract products.
  - WMAP[6] is created as the spectral file header.
  - Default image coordinates are Sky coordinates (X and Y).
  - Default WMAP coordinates are Detector coordinates (DETX and DETY).
  - Event file has one of the following names; ae*xis0*.evt, ae*xis1*.evt, ae*xis2*.evt, ae*xis3*.evt, or ae*hxd wel*.*.
  - The filter file has the name ae*mkf*, and is in the directory ../../auxil relative to the event file directories[7]
- XIS:
  - Default image binning is 8.
  - Default WMAP binning is 8.
  - "RAWX" and "RAWY" coordinates are set to "ACTX" and "ACTY", so the "set image raw" command creates ACT coordinate images.
  - Pixels in the WMAP outside of the selected region will have the value "-1"
  - Spawns "grppha" when saving a spectral file, three speed options – "fast", "medium", "slow" – are available. "Medium", the default, results in the following channel binning: 1× from channel 0 to 699, 2× from 700 to 2695, and 4× from 2696 to 4095. Channels 0–81 and 1645–2047 are flagged as "bad" (original PI channels 0–81 and 3290–4095).
  - Spawns "xisrmfgen", "xissimarfgen", "marfrmf", and, optionally, "rbnrmf" when saving a spectral response file, with the three speed options mentioned above. Again, "Medium" is the default.
- HXD:
  - The default energy column to make energy spectra is "PI_PIN" for a PIN event file and "PI_SLOW" for a GSO event file.

[6]WMAP is the part of the detector image from which the energy spectrum has been extracted, and will be used to create spectral responses by downstream `FTOOLS`.

[7]For *Suzaku* `FTOOLS` Version 13 and earlier the filter file has to be uncompressed or the file name has to be explicitly specified.

- The UNITID event file column is used in lieu of standard X, Y, RAWX, RAWY and DETX of imaging instruments, so that the “sky” or “raw” images will be a pseudo-diagonal image of UNITID[8].
- The PIN_ID event file column (defined only for DET_TYPE = 1) is used in lieu of DETY, so that the WMAP is created with UNITID vs. PIN_ID, which is useful when creating ARFs and RMFs for the PIN.
- No binning for “image” and WMAP.
- PIN and GSO spectra are saved with the original number of channels, i.e., 256 and 512, respectively.

[8]For each HXD event, UNITID and DET_TYPE tell the Well unit-ID and the detector type, respectively. UNITID takes a value in the range of 0 to 15 corresponding to the 16 Well units. DET_TYPE = 0 corresponds to the GSO, and DET_TYPE=1 to the PIN.

Chapter 4

Suzaku Data Analysis Overview

This chapter provides a brief outline of the standard analysis steps. Details are explained in subsequent chapters 5–7. Analysis topics covered in this chapter are:

1. Spectral analysis of the XIS and the HXD data.
2. Timing analysis of the XIS and the HXD data.
3. Imaging analysis of the XIS data.

We assume that the user has downloaded and decrypted the *Suzaku* data, and has access to the latest versions of the *Suzaku* `FTOOLS` and CALDB.

4.1 Important Events and Processing Version

Users should check

`http://www.astro.isas.jaxa.jp/suzaku/log/operation/`,
`http://www.astro.isas.jaxa.jp/suzaku/log/hxd/`, and
`http://www.astro.isas.jaxa.jp/suzaku/log/xis/` for any important events (operational or instrumental issues) that may affect your specific observation.

Users should also check the processing version of the data, as recorded in the `PROCVER` keyword in any of the FITS files. Users should then consult `http://heasarc.gsfc.nasa.gov/docs/suzaku/aehp_proc.html` to see if there are any issues for data processed using that version of the pipeline.

4.2 Checking for Updates

Users should check for any software or calibration updates that may affect the data in question. The *Suzaku* GOF disseminates information in several ways.

1. By targeted e-mails to the PIs of proprietary data. This method is used to communicate important updates that affect a specific subset of observations. We expect the PIs to pass the information to any collaborators who may be analyzing the data.

2. By e-mails to the `suzakunews` exploder. All types of *Suzaku* related news items are included in occasional messages through this exploder. All who are interested in the *Suzaku* mission should subscribe to this list at `http://heasarc.gsfc.nasa.gov/docs/heasarc/news.html`. if they are not already on the list. Note that users who are registered under a defunct address will get dropped if the exploder receives error messages several times in a row. On the other hand, after every proposal review cycle, we add the e-mail addresses of all successful US PIs who appear not to be on the `suzakunews` list.

3. Through this guide. Chapter 5 provides a list of important caveats that users should be aware of.

4. Via the *Suzaku* GOF web site. The *Suzaku* Data Analysis page: `http://heasarc.gsfc.nasa.gov/docs/suzaku/aehp_data_analysis.html` and links therein are updated more frequently than this guide. Of particular importance is the "Things to Watch Out For" page: `http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/watchout.html`.

These updates may simply note a newly discovered calibration problem, instruct users on how to obtain a software patch or updated calibration file, or provide workarounds such as an *ad-hoc* procedure that should be run on specific datasets.

4.3 Unfiltered or Cleaned?

The pre-extracted spectra and light curves in the `products` subdirectories, both for the XIS and the HXD, are provided for quick-look purposes only. We recommend against using these files for actual data analysis.

Event FITS files are provided to the users in two flavors (chapter 3), unfiltered (`event_uf`) and cleaned (`event_cl`). The latter were obtained using the pre-determined screening criteria given in Table 6.2 (for the XIS) and Table 7.2 (for the HXD). Although this procedure can never be perfect for each individual observation it generally produces reliable event lists.

If stronger *screening* criteria are required, the cleaned events can be further screened by the user to produce the desired new cleaned event files, see sections 6.3, 6.4, and 6.11 for the XIS and sections 7.3, 7.4, 7.6.3, and 7.12.1 for the HXD.

For less strong *screening* criteria, one has to start with *reprocessing* the unfiltered data. This is also the case if one wants to ensure that the newest *calibration* is used for producing the event lists. If modeled Non X-ray Background (NXB) events provided by the HXD team for the GSO are used in the analysis, it has to be kept in mind, however, that reprocessing of the source events has to be performed with the same gain calibration as used for the creation of those background events (see next paragraph; for the PIN this is not relevant since only one realization of the gain file has been in use). The reprocessing procedures are described in sections 6.3, 6.4, and 6.10 for the XIS and in sections 7.3, 7.4, 7.6.3, and 7.11 for the HXD.

For XIS data produced with a processing pipeline version earlier than Version 2.1.6.16 reprocessing is mandatory, as well as for PIN data taken after 2007 July 28 and processed with pipeline Version 2.0.6.13 or earlier. For GSO data users should check the `GSOGPT_F` and `GSOGPT_V` keywords in the FITS headers of the cleaned event (observed) and background (simulated) files. These keywords define which HXD GSO gain parameter table (GPT) was used in the processing. If the values match then there is no need to reprocess the GSO data (note: the files `ae_hxd_gsogpt_20091225.fits` and `ae_hxd_gsogpt_20100323.fits` are identical in content). If the values do not match the data have to be reprocessed. If these keywords are not present the data were processed with pipeline Version V2.4.12.27 or earlier corresponding to a different way of performing GSO calibration (using GHT [gain history table] instead of GPT type gain files) and should be reprocessed, preferentially using the new setup. For more details on the two different GSO setups see `http://heasarc.nasa.gov/docs/suzaku/analysis/gso_newgain.html`.

4.4 Barycentric Correction

`Aebarycen` is a *Suzaku* specific `FTOOL` to perform barycentric corrections for *Suzaku* event and housekeeping files. See Terada et al., 2008, PASJ 60, S25 for a brief description of the barycentric correction tool (and a detailed description of the timing calibration of the HXD).

Warning: In order for the barycentric correction tool to work correctly it is required to perform any good time interval filtering in `xselect`, i.e., removing times of telemetry saturation, **before running** `aebarycen`.

4.5 Spectral Analysis

The following are the steps, explained in detail in chapter 6, for the spectral analysis of XIS data:

1. Extract source and background spectra for the desired extraction regions.
2. Build the response files (RMF and ARF).
3. Combine the spectra taken with XIS0, XIS2 (if available), and XIS3.

Chapter 6 contains pointers on the size and shape of the source extraction region, and on the typical background extraction region for a point source. The particle background is a strong function of the location of the *Suzaku* spacecraft within the geomagnetic field, and therefore is variable in time. The X-ray background is a function of the pointing direction. Therefore, ideally, the background spectrum should be extracted from the neighboring source-free region(s) of the same CCD chip from the same observation. However, for the analysis of extended sources, it is sometimes necessary to consult other observations, including the non X-ray background (NXB) database compiled by the XIS team.

We also explain the RMF and ARF generators. The latter is based on ray-tracing and can be extremely time-consuming. We therefore describe several options for speeding up ARF generation, as well as subsequent spectral fits.

Three of the XIS units (two, after the damage to XIS2 occurred), each with a frontside illuminated (FI) chip, are sufficiently similar that it is usually safe to sum the spectra from these units. However, we never recommend combining the event files (this will lead to the loss of information critical to downstream software). Also, XIS1, with a backside illuminated (BI) chip, has a distinctly different response and so XIS1 data should not be combined with those from other units.

The following are the steps, explained in detail in chapter 7, for the spectral analysis of HXD data:

1. Obtain the appropriate background files.
2. Create a joint good time interval (GTI) file, when both the data and background models are available.
3. Extract spectra from the observation data and correct for deadtime.
4. Extract spectra from the background files and correct for the factor of 10 oversampling (PIN) and for deadime (GSO).
5. Select the appropriate response file and correct for off-axis location of the source if necessary.

Since the HXD is a non-imaging instrument, users need not/cannot consider "extraction regions". Instead, it is necessary to subtract the particle and X-ray background from the observation data. This is done using the background files generated by the HXD team, who model the particle background based on the orbital location and other information. In normal situations, the PIN background files are prepared within a few weeks of the distribution of the processed data to the PI; GSO background files are made about a month after distribution.

There is a noticeable deadtime even for faint sources because the particle background alone results in a high count rate. This must be corrected for in the data. The PIN background files, on the other hand, do not need a deadtime correction. However, in the case of the PIN, background files have an artificially inflated count rate to ensure sufficient statistical accuracy, and this has to be taken into account.

The HXD team provides the response files for the PIN and GSO, rather than response generators. The PIN settings have been adjusted since the initial operation several times, including changes in the bias voltage used on-board, and in the low energy thresholds used in ground processing. Therefore it is necessary to select a response file appropriate for the epoch of the observation.

4.6 Timing Analysis

The following are the steps for the timing analysis of XIS data:

1. Extract source and background light curve for the desired extraction region.
2. Subtract the latter from the former with appropriate scaling.
3. Combine the light curves taken with the XIS FI units.

Users who have become familiar with XIS spectral analysis should find little difficulties in performing XIS timing analysis.

The following are the steps for the timing analysis of HXD data:

1. Obtain the appropriate background files.
2. Create a joint good time interval (GTI) file, when both the data and background models are available.
3. Extract light curves from the observation data, and correct for deadtime. Keep in mind that the minimum recommended time resolution for *deadtime corrected* HXD lightcurves is 128 s.

4. Extract light curves from the background files and correct for the factor of 10 over-sampling (for PIN) and for deadtime (for GSO).

Again, this process parallels that of the spectral analysis, but requires the correction of time-variable deadtime, as explained in chapter 7.

4.7 Imaging Analysis

The following are the steps for the imaging analysis of XIS data:

1. Extract XIS images for the desired extraction regions.
2. Generate corresponding exposure maps.
3. Create exposure-corrected XIS images, and apply further arithmetic as desired.

Chapter 6 contains a detailed description on how to generate exposure maps.

4.8 Recipe 1: XIS Spectral Analysis

1. Make sure that you have access to the latest software and calibration files (chapter 2).
2. Download the data (chapter 3).
3. Check for any updates (this chapter).
4. Perform reprocessing (update energy calibration) and rescreening using `aepipeline`, if required (section 6.4).
5. Use `xselect` to make, display and save products from cleaned event files.
   Refer to the `xselect` User's Guide at
   `http://heasarc.nasa.gov/docs/software/lheasoft/ftools/xselect/xselect.html`
   for available commands. For example:

```
xsel:SUZAKU-XIS-1-STANDARD > read event
  > Enter the Event file dir >[] .
  > Enter Event file list >[] ae101005070xi0_0_3x3n066z_cl.evt
xsel:SUZAKU-XIS-1-STANDARD > filter region
xsel:SUZAKU-XIS-1-STANDARD > extract all
xsel:SUZAKU-XIS-1-STANDARD > plot image
xsel:SUZAKU-XIS-1-STANDARD > plot curve
xsel:SUZAKU-XIS-1-STANDARD > plot spectrum
xsel:SUZAKU-XIS-1-STANDARD > save spectrum
```

6. Build the response files, using `xisresp` (see chapter 6).

7. Use `addascaspec` to combine FI spectra and responses.

```
example% addascaspec fi.add fi.pha fi.rsp fi_b.pha
```

(see chapter 6).

4.9 Recipe 2: HXD Spectral Analysis

Note: The steps described below to produce PIN and GSO spectra can also be performed by applying the `FTOOLS` `hxdpinxbpi` (section 7.5.6) and `hxdgsoxbpi` (section 7.7.2) for PIN and GSO, respectively. Similar extraction tools exist to produce lightcurves: `hxdpinxblc` (section 7.9.1) and `hxdgsoxblc` (section 7.10.1).

1. Make sure that you have access to the latest software and calibration files (chapter 2).

2. Download the data (chapter 3).

3. Check for any updates (this chapter).

4. Perform reprocessing (update energy calibration) and rescreening using `aepipeline`, if required (section 7.4 and 7.6.3).

5. Determine if the observation was performed using the XIS nominal or the HXD nominal pointing position (PIN & GSO). Determine the epoch of the observation (PIN only, chapter 7).

6. Obtain the appropriate response files — one for the source (PIN & GSO), and one for the Cosmic X-ray background ("flat", PIN only) — from the `CALDB`, as well as, for the GSO correction arf, from `http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/gso_newarf.html`.

7. Obtain the non X-ray background (NXB) files — see `http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/pinbgd.html` and `ftp://legacy.gsfc.nasa.gov/suzaku/data/background/gsonxb_ver2.4/`.

8. Generate the GTI file common to data and NXB using `mgtime`.

9. Apply GTI and extract spectra in `xselect`.
Refer to the `xselect` User's Guide at
`http://heasarc.nasa.gov/docs/software/lheasoft/ftools/xselect/xselect.html`
for available commands.

The name of the "`*_cl2.evt.gz`" files referred to in the following indicates that not the original cleaned files are used but cleaned files that were produced by reprocessing and rescreening the original "`*_uf.evt.gz`" files (see chapter 7).

```
xsel > read event
xsel > ./
xsel > ae101005040hxd_0_pinno_cl2.evt.gz
xsel > filter time file ae101005040hxd_wel_pin.gti
xsel > extract spec
xsel > save spec ae101005040hxd_0_pinno_cl2.pha
xsel > clear all
xsel > yes
xsel > read event
xsel > ./
xsel > ae101005040hxd_0_pinbgd.evt.gz
xsel > filter time file ae101005040hxd_wel_pin.gti
xsel > extract spec
xsel > save spec ae101005040hxd_wel_pin_bgd.pha
xsel > exit
```

This creates the source spectrum (`ae101005040hxd_0_pinno_cl2.pha`) and background spectrum (`ae101005040hxd_wel_pin_bgd.pha`).

The procedure for the GSO data is the same and furthermore the GSO spectrum should be rebinned to at least the 64 bins that are used to create the GSO background. This grouping is available at
`http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/gsobgd64bins.dat`.

```
unix% grppha ae101005040hxd_gsono_cl2.pha ae101005040hxd_gsono_cl2bin.pha
GRPPHA[] group gsobgd64bins.dat
GRPPHA[] exit
```

10. Correct for deadtime

```
unix% hxddtcor event_fname="ae101005040hxd_0_pse_cl.evt" \
           pi_fname="ae101005040hxd_0_pinno_cl2.pha"
```

This is to be done for the PIN source spectrum (see above) as well as for the GSO source and background spectrum. Note that the deadtime effect in the PIN background spectra is already taken into account, please do not apply this procedure to background spectra.

11. Correct the exposure of the PIN background (this step is not required for the GSO) by multiplying it by a factor of 10:

```
unix% cp ae101005040hxd_wel_pin_bgd.pha \
           ae101005040hxd_wel_pin_bgd_expcor.pha
unix% fkeyprint infile=ae101005040hxd_wel_pin_bgd_expcor.pha keynam=EXPOSURE

----- output  ---
# FILE: ae101005040hxd_wel_pin_bgd_expcor.pha
# KEYNAME: EXPOSURE

# EXTENSION:    0
EXPOSURE= 1.755875832736492E+03 / Exposure time
# EXTENSION:    1
EXPOSURE= 1.755875832736492E+03 / Exposure time
# EXTENSION:    2
EXPOSURE= 1.755875832736492E+03 / Exposure time
-----------------

unix% fparkey value=1.755875832736492E+04 \
        fitsfile="ae101005040hxd_wel_pin_bgd_expcor.pha+0" keyword=EXPOSURE
unix% fparkey value=1.755875832736492E+04 \
        fitsfile="ae101005040hxd_wel_pin_bgd_expcor.pha+1" keyword=EXPOSURE
unix% fparkey value=1.755875832736492E+04 \
        fitsfile="ae101005040hxd_wel_pin_bgd_expcor.pha+2" keyword=EXPOSURE
```

Chapter 5

"README FIRST" for the *Suzaku* Data Analysis

5.1 Introduction

This chapter contains the details of the current status of the data analysis. Users should check this chapter to answer the following questions:

- Which significant changes occured to the instruments through the history of the *Suzaku* mission, and hence what should I expect in the data given the date of observation?
- What significant software changes have been provided by the *Suzaku* team, and are there useful tools that have become available since the last time I analyzed *Suzaku* data?
- Which significant calibration changes have been provided by the instrument teams? What are the major remaining calibration issues?

Users should also consult the following web pages:
`http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/watchout.html`
`http://www.astro.isas.jaxa.jp/suzaku/analysis/xis/`
which serve a similar purpose to this chapter but may be updated more frequently; and
`http://heasarc.gsfc.nasa.gov/docs/suzaku/aehp_proc.html`
`http://www.astro.isas.jaxa.jp/suzaku/process`
for information regarding the processing pipeline; and
`http://www.astro.isas.jaxa.jp/suzaku/process/caveats/`
which contains the calibration uncertainties.

Furthermore, users are encouraged to contact us via the comment webpage at `http://heasarc.gsfc.nasa.gov/cgi-bin/Feedback`.

5.2 On-board Changes

5.2.1 XIS2 Loss

One of the XIS units with an FI chip, XIS2, suffered catastrophic damage on 2006 November 9. Since then, no astronomically useful data have been obtained with XIS2, although some diagnostic mode data are taken. Users should therefore not expect any cleaned event files for XIS2 observations taken after 2006 November 9.

The default telemetry allocations for the different XIS units and their changes over time are described in the `Technical Description`.

5.2.2 XIS0 Anomaly

An anomaly occurred in XIS0 on 2009 June 23. In this case the leak charge is confined within a portion of the CCD resulting in a dead area in segment A (`ACTX`$\sim$`80` to $\sim$`140`). Therefore, an area discriminator (`ACTX=70`$-$`150`) is applied, in order to discard pseudo-events due to leak charge. How the leak charge affects the calibration of not only segment A but also the other segments is currently under investigation. Preliminary analysis indicates a very small but a detectable change in the gain of XIS0. Detailed information can be found in the *Suzaku* memo available at `http://www.astro.isas.ac.jp/suzaku/doc/suzakumemo/suzakumemo-2010-01.pdf`.

5.2.3 XIS1 Anomaly

The XIS1 showed an anomaly, starting 2009 December 18, some time between 12:50 UT and 14:10 UT. A bright and persistent spot ($\sim$90 pixels in FWHM) suddenly appeared at the end of the segment C in all images taken during day-earth observations, while none was found during night-earth observations. The XIS team believes that the anomaly stems from optical light leaked from a hole in the optical blocking filter created by a micrometeorite hit. The XIS team continues to operate the XIS1 in the same way as before the anomaly. Science observations of soft diffuse emission with low surface brightness might be impacted by data degradation. Possible effects under investigation are: increased inaccuracy of the calibration (flux calibration), increased noise due to optical and UV light, and a decreased rate of effective data recording (due to an increase in spurious events). Detailed information can be found in the *Suzaku* memo available at `http://www.astro.isas.ac.jp/suzaku/doc/suzakumemo/suzakumemo-2010-03v2.pdf`.

5.2.4 Additional Optical Blocking Filter Holes in XIS1 and XIS3

A total of 10 additional bright spots were found in the frame dump images of XIS1 and XIS3 in 2013, likely caused by small holes in the optical blocking filters. No effects on the X-ray data are expected in most cases. See *Suzaku* memo at `http://www.astro.isas.ac.jp/suzaku/doc/suzakumemo/suzakumemo-2013-01.pdf` for further details.

5.2.5 XIS Spaced-Row Charge Injection (SCI)

The cumulative effect of in-orbit radiation damage creates charge traps in CCDs, leading to an ever increasing charge transfer inefficiency (CTI). This changes the PHA-Energy conversion factor as a function of the number of transfers before the charge can be read out, hence on the position on the CCD. This also degrades the spectral resolution.

The ability to inject charge into the CCD chips has been designed into *Suzaku* XIS. This can be used to fill the charge traps and therefore ameliorate the effects of the CTI. This operation is called spaced-row charge injection, or SCI: `http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/sci.html`. In 2006 September, SCI has been used for selected observations to test its effectiveness. Once this has been confirmed, it was offered as an option to all users in 2006 November. Since 2007 April (Cycle 2 observations), the use of SCI is the default.

With Version 2 processing, this is purely a data quality issue. Users need not take action, since information about the SCI operation is encoded in the `CI` keyword, which is read by *Suzaku* `FTOOLS` as necessary and the appropriate calibration is used. However, users may wish to check the value of this keyword. The value of the `CI` keyword should be 0 for observations without SCI, and 2 for observations with SCI.

5.2.6 XIS1 Change to CI=6 keV in 2010/11

From the start of the SCI operation, a charge equal to the one produced by a 6 keV X-ray photon ("6 keV equivalent") was injected for the FI devices while a smaller amount ("2 keV equivalent") was used for the BI device, XIS1. By 2010 it had been shown that with an increased SCI amount of 6 keV equivalent for XIS1 the high-energy response improves significantly with no measurable degradation of the low-energy response. Therefore, the amount of charge injection for XIS1 was increased from 2 to 6 keV equivalent for better high energy response in 2010 and 2011. The changes were made gradually for different clocking modes and retrospectively for some calibration observations. More information can be found on the *Suzaku* GOF web pages at
`http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/nxb_ci6kev.html`,
in the *Suzaku* memo available at

Table 5.1: Dates for the XIS1 CI=2 keV to CI=6 keV change for different modes.

Date	Unit	Mode
2011-06-01	XIS1	Injection charge increased to 6 keV for Normal (no option).
2011-08-22	XIS1	Injection charge increased to 6 keV for Normal (1/4 window).
2011-09-01	XIS1	Injection charge increased to 6 keV for Normal (0.1 s burst).
2011-10-06	XIS1	Injection charge increased to 6 keV for Normal (1/4 win+1.0 s burst, 1/8 win).
2011-10-11	XIS1	Injection charge increased to 6 keV for Normal (1/4 win+0.1 s, 0.3 s, & 0.5 s burst).
2011-10-25	XIS1	Injection charge increased to 6 keV for Normal (0.5 s, & 0.62 s burst).

`ftp://legacy.gsfc.nasa.gov/suzaku/doc/xis/suzakumemo-2010-07v4.pdf`, and in the `CALDB` release note `http://heasarc.gsfc.nasa.gov/docs/heasarc/caldb/suzaku/docs/xis/ReleaseNote_20111022.pdf`. The “makepi” and “‘rmfparam” file versions listed in the release note (`ae_xi1_makpi_20111018.fits`, `ae_xi1_rmfparam_20111020.fits`) or later are required to analyze these data. `Xisrmfgen`, `xissimarfgen`, and `xisarfgen` automatically choose the appropriate `CALDB` files based on header information of the spectral input file (specified using the `phafile` parameter).

A general rule is that most (including all GO) observations were made with CI=2 keV before the change and with CI=6 keV after the change at the dates shown below in Table 5.1. Some exceptions can be found in XIS calibration observations made in 2010–2011; some calibration observations were made with CI=6 keV before the changes and with CI=2 keV after the changes in order to track the long-term gain change for both CIs.

Check CI Setting Using XIS1 Event File

Before 2011-04-01:

Check the “submode ID” which is part of the XIS1 event file name. If the file name includes “u” (e.g., `ae105027010xi1_0_3x3n069*u*_cl.evt.gz`), it was taken with CI=6 keV. If it includes “b” (e.g., `ae105027010xi1_0_3x3n069*b*_cl.evt.gz`), it was taken with CI=2 keV.

After 2011-04-01:

Check the “microcode ID” in the XIS1 event file.

```
fkeyprint ae103001020xi1_0_3x3n066c_cl.evt.gz  CODE_ID
```

If the ID is one of the ones listed in Table 5.2, the observation was made with CI=6 keV.

Table 5.2: Microcode IDs for XIS1 with CI=6 keV.

Code_ID	Comment
129	BI Normal Mode Periodic CI 1CI/54rows speed4x IA TrailMask (Obsolete)
130	BI Normal Mode Periodic CI 1CI/54rows speed4x IA TrailMask
131	BI Normal 1/4 Win at the XIS pos. with SCI and TrailMask
132	BI Burst 0.100sec SCI trail mask for CI=6keV
133	BI Burst 1/4Win 0.994sec SCItrailmask CI=6keV XIS1 XIS-nominal
134	BI Normal 1/8Win SCItrailmask CI=6keV XIS1 XIS-nominal
135	BI Burst 1/4Win 0.130sec SCItrailmask CI=6keV XIS1 XIS-nominal
136	BI Burst 1/4Win 0.299sec SCItrailmask CI=6keV XIS1 XIS-nominal
137	BI Burst 1/4Win 0.495sec SCItrailmask CI=6keV XIS1 XIS-nominal
138	BI Burst 0.500sec SCItrailmask CI=6keV
139	BI Burst 0.620sec SCItrailmask CI=6keV

XIS1 NXB Increase with CI=6 keV

The increased charge injection amount for XIS1 led to an increase in its NXB level: In the SCI operation, artificial charges are injected in every 54th row. Some fraction of the charges is carried over to the adjacent rows. Events in the charge injected rows (`SCI_ROW`) and in those next to them (`SCI_TRAILING_ROW`) are removed onboard, but a small fraction of the charges is carried over to the overnext rows (`SCI_2ND_TRAILING_ROW`). Due to the increase in the total amount of injected charges, the remaining charges in the second trailing rows increased, resulting in the increased NXB level. See section 5.3.7 for a description of how to estimate and/or mitigate the increased XIS1 NXB with CI=6 keV.

5.2.7 PIN Epochs: Low Energy Threshold & Responses

The bias voltage on-board and low energy threshold in the ground processing of various subsets of PIN units have been adjusted since launch to reduce noise events. This changes the characteristics of these PIN units in several discrete steps.

With Version 2 processing, data from all PIN units should be analyzed together. However, due to the changes in the bias voltage and the software threshold, response matrices appropriate for the epoch of the observation (see Table 7.3 in chapter 7) should be used in spectral fitting.

5.2.8 Additional Attitude Wobble

Since launch, the 3-axis attitude control using the Inertial Reference Unit (IRU) had been done with the combination IRU-X/Z/S1. On December 18th, 2009, a switch from IRU-S1 to S2 was performed. The IRU-S2 or S1 controls the attitude in the DET-X direction while the IRU-X controls the attitude in the DET-Y direction. In this configuration the accuracy of the attitude control along the DET-X axis declined by roughly a factor of two. On June 15th, 2010, another gyro, IRU-Y, was activated. The IRU-Y is more sensitive to the attitude of the DET-X direction than is the IRU-S2. IRU-S2 was used for attitude control, and the IRU-Y for attitude determination. Since June 25th, 2012, IRU-Y has also been used for attitude control which is good to $\sim$ 1 arcmin or better, with the attitude determination being good to $\sim$ 20 arcsec or better, i.e., back to the original situation. Table 5.3 summarizes these changes. The actual behavior differs from observation to observation. Some possible effects are listed in the following.

Table 5.3: History of IRU operations.

Time Period	Attitude Control Configuration, Accuracy	Attitude Determination Configuration, Accuracy
2006/07/10 – 2009/12/18	IRU-X/Z/S1, $\lesssim$ 1 arcmin	IRU-X/Z/S1, $\lesssim$ 20 arcsec
2009/12/18 – 2010/06/15	IRU-X/Z/S2, $\lesssim$ 2 arcmin	IRU-X/Z/S2, $\lesssim$ 2 arcmin
2010/06/15 – 2012/06/25	IRU-X/Z/S2, $\lesssim$ 2 arcmin	IRU-X/Z/Y, $\lesssim$ 20 arcsec
2012/06/25 – present	IRU-X/Z/Y, $\lesssim$ 1 arcmin	IRU-X/Z/Y, $\lesssim$ 20 arcsec

Possible pointing determination errors between December 18th, 2009, and June 15th, 2010: XIS images may be elongated along the direction of the DET-X axis by 1 arcmin. The recommended treatment is to:

- Apply the attitude correction tool "`aeattcorr.sl`", see section 5.3.3. It works to reduce the pointing determination error if the target is bright and point-like, producing a sharper image. *Caveat: If there is a clear double image of the source this tool cannot be used.*
- Choose the extraction region to be as large as possible.

Possible flux variations of the XIS data taken between Dec 18th, 2009, and June 25th, 2012: The pointing direction is corrected on the ground to within the calibration uncertainties. The calibration error of the pointing direction correction is larger for the data taken between December 18th, 2009 and June 15th, 2010 (see above). The image is reconstructed before the data are distributed to the users. But even in the attitude corrected data the count rate of the XIS detectors might vary by up to a few tens of percent. The variability is larger for off-axis sources because the variability results from a change of the effective area, where the XRT vignetting function is smooth on-axis while sharp off-axis (suzakumemo 2008-05). The count rate varies with the 96 min satellite orbit. The recommended treatment is to:

- Spectral analysis: run the arf generator `xissimarfgen` with the `attitude(=???.att)` option. The `xissimarfgen` tool calculates the variation of the effective area and produces an arf file that takes the effective area variation into account.
- Temporal analysis: use the `xissim` tool with `attitude` and `gtifile` options to simulate the effective area variation. A recipe for correcting the light curves will be announced in the future.

Photometry using XIS1 with a window option: The arteficial flux variation described above is most pronounced for the XIS1, especially when operated with a narrow window option such as 1/4 or 1/8 and/or at the HXD aimpoint. The inaccuracy in the attitude control along the DET-X axis is larger than along the DET-Y direction. Unfortunately, the narrower boundary of the window option is set on the DET-X axis for XIS1 (and the inoperable XIS2) while it is on the DET-Y axis for the others (XIS0 and 3).

Detailed information and example images can be found in the Suzaku memos available at `http://www.astro.isas.ac.jp/suzaku/doc/suzakumemo/` (2010-04, -05, -06).

5.3 XIS Software Tools, Recipes

5.3.1 Reprocessing and Screening: `Aepipeline`

Since 2010 the `FTOOL` `aepipeline` is available. It can be used to apply the newest energy calibration, as well as to perform data screeening for both XIS and HXD data. See section 6.4 for more information on using `aepipeline` for XIS data.

Warning:

(1) `Aepipeline` has an input directory parameter and an output directory parameter, among others. The output directory may not be a subdirectory of the input directory. If it is, wrong results can be produced (double counting of events), especially in the case of multiple reprocessing runs. While the reporting will soon be improved, this currently happens without warning or error messages.

(2) The header keyword in the event files indicating the version of the processing pipeline used for reprocessing "`PROCVER`" is not updated by `aepipeline`. Check the log file produced by `aepipeline` for pipeline version information.

5.3.2 `Cleansis` Runaway Problem

The `FTOOL` "`cleansis`" is applied in *Suzaku* data processing, when going from the unscreened (in the `event_uf` subdirectory) to the cleaned (`event_cl`) event files. When users reprocess data (e.g., to apply a new gain calibration), it is generally recommended to start with unscreened data, and the use of `cleansis` is one of the recommended screening steps. This tool was originally written for the *ASCA* SIS. Its algorithm is inherently statistical: it examines the distribution of the number of counts per raw detector pixels, and rejects those that have far more counts than likely. This step is usually repeated to eliminate lower level flickering pixels.

The versions of `cleansis` in `HEAsoft` v6.7 and earlier occasionally suffer from a runaway problem, creating a hole in the XIS data near the peak of the image. Users who encounter such a hole should first check if one is present in the unscreened event data. If this is the case, this is most likely due to a severe case of photon pile-up and is unrelated to `cleansis`. If, on the other hand, the hole is seen only in the cleaned data, `cleansis` is the likely cause.

The version of `cleansis` available since `HEAsoft` 6.8 incorporates an improvement in the algorithm which greatly reduces, if not completely eliminates, instances of such runaways. Alternatively, there are two run-time parameters that can be adjusted to reduce or eliminate this problem:

- The runaway problem only occurs when iteration is applied. The user can set iterate=no to avoid it (default: yes).
- The default probability is set to a level such that the number of non-flickering pixels that are incorrectly eliminated (due to statistical fluctuations) is approximately one per XIS segment. The probability (default: $logprob = -5.2$) can be lowered (to, say, $logprob = -7.2$).

Both these methods can prevent the runaway, at the possible cost of retaining some low-level flickering pixels in the screened data.

5.3.3 Improved Attitude Correction and Pile-Up Estimation

Section 6.7 provides a general description of the pile-up effect and gives typical count rate ranges that can be observed with minimal pile-up (Fig. 6.3).

In addition, a detailed pile-up study has been performed in 2011, see `http://www-utheal.phys.s.u-tokyo.ac.jp/~yamada/soft/XISPileupDoc_20120221/XIS_PileupDoc_20120220.html` and `Yamada et al., 2012, PASJ, 64, 53`. This study includes case examples that can be used as analysis recipes (web page: "Super Bright Source", "Relatively Bright Source", "Dim Source"; paper: Table 2 – exclusion regions for a sample of sources).

Two `FTOOLs` routines are available, `aeattcor2` and `pileest`, which were especially designed to aid in the analysis of *Suzaku* data that might be afflicted by photon pile-up.The tool `aeattcor2` further improves the attitude correction for the slow wobbling of the optical axis for bright sources by using their detected image to create a new attitude file. *Note that this tool cannot be used if a clear double image of the source is visible in* *the image.* `pileest` is designed to be run after `aeattcor2`. It will create an image that will show an estimated, minimum pile-up fraction for user specified levels. This allows the user to create a region file that excludes the most piled areas, and then to estimate the effective pile-up fraction of the remaining events. The two `FTOOLs` were created based on the externally contributed routines, `aeattcor.sl` and `pile_estimate.sl`, written in S-lang and are designed to be run on the command line using ISIS, the Interactive Spectral Analysis System, as a driver. Both utilize a number of S-Lang Modules Packages. For all intents and purposes, the scripts behave similar to typical Unix command line tools. They are available from `http://space.mit.edu/ASC/software/suzaku/`.

5.3.4 Exposure Maps, Vignetting Correction

For the study of extended sources with the *Suzaku* XIS, it is necessary to know the exposure times as well as vignetting at various sky locations within the XIS image. One type of exposure maps can be created by simply considering the detector field of view and the spacecraft attitude, the result being the actual exposure time per sky pixel. Such exposure maps can be created by using `xisexpmapgen`, which allows users to exclude unused pixels such as bad columns, hot/flickering pixels, SCI rows, and the ^{55}Fe calibration source area. For the other type, the effective exposure times per sky pixel are calculated, taking into account the vignetting of the XRT. A detailed description can be found in section 6.9 of the XIS chapter and at `http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/expomap.html`. It consists of the following steps:

- Simulating an event file using `xissim`.
- Extracting a flat field image using `xselect`.
- Smoothing and trimming the flat field image (optional, e.g., using `ximage` or `ds9`, and `xisexpmapgen`, `fimgbin`, `fimgtrim`, `farith`).
- Applying the flat field image using `farith`.

5.3.5 A faster ARF Generator than `Xissimarfgen`: `Xisarfgen`

The `FTOOL` `xisarfgen` was designed to calculate ARFs for point-like sources using pre-calculated (via ray-tracing) files in the `CALDB` (`ae_xrt*_effarea_XXXXXXXX.fits` and `ae_xrt*_psf_XXXXXXXX.fits`). This is usually much faster than using `xissimarfgen` (which always carries out ray-tracing), especially when the Euler angles are given as an input instead of the attitude file (see examples below). The different methods of calculation result in only small differences between the effective areas in the ARFs produced by `xissimarfgen` and `xisarfgen`. This is illustrated in the *Suzaku* memo "The fast ARF

generator xisarfgen"
(http://www.astro.isas.ac.jp/suzaku/doc/suzakumemo/suzakumemo-2011-01.pdf).

The usage of xisarfgen is similar to that of xissimarfgen, e.g.:

```
xisarfgen phafile=filename rmffile=filename \
source_mode=J2000 source_ra=value source_dec=value \
region_mode=SKYREG num_region=1 regfile1=filename arffile1=filename \
attitude=filename
```

or

```
xisarfgen phafile=filename rmffile=filename \
source_mode=J2000 source_ra=value source_dec=value \
region_mode=SKYREG num_region=1 regfile1=filename arffile1=filename \
attitude=none ea1=value ea2=value ea3=value
```

5.3.6 XIS Non X-Ray Background Estimation

Before *Suzaku* FTOOLS Version 7, the tool mk_corweighted_bgd_v1.1.pl and the data set of night Earth observations released from the XIS team were used to estimate the non X-ray background (NXB).

With *Suzaku* FTOOLS Version 7, which was a part of HEAsoft v6.4 released in December, 2007, the tool was upgraded to xisnxbgen and was released as one of the official FTOOLS. The NXB database was released as a part of the official *Suzaku* CALDB.

Now users should use xisnxbgen with the *Suzaku* CALDB instead of mk_corweighted_bgd_v1.1.pl to estimate the NXB. The tool mk_corweighted_bgd_v1.1.pl is now obsolete. The FTOOLS help document and section 6.8.1 give detailed information about xisnxbgen.

5.3.7 Estimation & Mitigation of XIS1 NXB Increase with CI=6 keV

The increased charge injection amount for XIS1 led to an increase in its NXB level: In the SCI operation, artificial charges are injected in every 54th row. Some fraction of the charges is carried over to the adjacent rows. Events in the charge injected rows (SCI_ROW) and in those next to them (SCI_TRAILING_ROW) are removed onboard, but a small fraction of the charges is carried over to the overnext rows (SCI_2ND_TRAILING_ROW). Due to the increase in the total amount of injected charges, the remaining charges in the second trailing rows increased, resulting in the increased NXB level. When the events in the second trailing rows are removed for CI=6 keV, the level is consistent with that for CI=2 keV.

Estimate XIS1 NXB

The tool `xisnxbgen`, when used with the appropriate `nxbevent` file in the `CALDB`, will estimate the NXB level appropriate for the amount of charges injected. Due to the current structure of the `CALDB`, `xisnxbgen` **is unable to pick the correct file automatically for XIS1 data taken with CI=6 keV**. For such data, please explicitly specify the `nxbevent calibration` file:

```
xisnxbgen nxbevent=ae_xi1_nxbsci6_XXXXXXXX.fits
```

If you have a copy of the *Suzaku* `CALDB` locally installed, this file can be found in the `CALDB` `data/suzaku/xis/bcf` directory. If you are using the `HEASARC` version of the `CALDB` remotely, it is best to download this specific file from:
`ftp://legacy.gsfc.nasa.gov/caldb/data/suzaku/xis/bcf/`

Note that the NXB calibration files `ae_xi*_nxb*_20121201.fits` are wrong and should not be used (section 5.5.8).

Mitigate XIS1 NXB Increase with CI=6 keV

In the pipeline processing, events in the second trailing rows are NOT removed. Users should make their own choice of whether they remove second trailing rows for a lower NXB level with a smaller effective area. The recipe for doing so is the following:

- Spectrum: Remove events in the second trailing rows using the `STATUS` bit mask pattern. Construct the spectrum using the `output.evt` file.

  ```
  fselect infile.evt outfile.evt '(STATUS%(2**19))<2**18'
  ```

- RMF: Use `xisrmfgen`. No special option is required.
- ARF: Use `xissimarfgen` with the following option:

  ```
  xissimarfgen 'pixq_and = 327680'
  ```

- NXB: Use `xisnxbgen` with the following option:

  ```
  xisnxbgen 'pixq_and = 327680' 'nxbevent = ae_xi1_nxbsci6_XXXXXXXX.fits'
  ```

  Please note that the `nxbevent` calibration file must be specified explicitly in this case as well. Note that the NXB calibration files `ae_xi*_nxb*_20121201.fits` are wrong and should not be used (section 5.5.8).

5.3.8 XIS Burst Option Exposure Times

The XIS team has released a version of `xistime` allowing to apply the option "`bstgti=yes`" as part of the *Suzaku* `FTOOLS` V14 in `HEAsoft` v6.8. This produces detailed good time intervals (GTIs). Previously, the GTIs of the XIS event files did not contain the detailed GTI information for burst mode data (e.g., one line for each 2 second exposure separated by 8 seconds). This led to inaccuracies in the exposure times after data filtering.

Note that the GTI extension may then contain a large number of rows, potentially causing problems in down-stream software. Also note that this option works even when the data were taken without burst mode, but in this case its application is not recommended.

5.3.9 Timing Mode

From AO-5 on, the Timing mode is used for a restricted numbers of observations. However, the calibration accuracy of the Timing mode remains worse compared to the normal mode. A recipe for reducing Timing mode data can be found at `http://www.astro.isas.jaxa.jp/suzaku/analysis/xis`

Due to comparably large numbers of hot/flickering pixels in the BI CCD and due to increased charge leakage in XIS0 in the Timing mode since the 2009 anomaly, the Timing mode is available only for XIS3. Since only one dimensional information is available in the Timing mode, the distinction between X-ray and non-X-ray events becomes inaccurate. This means that the Timing mode has a significantly higher non-X-ray background than the Normal mode. Preliminary analysis showed that the non-X-ray background in the Timing mode is one or two orders of magnitude larger than in the Normal mode. Because the available data are limited, its detailed behavior, e.g., dependence on the cut-off rigidity, is not known.

The in-flight calibration of the Timing mode is on-going and is expected to improve in the near future. However, it will not reach that of the normal mode, because (1) the Spaced-row Charge Injection (SCI) is not available on board and (2) the CTI correction is difficult in the ground processing. The updated calibration information of the Timing mode will be released as part of the `CALDB`. Unavailability of the SCI or the CTI correction means that the energy scale and resolution are significantly different from those of the normal mode. Preliminary analysis showed that the gain was lower than the nominal value by $\sim$10% and the energy resolution had degraded to $\sim$5% at 5.9 keV in early 2009. The former may be corrected if appropriate calibration information becomes available, but the latter not.

In addition, the effective area of the CCDs may change in the Timing mode: even a small number of hot/flickering pixels produces a relatively large dead area in the CCD, which reduces the effective area. This effect is time dependent. It should be noted that the accuracy of the ARF file may also be degraded, because we need to use a rectangular extraction region for the Timing mode.

The nominal time resolution in the Timing mode is 7.8 ms, but this depends on the image size of the X-ray source. If the X-ray image is much larger than 128 pixels ($\sim$2 arcmin) along the Y-address, the time resolution may become worse than 7.8 ms. Because the Y-address represents the photon arrival time in the Timing mode, the image extension (in the Y-direction) works as a low-pass filter. This means that, even for a point source, some signal is leaked to the adjacent time bins due to the tail of the XRT PSF. Therefore, the frequency response is somewhat reduced near the Nyquist frequency of the nominal time resolution of 7.8 ms.

5.4 HXD Software Tools, Recipes

5.4.1 Reprocessing and Screening: `Aepipeline`

Since 2010 the `FTOOL` `aepipeline` is available. It can be used to apply the newest energy calibration, as well as to perform data screeening for both HXD and XIS data. See section 7.4 and 7.6.3 for more information on using `aepipeline` for HXD data.

Warning:

(1) `Aepipeline` has an input directory parameter and an output directory parameter, among others. The output directory may not be a subdirectory of the input directory. If it is, wrong results can be produced (double counting of events), especially in the case of multiple reprocessing runs. While the reporting will soon be improved, this currently happens without warning or error messages.

(2) The header keyword in the event files indicating the version of the processing pipeline used for reprocessing “`PROCVER`” is not updated by `aepipeline`. Check the log file produced by `aepipeline` for pipeline version information.

5.4.2 HXD Spectra and Lightcurves: Extraction Tools

Since 2010 a set of `FTOOLS` is available that can be used to extract PIN (`hxdpinxbpi`, section 7.5.6) and GSO (`hxdgsoxbpi`, section 7.7.2) spectra, as well as PIN (`hxdpinxblc`, section 7.9.1) and GSO (`hxdgsoxblc`, section 7.10.1) lightcurves. These tools also perform additional tasks like background extraction or deadtime correction where necessary. See `fhelp` texts for these tools or sections indicated in the previous sentence for more detailed information.

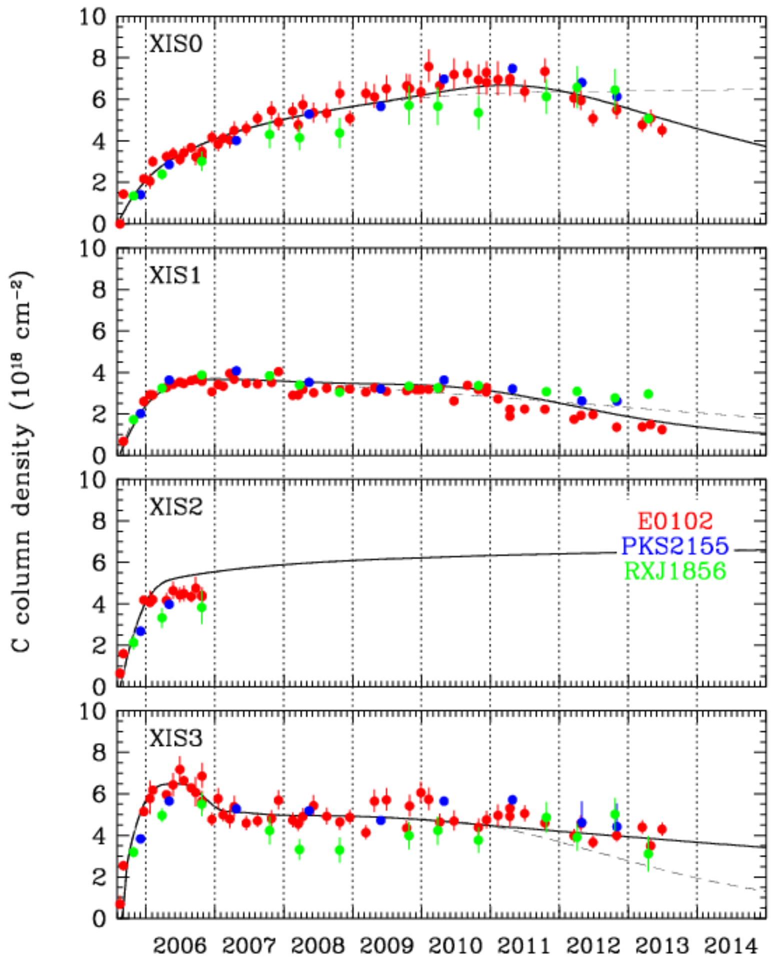

Figure 5.1: Data points indicate the C column density of the contaminant derived from observations. The solid lines indicate the best fit empirical model to the temporal evolution of the contamination for each sensor, as available, e.g. for `xissimarfgen`, through the `CALDB` files released in 2013 September (`ae_xiN_contami_20130813.fits`). The dashed lines indicate the previous version of the calibration files (`ae_xiN_contami_20120719.fits`).

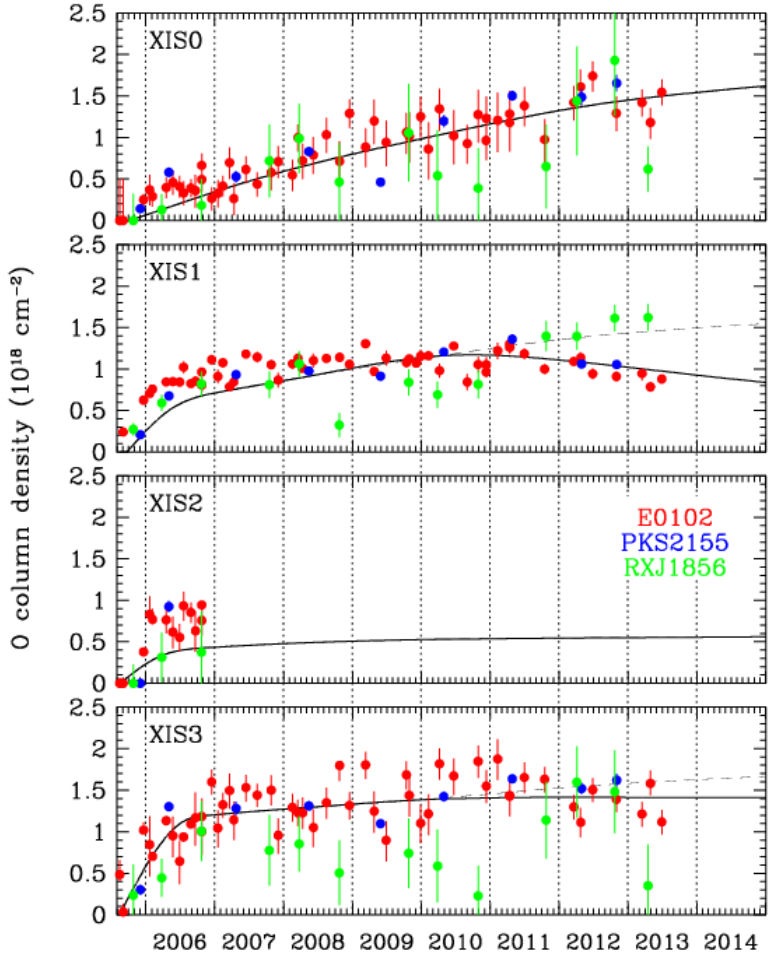

Figure 5.2: Same as Fig. 5.1 but for the O column density.

5.5 XIS Calibration Updates

5.5.1 Contamination Model

In late November 2005, contamination in the optical path of each sensor became apparent. Spectra of celestial sources show that the contaminant is predominantly carbon. Monitoring of 1E 0102.2−7219 and RX J1856.5−3754 showed that the contamination is changing at a different rate for each sensor leading to an equivalent additional column density of C

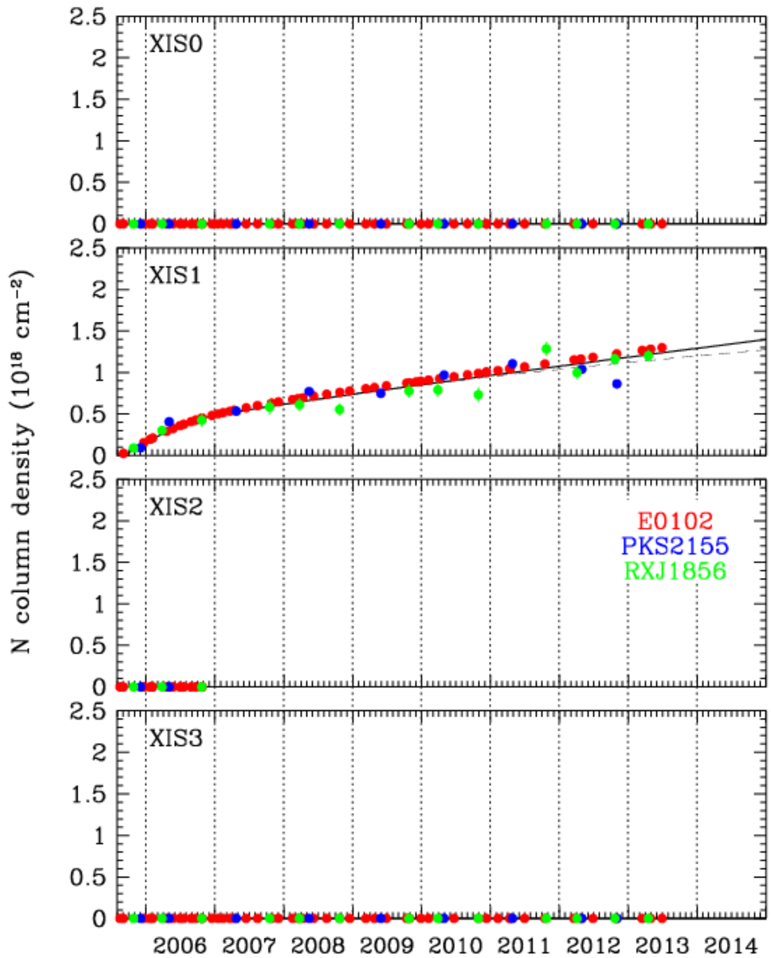

Figure 5.3: Same as Fig. 5.1 but for the N column density.

of $\sim 2-7\times 10^{18}\,\mathrm{cm}^{-2}$ (as of mid 2013; see Fig. 5.1). Observations of the bright earth show that the contaminant is twice as thick at the center of the field of view than at the edge, a pattern that tracks the temperature distribution on the optical blocking filter (OBF). This suggests that the contaminant is on the spacecraft side of the OBF, rather than on the CCD detector surfaces.

The ARF generator `xissimarfgen` takes the contamination effect into account. That is, **the ARF calculated with `xissimarfgen` by default includes transmission through**

the contaminant, taking observed data up to a certain date for each sensor into account. Those dates are defiend by the `CALDB` file used. Transmission values beyond those dates are extrapolated. The `FTOOL xiscontamicalc` is handy for determining contaminant transmission values at specified detector coordinates and dates, and for manually changing transmission information in an ARF file.

Contamination Model $\leq$ *Suzaku* `FTOOLS` Version 17 – released before 2011 June

Intitial studies suggested that the contaminant is mainly DEHP ($C_{24}H_{38}O_4$, or C/O=6 by number). The C/O = 6 description has been used for calibration up to *Suzaku* `FTOOLS` Version 17. This version corresponds to `CALDB` file tags 20081023 [XIS1, 2, 3] and 20090128 [XIS0] taking data up to March 15, 2008, and December 14, 2008, into account, respectively. ***Suzaku*** **`FTOOLS` Version 17 and below are not compatible with newer `CALDB` contamination files than these.**

Contamination Model $\geq$ *Suzaku* `FTOOLS` Version 18 – released in 2011 June

With *Suzaku* `FTOOLS` Version 18 an improved contamination model has been released. While the spatial dependence is the same as in the previous version, the elemental composition (C, O, H) of the contamination is now variable allowing for more accurate spectral modeling, especially in the 0.4–0.5 keV energy range. This version corresponds to `CALDB` file tag 20091201 [XIS0-3] taking data up to June 26, 2009, into account. ***Suzaku*** **`FTOOLS` Version 17 and below are not compatible with these new `CALDB` contamination files, while *Suzaku* `FTOOLS` Version 18 can handle the new as well as the old `CALDB` files.**

Contamination `CALDB` Files further improved – released in 2012 September

The 20120902 version of the *Suzaku* XIS `CALDB` includes updated calibration files for the XIS contaminant build-up (`ae_xiN_contami_20120719.fits`, for use with *Suzaku* `FTOOLS` Version 18 or higher). These represent a significant improvement in the calibration of the low energy response of the XIS. The XIS team has revised the spectral models for 1E 0102.2−7219 and RX J1856.5−3754, included PKS 2155−304 observations, and analyzed newer calibration observations obtained since the previous release.

For the center of the XIS FOV, the time dependence of the chemical composition of the contaminant was revised and for XIS1 is now including nitrogen. The model of the spatial distribution of contaminant was also updated. In addition to the use of the new model for the contaminant build-up at the center of the instrument, and the use of the recent calibration observations, the parameter for the spatial distribution is now allowed to vary over time. The `CALDB` update information at

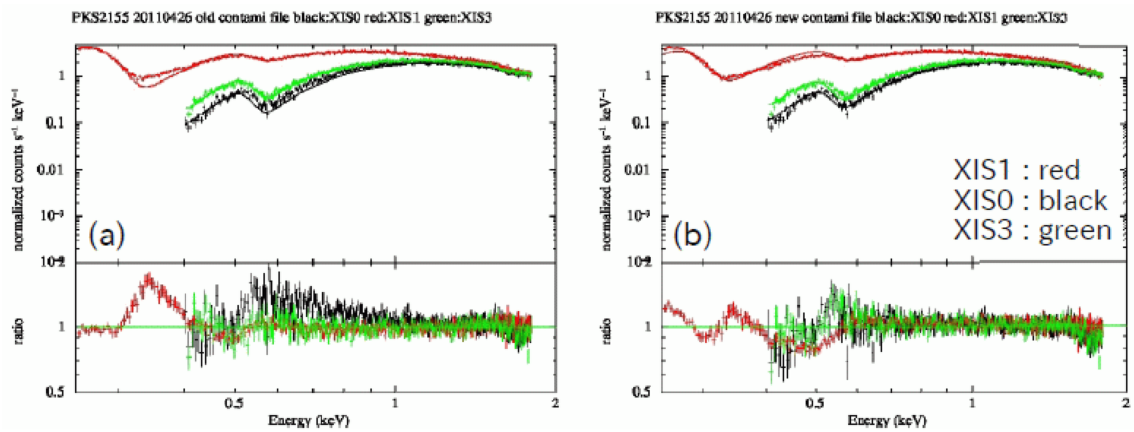

Figure 5.4: 2011 April 26 observation of PKS 2155−304 fitted using (a) old and (b) new models of the contaminant.

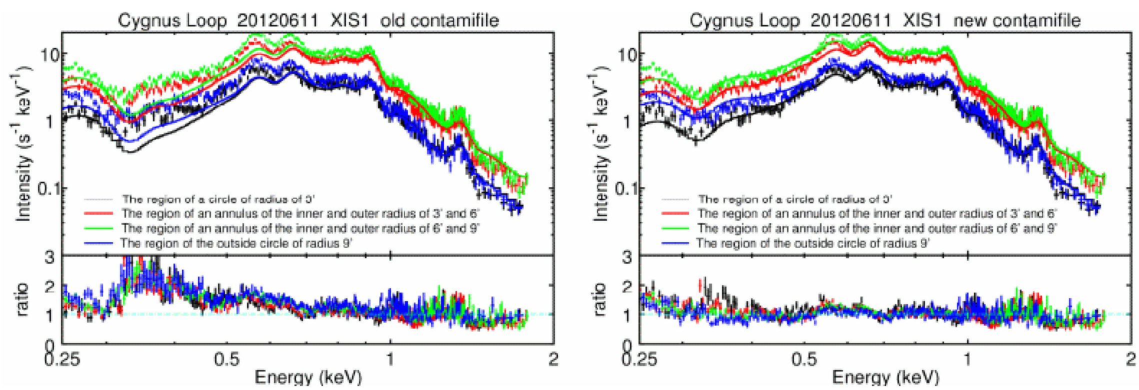

Figure 5.5: 2012 June 11 observation of the Cygnus Loop fitted using (a) old and (b) new models of the contaminant.

`http://www.astro.isas.jaxa.jp/suzaku/caldb/doc/xis/caldb_update_20120902_README.pdf` gives the equation used for the spatial dependence. See Fig. 5.4 and Fig. 5.5 for examples of the improvement of spectral residuals with the new model.

Contamination `CALDB` Files further improved – released in 2013 September

Building on the 2012 version the contamination files have been further improved. The calibration according to the further updated files (`ae_xiN_contami_20130813.fits`) is shown as black solid lines for the different XIS modules and for different elements in Fig. 5.1 to Fig. 5.3. The dashed lines represent the 2012 calibration (`ae_xiN_contami_20120719.fits`). While there is generally very little difference between the two for data taken before 2012, the improvement can be considerable for newer data.

5.5.2 XIS Reprocessing History

Table 5.4 gives a list of revisions of the `makepi` `CALDB` files that are used in the processing pipeline since V2.1.6.13:

Table 5.4: Revisions of the `makepi` file.

CALDB Update	File Name	Comments
2007-06-27	`ae_xiN_makepi_20070611.fits`	
2007-07-31	`ae_xiN_makepi_20070730.fits`	
2007-11-01	`ae_xiN_makepi_20071031.fits`	Important for SCI-on[a]
2008-02-01	`ae_xiN_makepi_20080131.fits`	
2008-09-05	`ae_xiN_makepi_20080825.fits`	Important for SCI-off 2×2[b]
2009-08-13	`ae_xiN_makepi_20090615.fits`	
2010-01-23	`ae_xiN_makepi_20091202.fits`	
2010-12-06	`ae_xiN_makepi_20100929.fits`	
2011-06-30	`ae_xiN_makepi_20110621.fits`	
2011-10-10	`ae_xiN_makepi_20110907.fits`	
2011-11-09	`ae_xiN_makepi_20111018.fits`	
2012-02-09	`ae_xiN_makepi_20111227.fits`	Do not use, see section 5.5.7
2012-07-03	`ae_xiN_makepi_20120527.fits`	
2012-11-06	`ae_xiN_makepi_20121009.fits`	

[a] `http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/sci_gain_update.html`
[b] `http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/watchout.html`

The energy scale calibration for both SCI and non-SCI data is included in Version 2 processing, and in general achieves an accuracy of 0.2% at 6 keV.

Significant `makepi` updates will continue to be announced on the *Suzaku* GOF web pages.

For window mode data only the *Suzaku* `FTOOLS` Version 12 `xispi` or later should be used to perform the reprocessing, see `http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/xis_window.html` for details.

5.5.3 Energy Scale for SCI Data

The XIS team constantly updates CTI and gain calibration of XIS data taken with SCI (Table 5.4). Note that cleaned data from processing Version 2.1.6.15 or earlier suffer from time and energy dependent effects in energy scale calibration, and should therefore be reprocessed. This can be done by running `xispi` on unscreened files (running it on screened files will lead to inaccurate results, since new calibration changes the event grades, which are used for screening). The updated files must then be screened to produce new cleaned files.

See: `http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/sci_gain_update.html` for more detailed instructions. Also see section 5.3.1 above for the introduction of a high-level script for both, reprocessing and screening.

5.5.4 Energy Scale for SCI-Off Data of 2006

For some non-SCI data taken in 2006, the energy scale calibration is noticeably worse than stated above. Discrepancies of up to 40 eV have been noticed among different XIS units.

5.5.5 Energy Scale for Window Option Data

A discrepancy in the energy scale of window option data compared to the full window data has been resolved with an `xispi` update in Version 12 of the *Suzaku* `FTOOLS` by incorporating a CTI correction formula that takes the two types of charge transfer into account. With this, the energy scale of the FI and BI data in 1/4 window mode with SCI-off are in agreement to within ± 20 eV at 6 keV with that of the full window mode (before 40 eV for the FI CCD and 60 eV for the BI CCD). For the SCI-on data good agreement between the full window and the 1/4 window modes has subsequently been shown as well.

5.5.6 Energy Scale for 2×2 Editing Mode Data

For SCI-off data there was an offset in the 2×2 mode energy scale relative to the $3 \times 3/5 \times 5$ modes. This is believed to have been fixed with the release of the `ae_xiN_makepi_20080825.fits` files in 2008 September. Users should apply the new calibration using the same procedure as for SCI-on data processed with V2.1.6.15 or earlier.

The energy scale for 2×2 mode with charge injection is expected to be similar to those of the $3 \times 3/5 \times 5$ modes. However, this expectation has not yet been verified with actual calibration. Users of 2×2 mode data with SCI should carefully check for gain discrepancies before combining 2×2 events with $3 \times 3/5 \times 5$ events. Note that 3×3 and 5×5 events can generally be combined.

5.5.7 Energy Scale Calibration Files `Ae_xi0,3_makepi_20111227.fits` wrong

A bug was found in the gain calibration files `ae_xi0,3_makepi_20111227.fits` in the `CALDB`. These files are used by `xispi` to calculate the PI and grade values from the PHA values. For window option data, an additional gain correction is usually made to match with the gain for the full window in the pipeline processing. The additional correction was mistakingly NOT made for these files, i.e., for processing the XIS0 and XIS3 data taken with a window option in the period between 2011-12-29 and 2012-07. This leads to line

Table 5.5: Observations processed with wrong gain files for XIS0 and XIS3.

Object	Observation Date	Sequence Number
PERSEUS_1_4_WIN	2012-02-08	106007020
E0102−72_1_4_WIN	2012-04-23	107003010
PKS2155−304	2012-04-27	107010010
GX 304−1	2012-01-31	406060010
4U 1705−44	2012-03-27	406076010
AX J1846.8−0240	2012-04-01	407019010
4U 1630−47	2012-02-13	906008010
EXO 2030+375	2012-05-23	407089010
3C273	2012-07-16	107013010

energies that are wrong by up to $\Delta E \sim 20 - 30\,\mathrm{eV}$ at $6 - 7\,\mathrm{keV}$. At lower energies, the effect is smaller. The affected ObsIDs are listed in Table 5.5.

Data processed with the `CALDB` version 20120703 (`ae_xi0,3_makepi_20120527.fits`) or newer are corrected for this issue. The affected data listed in Table 5.5 have to be reprocessed by the user using, e.g., `aepipeline` (see sections 5.3.1 and 6.4) or `xispi`:

```
xispi \
infile=ae${seqnum}xi${sensor}_*_uf.evt \
outfile=ae${seqnum}xi${sensor}_*_new.evt \
hkfile=ae${seqnum}xi${sensor}_*.hk.gz \
makepifile=ae_xi${sensor}_makepi_20120527.fits.gz
```

See also ISAS page `http://www.astro.isas.jaxa.jp/suzaku/analysis/xis/wingain_2012/` and `CALDB` release note `20120530_MakepiUpdate_win14GainTable.pdf` under `http://heasarc.gsfc.nasa.gov/docs/heasarc/caldb/suzaku/docs/index.html`.

5.5.8 XIS NXB Calibration Files `Ae_xi*_nxb*_20121201.fits` wrong

There was a problem in the 2013-01-10 release of the XIS `CALDB` regarding the NXB database (files `ae_xi*_nxb*_20121201.fits`), such that `xisnxbgen` will produce a background map for the 1/4 window region only, regardless of the option used for your observation.The XIS `CALDB` has since been updated. The 2013-03-05 release (files `ae_xi*_nxb*_20130228.fits`) corrects the above problem. See following ISAS page for more details:
`http://www.astro.isas.jaxa.jp/suzaku/analysis/xis/nxbdb_20130228/`

5.5.9 Calibration Uncertainties near 2 keV

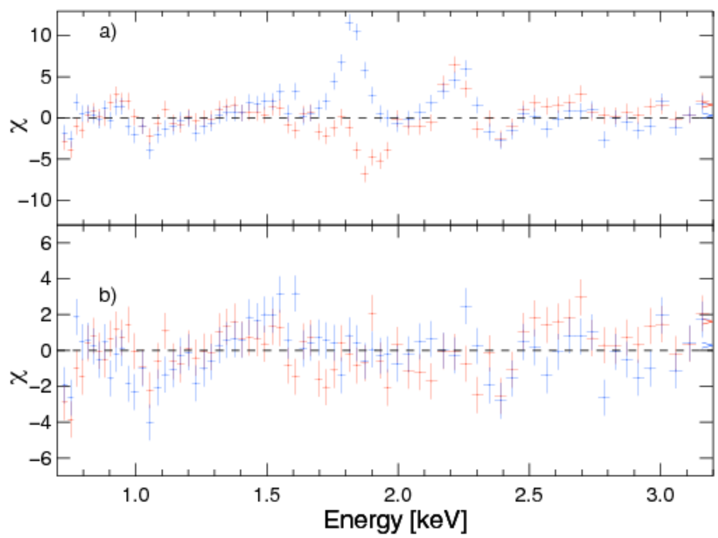

Figure 5.6: Example for typical residuals around 2 keV due to instrumental effects (blue: BI – XIS1, red, combined FI – XIS0+3), with respect to a smooth continuum fit (top) and modeled with two Gaussian lines (bottom), see text for line energies (`Suchy et al., 2011, ApJ, 733, 15`). The 2012 improvements (see text) are not taken into account. While these improvements reduce the residuals their typical shape is still apparent in some observations.

Spectral modeling residuals have often been seen in the 1.6 keV to 2.3 keV region, especially for bright sources. They are due to imperfect calibration of the instrumental Si K edge at ∼1.8 keV (and maybe some influence of imperfect calibration of the instrumental Si K-alpha fluorescence line at ∼1.7 keV as well) and the Au M edge at ∼2.2 keV. An example – not yet taking the 2012 improvements described below into account – is shown in Fig. 5.6, where residuals of a spectral fit to data from a 500 mCrab bright outburst of the accreting pulsar 1A 1118−61 are displayed (`Suchy et al., 2011, ApJ, 733, 15`), for a smooth continuum model (top) and a model with two additional Gaussian lines (bottom) at 1.82±0.01 keV (BI, "emission") or 1.89±0.01 keV (FI, "absorption") as well as 2.21±0.01 keV (BI and FI).

Improved Si Edge QE Calibration, mainly for XIS03 – released 2012 June

The XIS team has released a set of new quantum efficiency files (`ae_xiN_quanteff_20120428.fits`). This update or later versions modify the XAFS structures around the Si K edge (∼1.8 keV) and the Al K edge (∼1.6 keV) by adopting new absorption coefficients. This leads to the quantum efficiency for the BI CCD XIS1 changing only a little – not solving the 2 keV residual problem – while for the FI CCDs XIS03 it changes significantly – improving the residuals near 2 keV. The X-ray transmission of the optical blocking filter around the Al K edge has also been updated. To use the new calibration, install/use the latest `CALDB` and rerun `xisrmfgen`; there is no need to reprocess the event files or regenerate the ARF files. See also: `http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/sical_update.html`

Improved Si Edge Response Calibration for XIS1 – released 2012 December

Suzaku `FTOOLS` Version 20 was released in 2012 December as part of `HEAsoft` version 6.13. `Xisrmfgen` has two new hidden parameters in this release, `bi_si_edge_mode` and `fi_si_edge_mode`. The former is set to 1 by default, which instructs `xisrmfgen` to use a new and improved response model around the Si K edge for XIS1. Setting it to 0 reproduces the old response. The latter is reserved for future use. It is currently set to 0 by default and should not be changed from the default for the time being.

5.5.10 Calibration Uncertainties at low Energies for highly absorbed Sources

The response function of the XIS detectors includes a constant component seen below the main peak (`Koyama et al. 2007, PASJ, 59, S23`). Although the origin of the component is not fully understood, a part of the component is due to X-ray photons absorbed at a place close to the boundary between the depletion layer and the insensitive layer, in which case only a small fraction of electrons can be collected as a signal (`Matsumoto et al., 2006, SPIE Proc., 6266, 626641`).

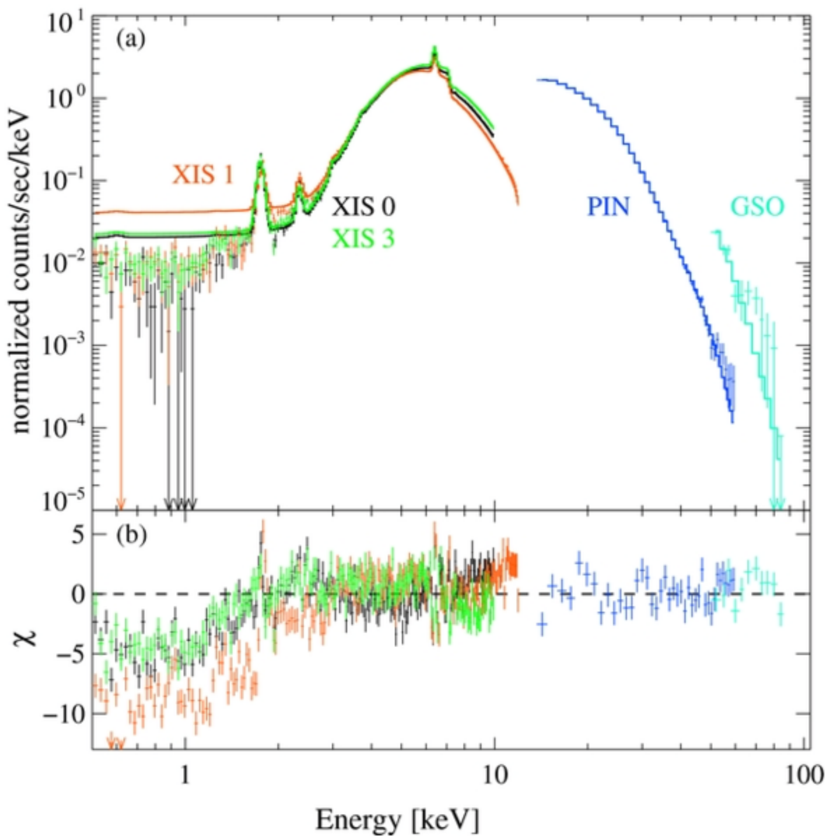

Figure 5.7: Spectra and best fit models for an observation of GX 301−2 including data from the three individual XIS instruments and the two HXD instruments. At lower energies, one clearly sees the constant level in the modeled flux discussed in the text (`Suchy et al., 2012, ApJ, 745, 124`).

In highly absorbed sources, like the accreting pulsar GX 301−2, this component can become dominant at low energies (pulse height channels). It is difficult to calibrate in space and therefore has a comparatively large uncertainty in the current response function. For sources that are weak at soft energies it might be necessary to ignore those energies if they are showing residuals associated with this component. In GX 301-2 the residuals seem to be stronger for the BI spectrum than for the FI ones (see Fig. 5.7 and `Suchy et al., 2012, ApJ, 745, 124`). In this case the $< 2\,\mathrm{keV}$ data were not included in the final fit.

5.5.11 XRT/XIS Effective Area

The 2008-07-09 release of the *Suzaku* `CALDB` contains an updated calibration of the XRTs and the corresponding updates to the XIS quantum efficiency files, while the *Suzaku* `FTOOLS` release Version 8 contains updates of the raytracing library used by the `xissim` and `xissimarfgen` response generator tools (older versions of these tools do not work with the new calibration files, while the new version of the raytracing library is backward compatible with the older calibration files). The new calibration can be applied without reprocessing the event data. The only requirement is to re-generate the response files using `xisrmfgen` and `xissimarfgen`.

As part of this release the vignetting and imaging calibrations have been updated. The geometry parameters for each quadrant of each XRT have now been individually adjusted. As a result, the calibration of the point-spread function (PSF)/encircled energy function (EEF) has improved, particularly beyond 2 arcmin from the image center. The simulated EEF now coincides with the observed values within 4% from 1 to 6 arcmin radius.

The combination of the XRT and XIS calibration changes regarding the effective area is such that, for observations at the XIS nominal position, analyzed using a large (e.g., 250 pixel radius) extraction region, changes are relatively small. Note, however, that the relative normalization for the PIN data is now 1.16 and 1.18 for the Crab nebula observed at the XIS and HXD nominal positions, respectively (with estimated errors of 0.015). Note also that the changes in the EEF and in the vignetting calibration affect the effective area calibration as a function of source location and extraction region radius. Be advised that effective area calibration may have changed significantly for some extraction regions.

5.6 HXD Calibration Updates

5.6.1 PIN Noise & Energy Range

The leakage current of the PIN sensors has been gradually increasing due to radiation damage. Therefore, the HXD team has updated the PIN threshold level file (`ae_hxd_pinthr_NNNNNNNN.fits`) several times. This file is used to remove the noise events so that the clean event file does not contain them. However, after releasing an updated threshold level file, the PIN noise level further increases, and noise events sometimes leak into the clean event files before the release of new threshold files, especially for observations where the HXD temperature was high. (The temperature can be checked at `http://www.astro.isas.jaxa.jp/suzaku/log/hk/` .) In that case, PIN noise events

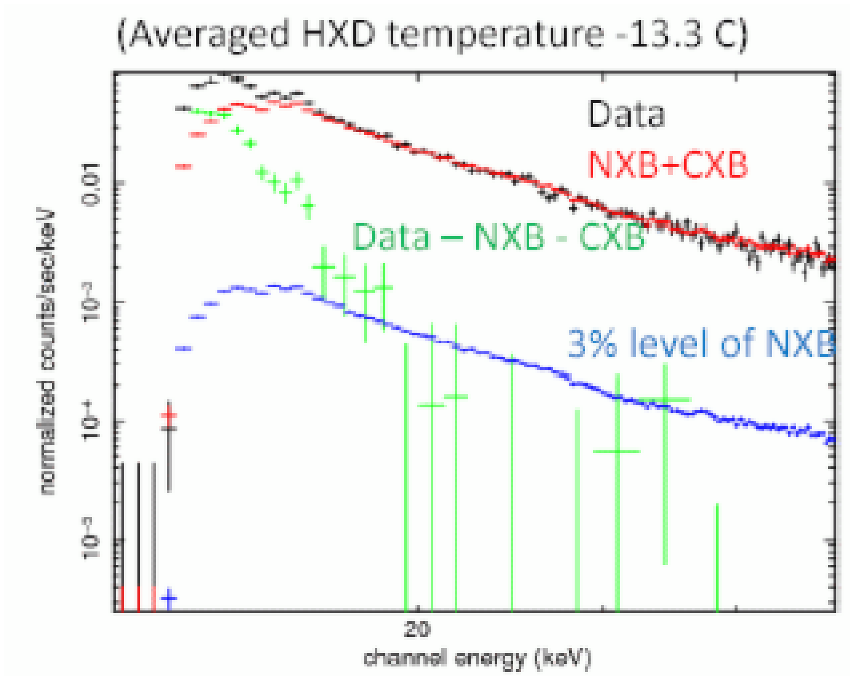

Figure 5.8: Example of an overall PIN spectrum with noise contamination.

appear at 10–15 keV as a steep increase to the lower energy as shown in Fig. 5.8. With the current PIN response matrices of all epochs, systematic uncertainties of typically 5% and 3% remain in the $12 - 15$ keV and the > 15 keV range, respectively. The HXD instrument team generally recommends to ignore data below 15 keV.

Looking at the individual 64 PIN spectra can already be used now to identify noise contamination. The noise level is different between PINs, unlike the cosmic signals and background signals. In the `XSELECT`, the following command selects the events of an individual PIN diode:

```
filter column "UNITID=2:2 PIN_ID=3:3"
```

In this example the events of PIN no. 3 of the Well UNIT no. 2 are extracted. UNITID is in the range of 0 to 15 and `PIN_ID` is in the range of 0 to 3. Fig. 5.9 shows an example of the individual 64 PIN spectra for data with noise contamination. An example of a C-shell script for creating the 64 PIN spectra and plotting them into postscript files using `XSELECT` and `XSPEC` can be found at:
`http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/pinnoise.html`

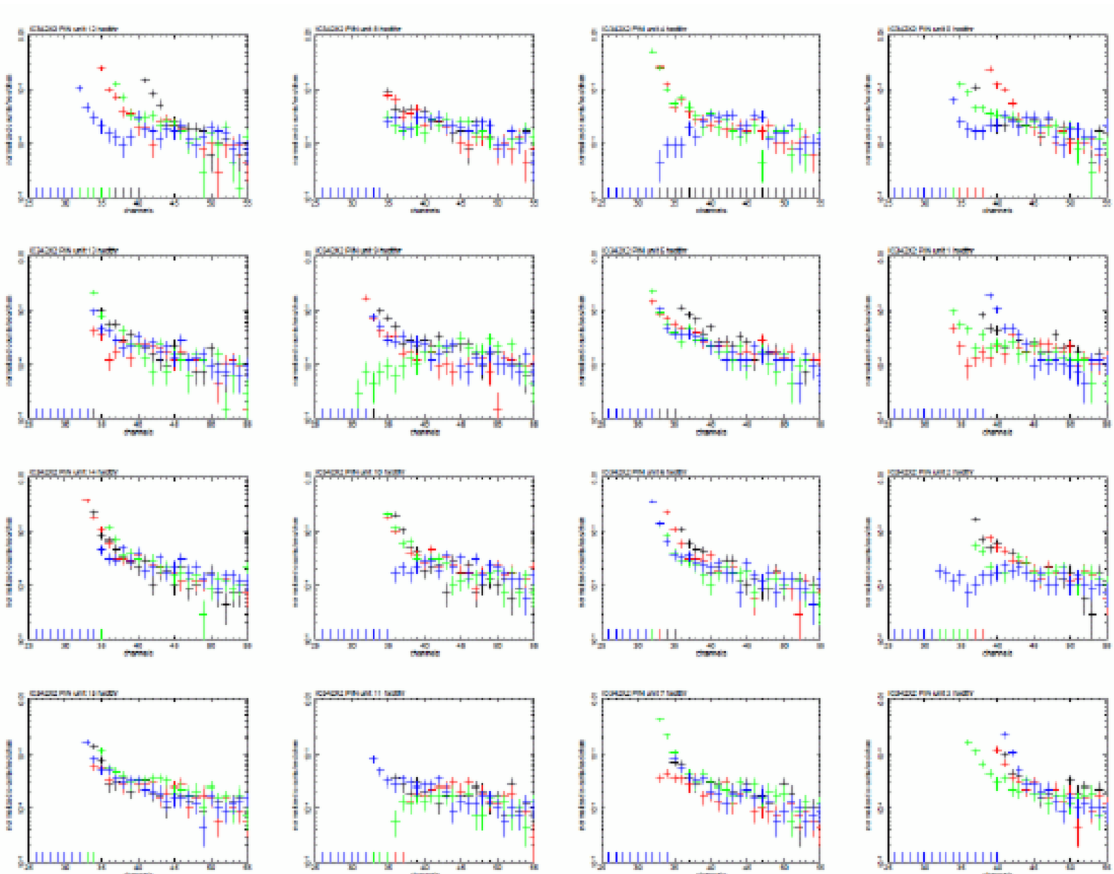

Figure 5.9: Example of 64 individual PIN spectra with noise contamination.

5.6.2 GSO Gain Calibration

GSO Gain Calibration ≥ *Suzaku* `FTOOLS` Version 16 – released in 2010 March

On 2010, March 29, the HXD team has released updated software (as part of *Suzaku* `FTOOLS` version 16 within `HEAsoft` v6.9) as well as a new `CALDB` file (`ae_hxd_gsogpt_20100323.fits`), implementing a revised gain calibration for the HXD-GSO data. This extends the low energy limit of the usable GSO data from 70 keV down to 50 keV. Note that a new type of `CALDB` gain history calibration file, new non X-ray background files, and new response + correction arf files have to be applied (Fig. 5.10). One of the most important differences in the pipeline processing is that instead of the old type of GSO gain calibration file, `ae_hxd_gsoght_YYYYMMDD.fits`, the new type, `ae_hxd_gsogpt_YYYYMMDD.fits`, has to be used with `hxdpi`. Details are described by Yamada et al., 2011, PASJ 63, No. 5, and at

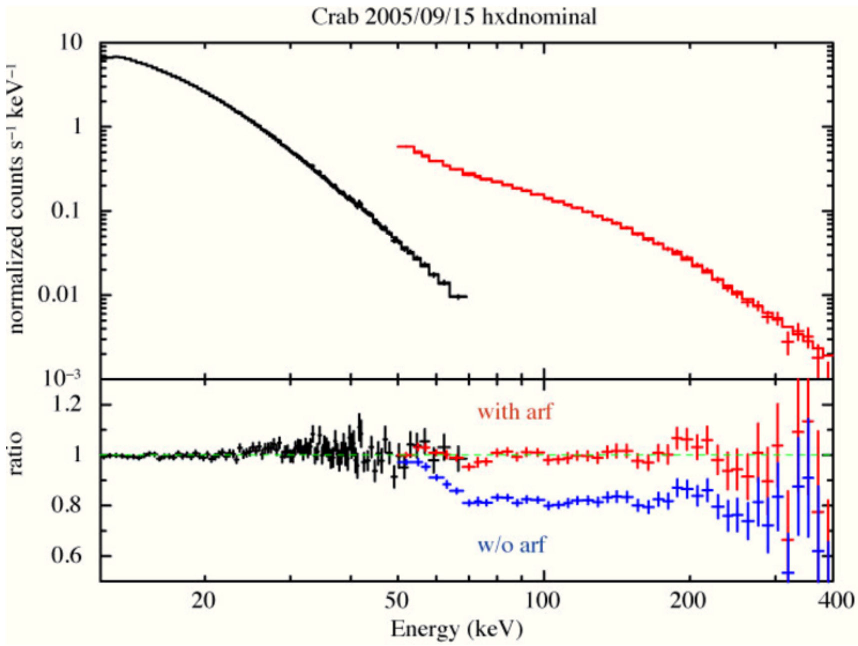

Figure 5.10: HXD-PIN (black) and HXD-GSO (red) spectra and fit residuals for the Crab as observed on 2005 Sep. 15 using the nominal HXD pointing position. The adopted model is `wabs`×`bknpowerlaw`, with $N_{\rm H}$=3.8×10^{21} cm^{-2}, photon indices of 2.09 and 2.27, a break energy of 103 keV, and a nomalization of 10.9 photos keV^{-1} cm^{-2} s^{-1} (at 1 keV). To illustrate the effect of the correction arf file, fit residuals without applying the file are displayed as well (blue). The 20% difference of the 70–400 keV flux between the data and the model without the arf and the bump-like residual around 50–70 keV due to calibration uncertainties around the Gd-K edge are reduced by introducing the correction arf file, resulting in better agreement with the HXD-PIN spectrum.

`http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/gso_newgain.html` and `http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/gso_newarf.html`. Support for the old software/calibration/backgrounds for *new* observations has stopped for observations from 2010 spring onwards. However, older observations can be reduced with both, the new and the old set up, the latter by using `hxdpi_old` in *Suzaku* `FTOOLS` Version 16+, instead of `hxdpi`, for reprocessing.

For an explanation on how to determine which calibration setup was used for the pipeline processing ("cleaned events") of a specific GSO dataset and of when and how to perform reprocessing for a specific GSO dataset see section 7.3, sections 7.6.1– 7.6.3, and paragraphs on the $\geq$ *Suzaku* `FTOOLS` Version 16 background model events below in this section.

Table 5.6: $\geq$ *Suzaku* FTOOLS Version 16 GSO NXB model event file properties.

Availability Dates	Directory	METHOD[a]	METHODV[b]	GSOGPT File
2005-08-17–2011-11-03	gsonxb_ver2.5	LCFIT(bgd_d)	2.5ver0912-64	20100323
2011-03-01–	gsonxb_ver2.6	LCFIT(bgd_d)	2.6ver1110-64	20110819

[a] FITS header keyword to distinguish background modeling methods.
[b] FITS header keyword to distinguish revisions.

GSO Gain Calibration GSOGPT CALDB File further improved – released in 2011 October

Since the initial release of the new GSO gain calibration setup described above an improved version of the CALDB file has been released (ae_hxd_gsogpt_20110819.fits). It corrects more recent GSO data in order to keep gain fluctuation below 1%. For more details see CALDB release note at
http://heasarc.gsfc.nasa.gov/docs/heasarc/caldb/suzaku/docs/hxd/GPT_CALDOC_201109.pdf.
This calibration file has been used in the pipeline processing ("cleaned events") since 2011, November 3. See paragraphs on the $\geq$ *Suzaku* FTOOLS Version 16 background model events below in this section for a statement on when data processed with the previous GSOGPT file (ae_hxd_gsogpt_20100323.fits) should be reprocessed.

GSO Gain Calibration $\geq$ *Suzaku* FTOOLS Version 16 – new GSO Non X-ray Background Files

Two new sets of HXD/GSO Non X-ray Background (NXB) event files corresponding to the version of hxdpi released with *Suzaku* FTOOLS Version 16 (HEAsoft v6.9) are available since early 2012. Table 5.6 shows for which dates they are available. They are called ver2.5 or ver2.6, with GSO energy calibration file ae_hxd_gsogpt_20100323.fits and ae_hxd_gsogpt_20110819.fits used in their creation, respectively. The NXB files can be downloaded from
ftp://legacy.gsfc.nasa.gov/suzaku/data/background/gsonxb_ver2.5/ and
ftp://legacy.gsfc.nasa.gov/suzaku/data/background/gsonxb_ver2.6/.
New ones become available around one month after the observation date.

The FTOOLS Version 16 and later pipeline processing ("cleaned events") uses ae_hxd_gsogpt_20100323.fits for observations performed before 2011, November 3, and ae_hxd_gsogpt_20110819.fits for observations performed after 2011, November 3, as indicated by the header keyword GSOGPT_F. Users should choose the background model accordingly. In most cases it is not necessary to reprocess $\geq$ FTOOLS Version 16 GSO data (for reprocessing of earlier FTOOLS version data see section 7.3 and sections 7.6.1– 7.6.3) taken before 2011, November 3, since the difference between the analysis results for the two `gsogpt` files is not large. Only for bright sources (above 100 mCrab in the GSO band), it is recommended to reprocess the data from 2010, March 1, to 2011, November 3. Once the data have been reprocessed with `ae_hxd_gsogpt_20110819.fits`, background ver2.6 should be used. `Aepipeline` automatically chooses the newest calibration file.

5.7 Cross Calibration

5.7.1 Flux Cross Calibration: XIS0,1,3

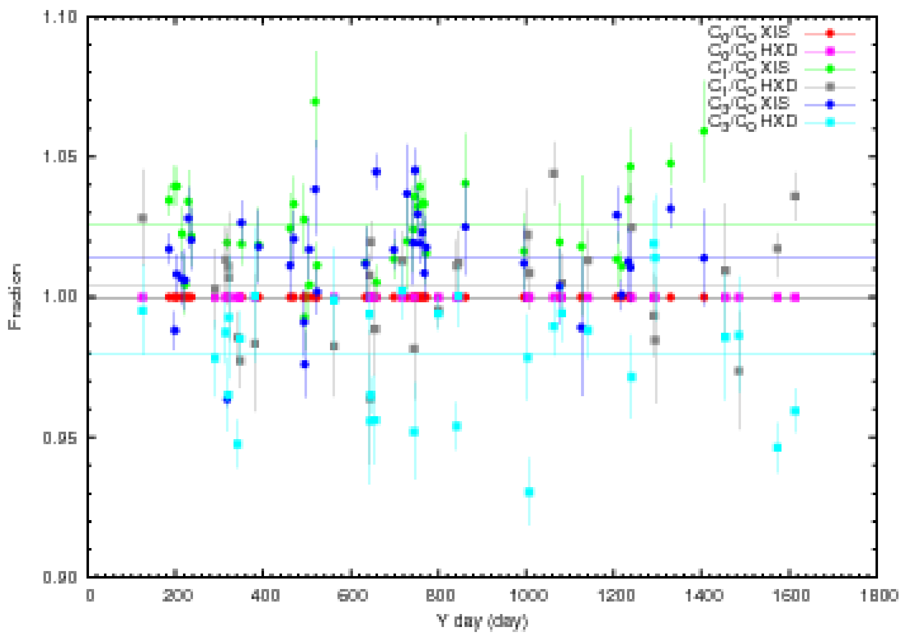

Figure 5.11: Relative flux normalization between different XIS sensors. The ratio of the best-fit normalization values are compared between two sensors at the XIS and the HXD nominal positions. Observations of a power-law source in the Normal clocking mode were used. The best-fit constant values are indicated by solid lines.

The stability of the relative flux normalization between the three XIS sensors is shown in Fig. 5.11. No significant time dependence is found. The relative normalization remains constant. The mean and standard deviation are summarized in Table 5.7, separately for the XIS and HXD nominal positions.

Table 5.7: Relative flux normalization between different sensors.

Position	Ratio	Mean	Standard deviation
XIS-norm	XIS1/XIS0	1.026	0.016
	XIS3/XIS0	1.014	0.017
HXD-norm	XIS1/XIS0	1.004	0.019
	XIS3/XIS0	0.980	0.022

5.7.2 Flux Cross Calibration: XIS and HXD

Observations of the Crab have been used to study the cross-normalization of XIS and HXD. With Version 2 processed data, the normalization of PIN data relative to XIS0 data is currently 1.16 for observations at the XIS nominal position, and 1.18 for those at the HXD nominal position (with estimated errors of 0.015).

The normalization of the GSO relative to the PIN was found to be ~ 0.8. This discrepancy can be considerably reduced with the temporary workaround of applying the GSO "correction arf" in addition to the standard arf, see `http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/gso_newarf.html`.

Cross normalization factors should be taken into account in joint spectral fits of XIS and HXD data.

5.7.3 Flux and Spectral Shape Cross Calibration: Multi-Mission

See, e.g., `Tsujimoto et al., A&A, 525, 25 (2011)`.

Chapter 6

XIS Data Analysis

6.1 Introduction

The XIS consists of four CCD detectors, three of which are "front-illuminated" (FI) and one "back-illuminated" (BI). The BI chip has an increased quantum efficiency at low ($< 1\,\mathrm{keV}$) energies with a small decrease at higher energies. Although the detectors have seen significant improvements since the ASCA SIS, the data reduction is quite similar to that of *ASCA* SIS and *Chandra* ACIS.

Users should familiarize themselves with the current issues with the XIS and XIS analysis (the loss of XIS2, the XIS0 anomaly, SCI, energy scale of non-SCI data, energy scale of SCI data, contamination, pile-up, timing mode, and others) in chapter 5.

6.2 Cleaned Event File Content

XIS data begin as part of the RPT telemetry downloaded from *Suzaku*, and are converted into a collection of FITS files by the mk1stfits routine at ISAS. `mk1stfits` does not reject any events or apply any calibration to the data but merely converts RPT into FITS files. Once the files have been processed through the pipeline, they are included in the standard data download in the directory `xis/event_uf`.

The XIS `mk2ndfits` pipeline task is then run on the mk1stfits output to create filtered, calibrated output event files, which are placed in the `event_cl` subdirectory. The calibration steps are summarized in Table 6.1. If updates of any of these tools became available since the initial processing of a dataset, the user can reprocess the data, see section 6.3 and 6.4 for details. A recalculation that is necessary in most cases in order to obtain the best available calibration, is *the update of the PI energy scale with the newest calibration using* `xispi` (next section).

Calibration Item	Tool	Comments
Assign Arrival Times	`xistime`	Not for P-sum mode
Calibrate Sky Coordinates	`xiscoord`	Attitude wobble is now modeled
Assigning Pixel Quality	`xisputpixelquality`	
Compute PI	`xispi`	Works for data with and without SCI
Compute GTIs	`xisgtigen`	Can be used to monitor telemery saturation
Add Microcode	`xisucode`	Updates header information about the mode

Table 6.1: XIS calibration steps.

In addition to the above calibration steps, the event files in the `event_cl` have been screened using two broad classes of screening, event by event and by good-time intervals (GTI). The former includes event grade, which encodes the pattern of charge distribution among neighboring pixels and can be used to distinguish between X-ray and charged particle events. The GTI screening is used to select time intervals where the instrument is stably pointed at the source without being blocked by the Earth, and to exclude high background intervals. Both classes of screening are applied by the processing pipeline.

The Version 2 pipeline screening criteria are summarized in Table 6.2. These are also the screening criteria applied by the tool `xisrepro`, see next section.

Type	Criterion	Comments
Event by event	`GRADE=0:0 2:4 6:6`	*ASCA* grades indicating X-ray events
	`STATUS=0:524287`	Bad columns, charge injection rows removed
	`cleansis`	Flickering pixels are removed
GTI	`AOCU_HK_CNT3_NML_P==1`	Attitude control in pointing mode
	`ANG_DIST<1.5`	Instantaneous pointing within 1.5 arcmin of mean.
	`Sn_DRATE<3`	Telemetry rate SuperHigh, High, or Medium
	`SAA_HXD==0`	Satellite is outside SAA
	`T_SAA_HXD>436`	Time since SAA passage >436 sec
	`ELV>5`	Pointing direction >5 deg above Earth
	`DYE_ELV>20`	Pointing direction >20 deg above sunlit limb of Earth

Table 6.2: XIS screening criteria.

6.3 Energy Scale Reprocessing (`Xispi`) and Screening using `Xisrepro`

The XIS team regularly updates the `CALDB` files (e.g., `ae_xiN_makepi_20090615.fits`), which are used by `xispi` which calculates the PI values. The files include time-dependent CTI parameters and thus enable us to correct the decrease in the gain after 2006 September.

The processing pipeline V2.1.6.16 is the first version to use these revised `makepi` files. Users should check the pipeline version used for processing their data by reading the `PROCVER` keyword in their data files. See chapter 5 for a history of `makepi` file releases. Significant `makepi` updates will continue to be annouced on the *Suzaku* GOF web pages.

For window mode data only the *Suzaku* `FTOOLS` Version 12 `xispi` or later should be used to perform the reprocessing, see
`http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/xis_window.html` for details.

The Version 2 processing pipeline used older versions of the `makepi` files up to V2.1.5.15. For SCI-on XIS data taken 2006 September, this resulted in the gain of Mn K alpha calibration line decreasing at a rate of about 30 eV/year in the FI chips — see `http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/xis_v2.html`.

Users can reprocess their own SCI-on data (processing Version 2.x) as follows.

First, run `xispi` to recalculate the PI values. Note that the XIS HK files are in the `xis/hk` subdirectory.

```
> xispi infile=ae101005070xi0_0_3x3n066z_uf.evt.gz \
        outfile=ae101005070xi0_0_3x3n066z_uf_new.evt \
        hkfile=../hk/ae101005070xi0_0.hk.gz
```

The hidden paramter `makepifile` should be set to `CALDB` if accessing the latest `CALDB`, or explicitly specify the latest "`makepi`" file.

Since the grade determination is based on the CTI-corrected pulse height values in the `PHA` column, users should reprocess starting with the unfiltered event files. Once all unfiltered event files are reprocessed with `xispi`, they must be screened. For convenience, we provide an `xselect` script
`http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/xisrepro.xco`, which references the event selection criterion file
`http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/xis_event.sel` and the standard good-time interval selection file
`http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/xis_mkf.sel`. Users should download these three files into the current working directory, make sure the filter file (`.mkf` in `../../auxil` directory) is uncompressed if using *Suzaku* `FTOOLS` Version 13 or earlier, read in the updated unscreened event file(s) into `xselect`, and then type

```
xsel > @xisrepro
```

This will cause `xselect` to apply the event selection, remove flickering pixels (using `cleansis`), and apply the standard GTI selection. If desired, users can edit `xis_mkf.sel` to adjust the screening criteria. `Xselect` will pause and ask the users to give the output (screened) event file name.

If there are more than one unfiltered event file, it is recommended to reprocess them all individually and then combine the reprocessed files in the screening step.

6.4 Full XIS Reprocessing and Screening using `Aepipeline`

The powerful `FTOOL` `aepipeline` (available since *Suzaku* `FTOOLS` version 14, i.e., `HEAsoft` v.6.8) duplicates the *Suzaku* processing pipeline. It allows the user to run all or part of the pipeline for XIS (detector selection available) and/or HXD (detector selection available) and to vary the calibration files used. A number of other pipeline processing parameters can also be changed. Please, refer to the help text available, e.g., by typing "`fhelp aepipeline`".

The pipeline performs *calibration* – for the XIS this includes running `xisgtigen`, `xistime`, `xiscoord`, `xisputpixelquality`, and `xispi` – as well as data *screening* – with defaults as given in Table 6.2 for the XIS. The screening criteria can be modified by changing the parameters `xis0/1/2/3_expr` from their default values.

The `GTI` file for telemetry un-saturated times created by `hxdgtigen` (`aeNNNNNNNNNxis_0_tlm.gti`) is applied by `aepipeline`.

The following is an example of a simple call of `aepipeline`, performing recalibration (`stage 1`) and rescreening (`stage 2`) of the XIS data for a given observation or sequence number (here: 403049010) applying the default calibration and the default screening criteria.

```
> aepipeline indir=/scratch/403049010 \
outdir=/scratch/reprocessed/xis \
steminputs=ae403049010 entry_stage=1 \
exit_stage=2 clobber=yes instrument=XIS
```

Warning:

(1) The `outdir` directory may not be a subdirectory of the `indir` directory. If it is, wrong results can be produced (double counting of events), especially in the case of multiple reprocessing runs. While the reporting will soon be improved, this currently happens without warning or error messages.

(2) The header keyword in the event files indicating the version of the processing pipeline

used for reprocessing "PROCVER" is not updated by aepipeline. Check the log file produced by aepipeline for pipeline version information.

6.5 Extracting Products

The primary tool for extracting data products (spectra, lightcurves, exposure maps) from XIS data is xselect, which is part of the general HEAsoft distribution. xselect can apply filters which select user-defined times, sky regions, or particular event flags. It then uses the filtered events to create a (binned) spectrum (as well as generating the necessary calibration files), a lightcurve, or an exposure map. Basic parameters commonly used for common data screening are in the filter, or mkf, file. See section 3.7 for a list of xselect default settings for *Suzaku*.

6.5.1 Combining 3x3 and 5x5 Editing Mode Data

The editing mode (3x3, 5x5, or 2x2) is chosen by the operations team for every interval of an observation, based on the available telemetry (see section 3.6.3). The observed data are sorted by editing mode and stored in separate files, with the mode indicated in the file names. The event files from all available modes need to be combined in order to obtain the full exposure. For the 3x3 and 5x5 modes this can be done in a straight forward way by reading the event files from both modes into xselect together and then proceeding with the filtering and extraction of products (images, lightcurves, spectra) in the same way as for a single event file. In the standard product extraction, only the central 3x3 pixel information is used even for the 5x5 event data, so there is no qualitative difference between the 3x3 and 5x5 event data. Some observations of bright sources contain 2x2 event data, however. Products from those should be extracted and analyzed separately, at least for the spectral analysis, since these event data do not contain a part of the pixel information useful for refining the photon energy determination.

6.5.2 Additional Screening

Additional filtering can be applied to the screened data at this stage using the "select mkf" command. Xselect assumes that the filter file is located in ../../auxil relative to the current working directory, with the file name *.mkf. Users who prefer to work under a different directory can use the set mkfdir command to change the location of the filter file. Note that if aepipeline is used to reprocess the data (section 6.4), a copy of the .mkf file is placed in the output directory of that tool. With the default set-up it has a file name ending with .mkf and for *Suzaku* FTOOLS Version 13 and earlier it is necessary to uncompress it.

Additional filtering could include applying a more strict version of the screening already applied in pipeline processing. For example, some observations may be more sensitive to the effects of solar X-rays scattered from the sunlit Earth. In this case, users may want to experiment applying `DYE_ELV>25` to the data and see if it makes a difference.

Another item that affects the particle background rate is geomagnetic cut-off rigidity (`COR`, which is in the mkf file; a slightly updated version, `COR2`, is currently available only in the ehk file). For example, applying the criterion "`COR>6`" can reduce the effective exposure time somewhat but may improve the signal-to-noise ratio.

One final type of screening concerns telemetry saturation. It is not expected that this is a major issue in the majority of observations, as long as data obtained with a low telemetry rate setting are excluded, hence the pipeline does not apply GTIs based on non-saturation of telemetry. However, GTI files for intervals of unsaturated telemetry are available in the `xis/hk` subdirectory with filename ending in `_tel_uf.gti`, and these can be applied by using the "select time file" command in `xselect`.

In general, users are encouraged to explore the effects of different values for all the cuts and selections described above on their own dataset by making lightcurves of `mkf` parameters.

6.5.3 Relaxing Screening Criteria

In case the user wants to relax some of the screening criteria, this can be done by starting from the unfiltered data and applying a different set of screening criteria than the standard one, e.g., using the `xisrepro` tool, see section 6.3.

6.5.4 Region Selection

For a point source, circular extraction regions centered on the source should be used to extract source spectra and light curves. Generally an extraction radius of 260 arcsec (250 pixels), which encircles 99% of the point source flux, is recommended. Recent software and calibration releases, however, allow radii as small as 60 arcsec (*Suzaku* `FTOOLS` verion 8 and `CALDB` release 2008-07-09, or later). As the vignetting is relatively small, a large fraction of the remainder of the XIS chip is in principle available for background subtraction.

Sky Regions

Users generally want to extract light curves or energy spectra from specific regions on the sky. Such region selections can be done in the "`SKY`" image displayed by ds9/saoimage. Select a region and create a region file. This file can then be applied by the `xselect` "filter region" command. Note that sky coordinates are the default image coordinates in `xselect`. After using other coordinates enter "`set image sky`" to go back to sky coordinates.

Detector Regions

Particular regions within a single detector can also be selected using detector coordinates. Since the default image coordinates in `xselect` are sky coordinates, enter "`set image det`" to switch to detector coordinates before extracting images. While detector coordinates are defined so that all the XIS images have the same direction (§3.3), the four XIS sensors on the baseplate are rotated by 90° or 180° relative to each other. The ACT coordinates are the actual location on the CCD chip, which may be useful when investigating instrumental characteristics at particular chip positions (such as extracting the calibration source spectra). Entering "`set image raw`" followed by "`extract image`" will extract XIS `ACT` images. XIS performance is dependent on segments, and particular segments may be selected with the "`select event`" command. Events on segment A, B, C, and D have "`SEGMENT`" column values 0, 1, 2, 3, and 4, respectively.

6.5.5 Calibration Source Locations

The two far-end corners from the read-out node (i.e., those with large ACTY coordinates) of each sensor are illuminated by the ^{55}Fe calibration sources. The illuminated areas are roughly sketched on the two-page XIS instrument summary that can be found at `http://www.astro.isas.jaxa.jp/ tsujimot/pg_xis.pdf`. In addition, XIS images for events with PI values between 1500 and 1800 clearly show the illuminated areas.

6.5.6 BACKSCAL

The area of the extraction region, as a fraction of total area of the coordinate space (sky or detector), is recorded in the extracted spectra in the `BACKSCAL` keyword. Since the total area of the coordinate space is different between sky and detector coordinates for *Suzaku* same size regions will have different BACKSCAL values depending on the coordinate system. XSPEC automatically scales the background using the ratio of the `BACKSCAL` keywords before subtracting it from the source spectrum. *For timing analysis, users must manually check the* `BACKSCAL` *keywords and subtract the correctly scaled version of the background lightcurve from the source lightcurve.*

6.6 Generating RMF and ARF Files

6.6.1 Rebinning XIS Spectra + Generating Responses using `Xisresp`

`Xselect` gives the user the option to rebin/group the spectra, when saving them. If the user answers "yes", the result will be physically rebinned from 4096 channels to 2048, with the following variable binning scheme:

0 699 1
700 2695 2
2696 4095 4

`Xselect` writes the above 3 lines into a file, `chanfile.txt`, then runs "`rbnpha binfile=chanfile.txt`" – users can do the same outside `xselect` for any XIS spectra that have been saved with "no" as the answer to the "rebin/group" question.

Building Response Files: The simple Way (1)

If the object in question is a point source, and the extraction region is centered on that source, user can use the "response=yes" option when saving the spectrum:

```
xsel> save spec resp=yes
```

For an extended source the user can use the "response=extend" option:

```
xsel> save spec resp=extend
```

`Xselect` will run `xisrmfgen` and `xissimarfgen` to build the response file. In the case of an extended source, the WMAP image in the spectral file is used as the input image. If, in addition, the user opts to rebin the spectrum, `xselect` will also rebin the response files. This will leave a `.rsp` file, combining the `.rmf` and `.arf` files.

Note, however, that the `.rmf` and `.arf` generation with `xselect`, and therefore `xisresp` (next section), is not recommended for complicated cases, especially complex extended sources. For such cases, please run `xisrmfgen` (section 6.6.3) and `xissimarfgen section 6.6.4` individually.

Building Response Files: The Simple Way (2)

The script used by `xselect` to build the response is also available as a stand-alone script, `xisresp`. Usage:

```
xisresp filename <fast|medium|slow> regionfile extend? echo?
```

`Xisresp` is available at:
`http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/xisresp`

The fast/medium/slow parameter controls the binning of both the spectrum and the response: slow corresponds to no rebinning, medium to the default channel binning of `xselect` (and a similar binning in photon energy space), and fast a father linear factor 2 binning.

Note that *`xisresp` does not rebin the background spectrum, when "medium" or "fast" is specified.* That must be done by the user using the "`rbnpha binfile=chanfile.txt`" command described above.

Also note that `xisresp` does not check if the input spectrum has already been rebinned. *Thus, using `xisresp` with the fast or the slow option on a spectrum saved rebinned in `xselect` will result in an error.* (Using xisresp with the medium option on a spectrum that was rebinned and saved will produce an error message from `rbnpha` — however, in this case, the error message can be ignored, since the script tries to rebin the spectrum as the last step, which fails but was unnecessary to begin with.)

6.6.2 Combining Spectra and Responses using `addascaspec`

`Addascaspec` is available as an *ASCA* `FTOOL` which can be used to combine the spectra and responses of *Suzaku* XIS (FI chip) data. It requires a 4-line Ascii file, listing the source spectral files, background spectral files, ARF files, and RMF files. It should have two or three columns depending on the number of active FI XIS units. For example, create the following file

```
x0.pha x2.pha x3.pha
x0b.pha x2b.pha x3b.pha
x0.arf x2.arf x3.arf
x0.rmf x2.rmf x3.rmf
```

and call it `fi.add` (this assumes a specific but obvious file naming convention). Then,

```
> addascaspec fi.add fi.pha fi.rsp fi_b.pha
```

will run several `FTOOLS` to create a combined source spectral file (`fi.pha`), a combined background spectral file (`fi_b.pha`), and a combined (RMF x ARF) response file (`fi.rsp`). Note that the operation to multiply and add the individual response files may be extremely memory-intensive, depending on the quality and the size of the original response files.

Note the update of the default and handling of the error statistic (`errmeth` parameter) in `addascaspec` with `HEAsoft` Version 6.7 and a bug fix with `HEAsoft` Version 6.8, see `http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/addascaspec67.html`.

6.6.3 Generating RMF Files using `Xisrmfgen`

The XIS response generator, `xisrmfgen`, takes into account the time variation of the energy response, appropriate for XIS data obtained with or without spaced-row charge injection

(SCI). It is relatively straightforward to use, see example below.

```
> xisrmfgen
xisrmfgen version 2006-11-26
Name of input PI or IMAGE file or NONE[xis0-5b5w.pi]
Name of output RMF[xis0-5b5w.rmf]
```

The information concerning the instrument, clock mode, and observation date is taken directly from the header of the spectral file given[1].

Note that `xisrmfgen` requires the spectral file to have a WMAP (weighted map) in detector coordinates. This is the default in recent (`HEAsoft` 6.1.2 or later) releases of `xselect`, although older versions defaulted to sky coordinates.

The following warning message:

```
xisrmfgen: WARNING: Weighted map or image is not in DET coordinate.
xisrmfgen: WARNING: Use constant weight on whole CCD.
```

indicates that the WMAP is in `SKY` coordinates. In this case, `xisrmfgen` generates a response file assuming a constant WMAP over the whole CCD. The current `xisrmfgen` does not consider spatial variation of spectral response on the CCD chip, which is negligible for the current data. Therefore, the practical effect of this is negligible. Nevertheless, it is advisable to generate spectral files with the WMAP in DET coordinates. To do so with older versions of `xselect`, issue the command:

```
xsel:SUZAKU-XIS1-STANDARD  set wmapname detx dety
```

6.6.4 Generating ARF Files using `Xissimarfgen` (or `Xisarfgen`)

`Xissimarfgen` is a ray-tracing based generator of ancillary response files (ARFs) for the *Suzaku* XIS. It is a powerful tool, which has far more parameters and modes of usage than the typical guest observer needs (or probably wants to know about). Since `xissimarfgen` calculates ARFs through Monte-Carlo simulations (it ray-traces X-ray photons through the *Suzaku* XRT and XIS and counts the number of events detected in the user-defined extraction regions), users need to simulate a sufficient number of photons to limit the statistical errors to an acceptable level.

For further details, users should refer to the paper by Ishisaki et al. in the Publication of the Astronomical Society of Japan (Ishisaki et al. 2007, PASJ, 59, 113; `http://arxiv.org/abs/astro-ph/0610118`).

[1]It is also possible to run `xisrmfgen` without specifying a spectral file; see the help file for details

For point sources very similar ARFs to the ones produced by `Xissimarfgen` can alternatively be produced by `Xisarfgen`, an `FTOOL` available since 2011. It uses a faster though potentially less accurate approach based on pre-calculated `CALDB` files (table interpolation) instead of on full ray-tracing. Further details are given in section 5.3.5 and in the *Suzaku* memo "The fast ARF generator `xisarfgen`"
(`http://www.astro.isas.ac.jp/suzaku/doc/suzakumemo/suzakumemo-2011-01.pdf`).

Example: ARF of a Point Source

Here we give an example of generating an ARF file for a point source observed on-axis, using the data set ID 100012010. The following is an XIS1 image of the observation, in which one can see a bright point source at the center (Fig. 6.1). We assume that a spectrum from the white encircled region in the image has been extracted, and show how to generate a corresponding ARF file.

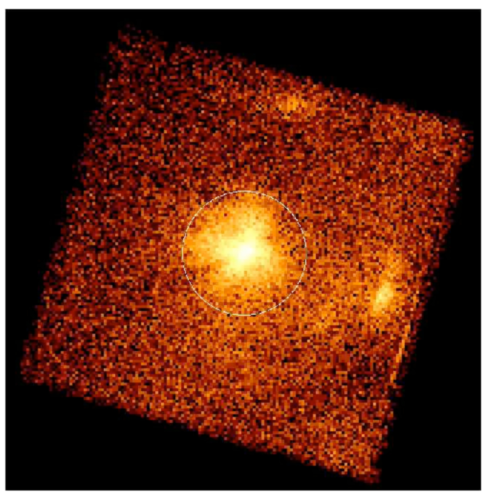

Figure 6.1: Example for an extraction region for a point source.

Region files in ds9 format and in physical coordinates can be fed into `xissimarfgen`; when using this combination, the binning used to extract the image does not matter. To save a source region, one specifies the coordinate system "Physical" in the "File Coordinate

System" row in the "Region" menu on ds9. Here is the example etacar_phys.reg:

```
# Region file format: DS9 version 3.0
# Filename: ae100012010xi1_1_5x5n001_cl.evt.gz[EVENTS]
global color=green font="helvetica 10 normal" select=1 edit=1 \
move=1 delete=1 include=1 fixed=0 source
physical;circle(784.5,786.5,172.71158)
```

corresponding to the white encircled region above in the physical coordinates. Then, run the following

```
xissimarfgen clobber=yes \
instrume=XIS1 \
pointing=AUTO \
source_mode=J2000 \
source_ra=161.264962 \
source_dec=-59.684517 \
num_region=1 \
region_mode=SKYREG \
regfile1=etacar_phys.reg \
arffile1=xis1_etacar.arf \
limit_mode=NUM_PHOTON \
num_photon=400000 \
phafile=etacar.pi \
detmask=none \
gtifile=100012010/xis/event_cl/ae100012010xi1_1_3x3n001_cl.evt \
attitude=100012010/auxil/ae100012010.att \
rmffile=ae_xi1_20060213.rmf \
estepfile=default
```

Some options specify calibration files or Monte-Carlo simulation parameters that can be adjusted each time `xissimarfgen` is run. These are:

- The pointing option `AUTO` takes care of the referencing coordinate system
- In this example, we use the "`limit_mode`" option `NUM_PHOTON` and set the number of simulated photons ("`num_photon`") to 400,000, to minimize the Poisson noise in the ARF.
- Through spectrum passed using the "`phafile`" parameter, `xissimarfgen` knows the XIS observing mode such as the window option and spaced-row charge injection option.

- In this example, we do not use the "detmask" option since the calibration source events do not fall on the source region.
- The default selection for the "estepfile" option has a sufficient energy resolution for most purposes.

Other options fixed by the observation or by the upstream analysis. These are:

- The "instrume" option is XIS1, set by the spectrum being analyzed.
- In this example, we specify the source position in the J2000 coordinate system. Thus, the "source_mode" is J2000. Therefore we also provide the source coordinates (R.A., Dec. (J2000) = 161.264962, -59.684517) using the "source_ra" and "source_dec" parameters. See the example below for using physical (X, Y) coordinates.
- The "num_region" option should be 1 since, in this case, we generate only one ARF file. The "region_mode" parameter is set to SKYREG since the region file is described in the sky coordinate system. The region file name, etacar_phys.reg, is specified via the "regfile1" parameter.
- The output ARF file name xis1_etacar.arf is specified using the "arffile1" parameter.
- To take the attitude wobble into account, the attitude file in the auxil directory, is loaded using the "attitude" parameter. To specify the time span of the observation, a FITS file with the GTI table of the observation (ae100012010xi1_1_3x3n001_cl.evt in this case) is loaded using the gtifile parameter.
- We also specify the RMF to be used in spectral fitting (ae_xi1_20060213c.rmf in this case).

The "pixq_[min,max,and,eql]" parameters are not specified on the command line since we use the default setting (bad columns, pixels, and charge injection rows are excluded; the calibration source region is not subtracted).

Here is an example, in which the source position is specified in SKYXY coordinates.

```
xissimarfgen clobber=yes \
instrume=XIS1 \
pointing=AUTO \
source_mode=SKYXY \
source_x=784.5 \
source_y=786.5 \
num_region=1 \
```

```
region_mode=SKYREG \
regfile1=etacar_phys.reg \
arffile1=xis1_etacar.arf \
limit_mode=NUM_PHOTON \
num_photon=400000 \
phafile=none \
detmask=none \
gtifile=100012010/xis/event_cl/ae100012010xi1_1_3x3n001_cl.evt \
attitude=100012010/auxil/ae100012010.att \
rmffile=ae_xi1_20060213.rmf \
estepfile=default
```

Example: ARF of a Uniformly Extended Source

Here we show an example of generating an ARF file for a uniformly extended source, using observation 102002010. The following is an XIS0 image of the observation, in which the strong emission from SNR E0102.2−7219 is evident. The goal is to search for possible extended emission from the surrounding areas. The calibration sources have to be cut out in order to avoid degradation of the data quality. This is done by typing

```
XSEL> select events "(STATUS<524287)&&(STATUS%(2**17)<2**16)"
```

in `xselect`.

As can be seen in the image (Fig. 6.2), events at the two corners where the calibration sources are located have been removed. We extract two spectra from the top-left half and bottom-right half of this image, using the region files `e0102_tophalf_phys.reg`

```
# Region file format: DS9 version 3.0
# Filename: xsel_image.xsl
global color=green font="helvetica 10 normal" select=1 edit=1 \
move=1 delete=1 include=1 fixed=0 source
physical;box(543.14102,923.78203,1027.6537,502.82032,60)
physical;-circle(756.5,788.5,200)
```

and `e0102_bottomhalf_phys.reg`

```
# Region file format: DS9 version 3.0
# Filename: xsel_image.xsl
global color=green font="helvetica 10 normal" select=1 edit=1 \
move=1 delete=1 include=1 fixed=0 source
physical;box(985.31535,667.85314,1026.428,507.58708,60)
physical;-circle(756.5,788.5,200)
```

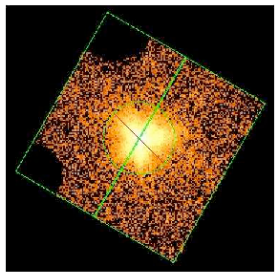

Figure 6.2: Example for extraction regions for an extended source.

Then, the appropriate ARFs can be generated using the following command:

```
xissimarfgen clobber=yes \
instrume=XIS0 \
pointing=AUTO \
source_mode=UNIFORM \
source_rmin=0 \
source_rmax=20 \
num_region=2 \
region_mode=SKYREG \
regfile1=e0102_tophalf_phys.reg \
regfile2=e0102_bottomhalf_phys.reg \
arffile1=e0102_tophalf.arf \
arffile2=e0102_bottomhalf.arf \
limit_mode=MIXED \
num_photon=2000000 \
accuracy=0.005 \
phafile=e0102_tophalf.pi \
```

```
detmask=none \
gtifile=../xis/ae102020010xi0_cl.evt \
attitude=../auxil/ae102020010.att \
rmffile=e0102_tophalf.rmf \
estepfile=medium
```

As in the point source example, certain parameters specify calibration files or Monte-Carlo simulation parameters that can be adjusted for each run of `xissimarfgen`:

- The pointing option `AUTO` takes care of the referencing coordinate system.
- This set-up (`source_rmax=20`) also simulates emission from outside of the detector field of view. This is useful for considering contribution from stray light and from the tail of the PSF outside of the extraction region, but, since many of the simulated photons do not reach the detector and are hence discarded, more photons than in the point source case need to be simulated to obtain enough statistics (e.g., `num_photon`=2,000,000). This requires a long computation time. In order to reduce the computation time in the hard energy band (>∼10 keV) where such high photon statistics are generally unnecessary, we specify the `MIXED` option of the "`limit_mode`" parameter and also "`accuracy=0.005`" and set the energy binning of the calculation to medium.
- The calibration source region is masked in the arf calculation with the default set-up. In order to include it "`pixq_and=0`" has to be specified.
- The charge injection rows are automatically masked by providing a spectral file of this observation (`e0102_tophalf.pi`) using the "`phafile`" parameter (or by using a special setting of the "`pixq_`" parameter).

Other parameters depend on the data or on the upstream analysis:

- The "`instrume`" parameter is set to `XIS0`, appropriate for the spectral file in question.
- The source emission is assumed to be `UNIFORM`, which is specified using the "`source_mode`" parameter. We assume source emission from an $r = 20$ arcmin encircled region centered on-axis (`source_rmin=0`, `source_rmax=20`) so that the source emission region is significantly larger than the detector field of view.
- The "`num_region`" parameter is set to `2` since, in this example, we generate two ARFs (one for the top region and the other for the bottom) (`regfile1`=`nep_tophalf_phys.reg`, `regfile2`=`nep_bottomhalf_phys.reg`), in one go. The "`region_mode`" parameter is set to `SKYREG` to reflect the coordinate system used in the region file.

- The two output ARF file names are specified using parameters "`arffile1`" and "`arffile2`".
- To take the attitude wobble into account, the attitude file in the auxil directory (`ae102020010.att`) is loaded using the "`attitude`" parameter. To specify the time span of the observation, a FITS file with the GTI table of the observation (`ae102020010xi0_cl.evt` in this case) is loaded using the gtifile parameter.
- We also specify the RMF to be used in spectral fitting (`e0102_tophalf.rmf` in this case).

To double-check that the intended source region was used by `xissimarfgen`, it can be displayed using `ds9`. For example, type

```
> ds9 e0102_tophalf.arf
```

while the selected STATUS bits can be confirmed in the standard output from `xissimarfgen`.

Note that the ARF files generated using the above command are normalized to the sizes of defined emitting regions. In the above example, the `xspec` output (e.g., the normalization parameter, the flux) assumes emission from an encircled region with 20 arcmin radius.

Generating ARFs in Sky Coordinates: Caveats

Users may need to specify the sky reference position when generating ARFs in `SKY` coordinates. Please refer to Appendix 2.3 of Ishisaki et al. (2006) for more details.

When users choose

- `source_mode = SKYFITS`
  - "`skyref`" is automatically read from the FITS header.
- `source_mode = SKYXY` or `region_mode = SKYFITS, SKYREG, SKYCIRC`
  - If `pointing = USER`
    - Users must specify the "`ref_alpha`", "`ref_delta`", and "`ref_roll`" parameters, which are used for "`skyref`".
  - If `pointing = AUTO` (default)
    - If an attitude file is supplied
      - "`skyref`" is read from the header of the attitude file (recommended).
    - If `attitude = NONE`
      - Users must specify the Euler angles, from which "`skyref`" is calculated.

Reducing Run Time for `xissimargfgen`

1. Reducing the number of energy bins of the ARF:

   Computation time of an arf table is proportional to the number of energy steps used in the calculation, where the energy steps are defined by the "`estepfile`" parameter:

   ```
   estepfile [filename]
      Energy step file or built-in steps. The built-in energy steps are:
      "full" : calculate effective area for each RMF energy bin. Very slow.
      "dense" or "default" : dense sampling (2303 steps). Slow.
      "medium" : medium sampling (157 steps). Moderate.
      "sparse" : sparse sampling (55 steps). Fast.
   ```

   In many cases it will be sufficient to use the `estepfile=medium` option: while a broad band fit will not yield significantly different results or improvements compared to the `estepfile=default` case, the arf computation time will go down by a factor of ~ 15 (2303/157).

2. Optimizing the "`num_photon`" and "`accuracy`" parameters:

   When `limit_mode=NUM_PHOTON`, computation time is also proportional to the number of faked photons defined by the "`num_photon`" parameter.

   For a point source ARF `limit_mode=NUM_PHOTON` and `num_photon`=400000 is recommended, but for faint sources `limit_mode=MIXED`, `num_photon=200000`, and `accuracy=0.005` is acceptable.

   For a uniform sky ARF `limit_mode=MIXED`, `num_photon=2000000`, and `accuracy=0.005` is recommended.

   For ARFs of extended sources (including uniform sky ARFs), visual inspection of the accuracy of ARFs, by plotting the effective area in `xspec`, is highly recommended.

3. Running `xissimarfgen` with a fast CPU using a fast code:

   The Monte-Carlo ray-tracing simulation runs numerous floating point calculations, and so Athlon64s usually run `xissimarfgen` faster than Pentium4s. If available, 64-bit codes compiled on 64-bit Linux run about 1.5 times faster than 32-bit codes on the same PC.

4. Running ARF caluculations for different sensors (XIS0/1/2/3) on different machines.

5. Generating ARFs of multiple accumulation regions within the same observation simultaneously.

6. Defining the smallest emission region possible when generating diffuse source ARFs.

   If an emission region defined by the "`source_image`" parameter is too large compared with the event extraction region, computation time gets slower without improving the quality of the simulation. For generating a uniform sky ARF, we recommend `source_mode=UNIFORM`, `source_rmin=0`, and `source_rmax=20`.

   Similarly, if the spacecraft attitude is not stable after a maneuver and the emission region moves out from the event accumulation region, the ARF calculation becomes slow.

6.6.5 Faster Fitting of XIS Spectra

1. Rebinning the RMF:

   Because the standard RMF of the Suzaku XIS has 7900 energy bins (2 eV steps, 0.2–16 keV) times 4096 PI bins, `xspec` needs a lot of memory to read the RMF and time to fit a spectral model. This fine-step matrix is usually over-sampled for moderate flux sources with featureless X-ray spectra (e.g., AGNs).

   Users can rebin the RMF in both channel- and energy-spaces with `rbnrmf`. Note that the spectral file also needs to be rebinned, when the RMF is rebinned in channel-space. Users can also specify the channel-space rebinning factor using the "rebin" parameter of the `xisrmfgen`.

   The RMF energy bins are determined with the default set of parameters `ebin_lowermost=0.20`, `ebin_uppermost=16.0`, and `ebin_width=2.0`. Users who are only interested in the soft band spectrum can reduce the RMF size by 25% with `ebin_uppermost=12.0`. When the spectral model to fit is featureless (no strong emission lines), `ebin_width=4.0` or `ebin_width=8.0` will give almost the same fit result. Older versions of the RMF, e.g., `ae_xi0_20050916.rmf`, in the CALDB has non-equal-width energy bins with 4096 steps in 0.2–12.0 keV. Users can copy these energy steps, by specifying

   ```
   ebin_mode=1 ebinfile=ae_xi0_20050916.rmf
   ```

   ARFs must be re-created when the RMF energy bins are changed.

2. Combining XIS0, (XIS2,) and XIS3:

   The XIS team recommends adding the spectra and response for the units with the frontside illuminated (FI) chips. XIS1 spectra, however, must be fitted separately since its (backside illuminated, or BI chip) response is distinctly different from those of the FI chips.

6.7 Pile-Up

The XIS is a position-sensitive integrating instrument, with a nominal interval of 8 s between readouts. If during the integration time more than one photon strikes the same CCD pixel, or one of its immediate neighbors, these cannot be correctly detected as independent photons; this is the phenomenon of photon pile-up. Here, the modest angular resolution of the Suzaku XRT is an advantage. However, photon pile-up can be a problem when observing bright sources. Note that the attitude fluctuation of the satellite does not mitigate the photon pile-up, because the attitude drift is negligible within the exposure of 8 s. Fig. 6.3 shows the range of the incident counting rates that can be observed without the pile-up.

When pile-up occurs, both image and spectral data are distorted. The energy spectrum tends to become harder and the total photon flux tends to decrease. In extreme cases, all events may be discarded as non-X-ray events at the image center, and the local photon flux becomes effectively zero. This means that a point source image would have a hole at the center. This is the simplest method to detect photon pile-up.

The fraction of *ASCA* grade 1 events shows a strong correlation with the pile-up fraction, i.e., guest observers can check the significance of the pile-up in their data by studying the fraction of *ASCA* grade 1 events. The simplest method to correct for pile-up is to remove the image center from the event extraction region. This means that the events are extracted from a ring shaped region. In this case, a corresponding ARF file needs to be calculated.

See also section 5.3.3 for (a) links to a 2011 XIS pile-up study with case examples and (b) introduction of two routines to determine pile-up (`aeattcor2`, `pileest`).

6.8 XIS Non X-Ray Background

Screened XIS event data still include particle background events (Non X-ray Background: NXB) and X-ray background events. These contributions can best be estimated from off-source area of the same XIS CCD chip, but this is not always possible for extended sources. Alternatively, we can estimate the particle background during an observation from data taken when the satellite sees the night side of the Earth (night Earth), i.e., when Suzaku sees no X-ray emission through the telescopes. Night Earth data are collected by the XIS team and stored in the `CALDB`. Related files are:

```
ae_xi?_nxbsciof_yyyymmdd.fits: SCI-OFF event file
ae_xi?_nxbscion_yyyymmdd.fits: SCI-ON event file
ae_xi?_nxbvdchk_yyyymmdd.fits: HK file with the detector temperature
ae_xis_nxbcorhk_yyyymmdd.fits: HK file of the cut-off rigidity
ae_xis_nxborbit_yyyymmdd.fits: orbit file
```

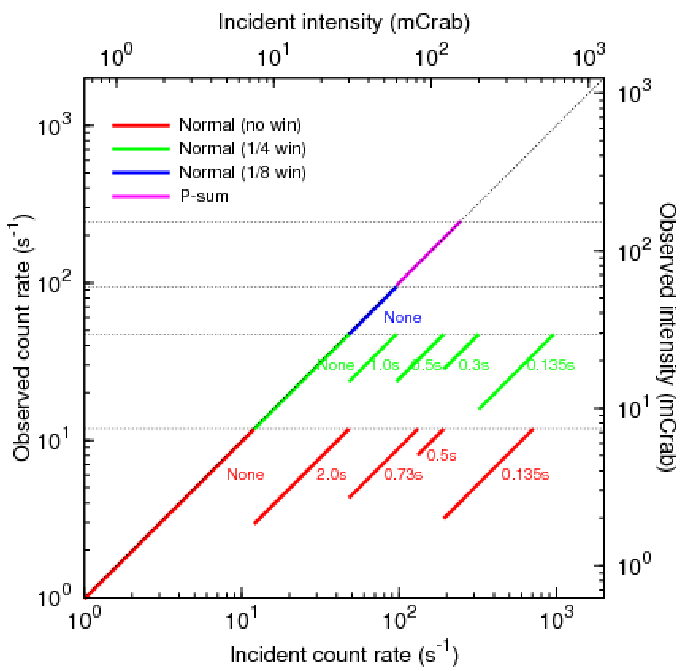

Figure 6.3: Incident versus observed count rates of a point source for the FI sensor. The thick colored lines show the range that can be observed without strong pile-up for a given window option (defined by the figure legend) and burst option (defined by the time values $t_{\rm b}$ indicated in the figure). Note that the window frame times $t_{\rm W}$ are 8, 2, and 1 s for the full, 1/4, and 1/8 window options, respectively, with exposures per frame of $t_{\rm b}$ for a given burst option.

Here, yyyymmdd is the release date of these CALDB files. If a source observation in question was taken after the time period in the "DATE-END" column of a set of those files – normally ending several days to a month before the release date – newer background files have to be downloaded from the CALDB page.

The XIS team has developed a tool that collects the appropriate NXB data from CALDB and automatically generates NXB images and spectra. The tool xisnxbgen is available in the HEAsoft version 6.4 or later.

6.8.1 Xisnxbgen

Tawa et al. (2008, PASJ, 60, 11) have shown that the XIS NXB only varies with the cut-off-ridigity (COR) value at the satellite location. Based on this result, xisnxbgen sorts NXB data by COR values, generates an NXB spectrum and image for each COR range (defined by the "sortstep" option), and combines them weighted by the exposure time ratio of each COR range included in the GTIs of the supplied spectral source file. The default NXB indicator is COR2 (revised cut-off rigidity). The other indicators such as the obsolete cut-off rigidity COR and the PINUD rate, which can be calculated with aemkpinudhk, can also be used via the hidden option "sortkey".

When users choose non-standard *event by event* selection criteria, this has to be defined using hidden parameters of xisnxbgen ("grades", "pi_min", "pi_max", etc.). Xisnxbgen takes care of non-standard *gti* filters (for example, screening with satellite elevations from the bright/night earth) when it calculates the exposure time ratio of each COR2 range from the GTIs of the supplied spectral source file.

Here, we show an example of generating an NXB spectrum and image. First, we need to create a spectral FITS file of the source, which we call etacar_nebula_x0.pi in this example. We name the output NXB spectral file etacar_nebula_nxb.pi. We also need to input the source region file (etacar_nebula_x0.reg), from which we created etacar_nebula_x0.pi, and the coordinate system (SKYREG), on which the region file is described. The attitude and orbital files for the data are ae402039010.orb and ae402039010.att, respectively, which are found in the auxil directory in the data distribution. With this, we can run:

```
> xisnxbgen etacar_nebula_nxb.pi etacar_nebula_x0.pi \
SKYREG etacar_nebula_x0.reg \
ae402039010.orb ae402039010.att
```

Xisnxbgen displays all the options that were selected after the text ANL: *** xisnxbgen show parameter ***. We recommend that the user confirms that the options are specified as intended. The ouput file has an NXB spectrum in the 1st extension, an NXB image in detector coordinates in the 2nd extension, and an NXB image in sky coordinates in the 3rd extension. The sky coordinates map in the 3rd extension ignores the region file selection, i.e., the user will get a sky NXB background image of an entire CCD chip (to display the detector/sky background images with `ds9`, type `ds9 etacar_nebula_nxb.pi[2]` or `ds9 etacar_nebula_nxb.pi[3]` on the command line). These results can be used in `xspec` as background, or for NXB subtraction in the sky image.

To produce an NXB *image* within a certain energy range, the lower and upper boundary PI values (3.65 eV/channel) can be specified using the `pi_min` and `pi_max` parameters. For example:

```
> xisnxbgen etacar_nebula_nxb.pi etacar_nebula_x0.pi \
SKYREG etacar_nebula_x0.reg \
pi_min=274 pi_max=548 \
ae402039010.orb ae402039010.att
```

The NXB *spectral* file is not affected by these options, that is, it also has values below `pi_min` and above `pi_max`.

Things to be considerd when using `xisnxbgen`:

- `Xisnxbgen` automatically chooses appropriate `CALDB` files based on header information of the input spectral file (specified using the `phafile` parameter), including whether data were taken with Spaced-row Charge Injection options on (SCI-on) or off (SCI-off).

  Warning — Exception: Due to the current structure of the `CALDB`, `xisnxbgen` **is unable to pick the correct file automatically for XIS1 data taken with CI=6 keV**. For such data, please explicitly specify the `nxbevent calibration` file:

  ```
  xisnxbgen nxbevent=ae_xi1_nxbsci6_XXXXXXXX.fits
  ```

  If you have a copy of the *Suzaku* `CALDB` locally installed, this file can be found in the `CALDB` `data/suzaku/xis/bcf` directory. If you are using the `HEASARC` version of the `CALDB` remotely, it is best to download this specific file from:
  `ftp://legacy.gsfc.nasa.gov/caldb/data/suzaku/xis/bcf/`

  Note: The NXB calibration files `ae_xi*_nxb*_20121201.fits` are wrong and should not be used (section 5.5.8).

  Note: The increased charge injection amount, CI=6 keV, for XIS1 led to an increase in its NXB level. Further explanation and a recipe for reducing the background level in the observed data again and for how to use `xisnxbgen` in this case are given in section 5.3.7.

- `Xisnxbgen` automatically runs `xispi`, `xisputpixelquality`, and `cleansis` on the NXB data to use the latest calibration unless `apply_xisftools=no` is specified (this option requires that the user has run `xispi` etc. on the NXB files and has specified this event file explicitly, e.g., `xisnxbgen apply_xisftools=no nxbevent=nxb.evt`).

  If `apply_xisftools=no` is not specified, `xisnxbgen` screens out events that do not satisfy the event selection criteria specified using the hidden parameters `grades`, `enable_pixq`, `pixq_min`, `pixq_max`, `pixq_and` and `pixq_eql`. If the standard filtering criteria[2] are applied to the source data or cleaned event data without further data screening are to be used, the default parameters do not need to be changed. See definition of these parameters in Table 6.2.

- Region files need to be described in sky coordinates (`SKYFITS/SKYREG/SKYEXPR`) or detector coordinates (`DETFITS/DETREG/DETEXPR`).

- `Xisnxbgen` projects the NXB map in detector coordinates onto the sky coordinates plane, only considering the satellite wobbling. That is, NXB variations during the observation are averaged over the entire CCD chip before the projection, and any NXB variations that are correlated with the attitude wobble will not be properly reflected. We thus recommend to remove data taken during large pointing offsets, for example, just after the satellite maneuver.

- Considering possible long-term NXB variation and steady decay of the ^{55}Fe calibration isotope (2.73 years half-life), by default, `xisnxbgen` extracts events from the NXB database between (`TSTART` - 150 days) and (`TSTOP` + 150 days), in which `TSTART` and `TSTOP` are referred to the header of the input spectral file. However, some observations may have limited NXB data within the default extraction interval. In this case one needs to define a wider accumulation interval of NXB data to obtain enough photon statistics.

  The effective accumulation time of NXB data can be checked in the standard output of the `xisnxbgen` runs, see example outputs below. The first table shows exposure times within each `COR2` grid of the input spectrum and the second one shows effective accumulation times of NXB data. If the NXB accumulation time is not significantly longer than the exposure time of the source spectrum, the NXB data accumulation interval should be widened.

```
===========================================
COR2          :  EXPOSURE (s)  FRACTION (%)
-------------------------------------------
  0.0 -   4.0 :       1184.0          2.161
  4.0 -   5.0 :       3560.0          6.498
  5.0 -   6.0 :       3224.0          5.885
```

[2] see http://heasarc.gsfc.nasa.gov/docs/suzaku/processing/criteria_xis.html

```
  6.0 -   7.0 :       3672.0         6.703
  7.0 -   8.0 :       3408.0         6.221
  8.0 -   9.0 :       3808.0         6.951
  9.0 -  10.0 :       4288.0         7.827
 10.0 -  11.0 :       5096.0         9.302
 11.0 -  12.0 :       7368.0        13.449
 12.0 -  13.0 :       6440.0        11.755
 13.0 -  99.0 :      12736.0        23.248
-------------------------------------------
          SUM :      54784.0       100.000
        TOTAL :      54784.0       100.000
-------------------------------------------
........
........
===================================================================
COR2          :  EXPOSURE (s)  FRACTION (%)  SPEC (cts) IMAGE (cts)
-------------------------------------------------------------------
  0.0 -   4.0 :       4584.0         1.254        37.2       878.0
  4.0 -   5.0 :      19136.0         5.235       129.3      3077.0
  5.0 -   6.0 :      18816.0         5.148       122.7      2547.0
  6.0 -   7.0 :      18640.0         5.099       104.1      2275.0
  7.0 -   8.0 :      20520.0         5.614       104.4      2308.0
  8.0 -   9.0 :      23792.0         6.509       112.0      2491.0
  9.0 -  10.0 :      43136.0        11.801       162.7      4004.0
 10.0 -  11.0 :      45496.0        12.446       179.9      4098.0
 11.0 -  12.0 :      42992.0        11.761       174.1      3710.0
 12.0 -  13.0 :      44456.0        12.162       171.2      3698.0
 13.0 -  99.0 :      83968.0        22.971       310.0      7219.0
-------------------------------------------------------------------
          SUM :     365536.0       100.000      1607.6     36305.0
        TOTAL :     365536.0       100.000     36305.0     36305.0
-------------------------------------------------------------------
    EFFECTIVE :     370262.3       101.293      1679.1     37775.9
-------------------------------------------------------------------
```

6.9 Creating an Exposure Map

For the study of extended sources with the XIS, it is necessary to know the exposure times as well as vignetting at various sky locations within the XIS image.

6.9.1 Types of Exposure Maps

One type of exposure map can be created by simply considering the detector field of view and the spacecraft attitude, the result being the actual exposure time per sky pixel. Such exposure maps can be created by using `xisexpmapgen`, which allows users to exclude unused pixels such as bad columns, hot/flickering pixels, SCI rows, and the ^{55}Fe calibration source area. See section below as well as the help file of `xisexpmapgen` for further details.

In the other type, the *effective* exposure times per sky pixel are calculated, taking into account the vignetting of the XRT. Below, we describe how to use `xissim` to simulate a "flat field" image for this purpose.

6.9.2 Running `Xissim`

As an example, we show how to simulate an XIS0 flat field image at 2.45 keV of the observation sequence 102002010. The attitude wobbles during this observation are included in the simulation by supplying the attitude file and a GTI table.

```
> xissim instrume=XIS0 enable_photongen=yes photon_flux=1 flux_emin=1.0 \
flux_emax=10.0 spec_mode=1 image_mode=2 time_mode=0 limit_mode=1 energy=2.45 \
ra=16.0083 dec=-72.0313 sky_r_min=0 sky_r_max=20 exposure=15825.09 \
pointing=AUTO gtifile=cleaned.evt\[GTI\] attitude=ae102002010.att \
ea1=16.007012398071 ea2=162.031577674707 ea3=29.330729822566 \
xis_rmffile=/FTP/caldb/data/suzaku/xis/cpf/ae_xi0_20060213.rmf \
outfile=sim_x0.fits phafile=allarea.pi
```

Notes:

- In this example, we supply the name of the event file after screening (`cleaned.evt`) as the "`gtifile`" parameter value, and use a spectral file made from `cleaned.evt` (`allarea.pi`) as the "`phafile`" value (this is used by xissim to determine the observation mode, such as the window and the spaced charge injection options; `cleaned.evt` would also work).
- The Euler angles (`ea1`, `ea2` and `ea3` parameters) are used if, any time during the specified good time intervals, the attitude file does not have data. These can be obtained from the header keywords `MEAN_EA1`, `MEAN_EA2`, and `MEAN_EA3` in the event file.
- The value of the "`exposure`" parameter should be equal to (or an integer multiple of) the actual exposure time of the observation, to consider the effect of the attitude wobbles correctly. Increase the value of the "`photon_flux`" if more photons are needed.

- In the above example, simulation is carried out for a single energy (`spec_mode=1`) of 2.45 keV (`energy=2.45`). To consider a range of photon energies, change `spec_mode` to 0, and supply a QDP file of the spectral model ("`qdp_spec_file`"), which can be created in XSPEC with the "`iplot model`" command.

Note that the output file has only ∼10% of the seed photons. This is because most of the photons are absorbed or blocked by mirrors or instruments.

6.9.3 Extracting a Flat Field Image

The simulated events created by `xissim` have STATUS information, which describes the quality of each simulated photon. Thus the simulated event files should be screened using the same STATUS criteria as for the observed events (see Table 6.2).

Then the flat field image can be extracted in `xselect`, making sure that the same XY binning as the observed image is used.

6.9.4 Smoothing the Flat Field Image

It is difficult to avoid statistical fluctuation in a simulated flat field map, so it is often desirable to smooth the map using, e.g., ximage or ds9. We assume that the flat field map has been smoothed, with the file name `flatfield_smo.img`.

6.9.5 Trimming the Flat Field Image

A smoothed map generally has rough edges, so it is useful to trim such a map with a masking image, which can be done using `xisexpmapgen`.

```
> xisexpmapgen expmap.img cleaned.evt ae102002010.att
```

Here `ae102002010.att` is the attitude file, and `cleaned.evt` is used as the value of the "`phafile`" parameter to supply the XIS mode (such as the window option).

The output file (`expmap.img`) contains two maps; a mask image in detector coordinates in the 1st extension and an exposure map in sky coordinates in the 2nd extension. Here, we need a masking image in sky coordinates, and so use the image in the 1st extension.

By displaying the 1st extension, one can empirically determine a good threshold for masking. For a threshold of 5000 s, for example, use:

```
> fimgtrim infile=expmap.img\[1\] threshlo=5000 threshup=5000 \
const_lo=0 const_up=1 outfile=skymaskmap.img
```

This produces a masking image, called `skymaskmap.img`. This may have to be rebinned to match the binning of the exposure map (by default, `xselect` bins *Suzaku* images by a factor of 8), before multiplying with the smoothed flatfield image.

```
> fimgbin skymaskmap.img skymaskmap_8bin.img 8
> farith flatfield_smo.img skymaskmap_8bin.img flatfield_smo_trim_8bin.img "*"
```

6.9.6 Applying the Flat Field Image

```
> farith source_raw.img\[0\] flatfield_smo_trim_8bin.img input_vigcor.img "/"
```

The above applies the smoothed, trimmed, binned flatfield image `flatfield_smo_trim_8bin.img` to the primary extension of the observed image `source_raw.img` by dividing the latter by the former. A vignetting corrected image, here `input_vigcor.img`, is produced. The flat field image can be scaled to make it a true effective exposure time map, although the normalization depends on the purpose of such an operation.

Depending on the scientific objectives, it may well be desirable to subtract particle, cosmic X-ray, or Galactic X-ray background from the observed image before dividing by the flat field.

6.10 Initial Processing: Details

The remainder of this chapter describes the details of the initial processing for the XIS. These steps, already performed in the processing pipeline (Table 6.1), can be repeated by users if necessary.

6.10.1 Assigning Arrival Times

`xistime` assigns the corrected arrival time to the XIS events, and performs the fine time measurement for the Burst mode and Window option. Here is an example for its application:

```
xistime infile=filename_uf.evt.gz \
              outfile=xistime_outfile.fits \
              timfile=filename.tim
```

where:
`infile` is the the name of the XIS event fits input file,
`outfile` is the name of the output event fits file created,

`timfile` is the name of the input fits file with timing information, `ae<obsid>.tim`, which can be found in the *Suzaku* data distribution package of each observation.

6.10.2 Calculating Sky Coordinates

`xiscoord` combines the position of the observed counts on the XIS detector with the orbit and attitude information to calculate the `ACT`, `DEC`, `FOC` and `sky X/Y` values for XIS event files. `xiscoord` uses either the attitude file assigned on the basis of the event input file name (the default), or fixed Euler angles if the parameter `attitude` is set to EULER. The RA and DEC used by the program can either be read from the header of the input event file or set manually. In the former case the command is:

```
xiscoord infile=xistime_outfile.fits outfile=xiscoord_outfile.fits \
attitude=DEFAULT pointing=KEY
```

where
`infile` is the name of the XIS event fits input file,
`outfile` is the name of the output file created – see caveat below,
`attitude` indicates where to get the attitude information from,
`pointing` indicates where to read the RA and Dec – `pointing` set to `KEY` reads them from the header of the input event file
Users should be aware of the following:
1) When the attitude parameter is set to "`Default`", the code searches for a file named `***.att` in the *same* directory as the input file. This can be bypassed by specifying the full path to the file on the command line.
2) We have found that `xiscoord` does not produce output files on several unsupported platforms (Mandrake 10,..). Users are advised to check the supported platforms (see `http://heasarc.gsfc.nasa.gov/docs/software/lheasoft`) and run only on a supported platform.

6.10.3 Put Pixel Quality

`xisputpixelquality` runs on the output of `xiscoord`. The command is:

```
xisputpixelquality xiscoord_outfile.fits xisputpixelquality_outfile.fits
```

where
`infile` is the name of the XIS event fits input file (output from `xiscoord`),
`outfile` is the name of the output file created.

The hidden parameters, `badcolumfile` and `calmaskfile`, should point to `CALDB`. Users may want to examine the differences (if any) between the input and the output files of `xisputpixelquality`.

6.10.4 Computing PI Energy Channels

As its name indicates, the `xispi` routine calculates the XIS PI and grades values from the PHAs, see also section 6.3. In addition to the input event file, the routine needs the `CALDB` files `ae_xi[0-3]_makepi_[date].fits` and the housekeeping file associated with the input event file. If the `CALDB` option is not set properly and the file has to be input manually, users should check that the latest "`makepi`" file is used. The command to run `xispi` is:

```
xispi infile=xisputpixelquality_outfile.fits outfile=xispi_outfile.fits \
 hkfile=HKFILE.fits makepifille=CALDB
```

where
`infile` is the name of the XIS event fits input file,
`outfile` is the name of the output file,
`hkfile` is the House Keeping file located in the `xis/hk` directory. This is not the hk file from the `auxil` directory,
`makepifile` is a hidden parameter, set to "CALDB" by default.

6.11 Standard Screening

Both bad pixel filtering and grade selections are done by the processing pipeline and implemented in the cleaned files distributed to the users. Users can find a complete example of filtering at: `http://lheawww.gsfc.nasa.gov/users/kaa/xselect/suzaku.html`. In addition, we provide an `xselect` command file and files containing event and mkf selection expressions via:
`http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/sci_gain_update.html`. We explain the steps below, but see also section 6.3 for the availablity of a screening script.

6.11.1 Bad Pixel Filtering

The cleaning of hot and flickering pixels is done using `cleansis`, available as a standalone script at the GOF website `http://suzaku.gsfc.nasa.gov`.

`cleansis` was originally written for analysis of the *ASCA* SIS data and removes hot and flickering pixels based on a Poissonian analysis. It has since been adapted for work on *Swift* and *Suzaku* data. This generalized version is available in all releases after 6.0.6 of `HEAsoft`. Users should make sure that their version of `HEAsoft` is current.

To run cleansis on *Suzaku* XIS event files type `cleansis chipcol=SEGMENT` on the command line, give the input and output filenames, and use the default values of the remaining parameters.

6.11.2 Grade Filters

The GRADE column shows the event grade, which is determined from the distribution of pulse heights among the 5x5 (or 3x3 or 2x2) pixels. The standard spectral responses provided by the XIS team assume GRADE 0,2,3,4, and 6. Only events with these grades should be selected (within the `xselect` task):

```
select event "GRADE==0||GRADE==2||GRADE==3||GRADE==4||GRADE==6"
```

Or, equivalently:

```
filter grade "0,2-4,6"
```

The *Suzaku* instrument teams recommend the following cuts to be applied within `xselect`:

```
select mkf  "SAA_HXD==0 && T_SAA_HXD>436 && ELV> 5 && DYE_ELV>20" \
mkf_name=MKF_filename  mkf_dir=/path-to-the-MKF-file/
```

Notes:
1) `mkf_name` and `mkf_dir` should be set automatically by `xselect` by "`read events`",
2) The "`select mkf`" command creates a time filter of good times. To actually filter the events, users must then issue the command "`extract events`".

Satellites launched into low-Earth orbit, such as *Suzaku*, pass through the South Atlantic Anomaly (SAA). During a passage, the high particle flux makes the instruments unusable. The `mkf` column SAA_HXD has a value of 0 when the satellite is **not** in the SAA and so the selection condition is `SAA_HXD==0` (this is based on the current extent of the SAA as determined empirically using the HXD data). Even when the satellite emerges from the SAA, the background is still high, the `mkf` column `T_SAA_HXD` indicates the amount of time since an SAA passage. For the XIS, `T_SAA_HXD` can be as low as 60 seconds. However, the HXD background stays high for much longer. The instrument teams have recommended adopting the same condition for both instruments, hence the cut of `T_SAA_HXD>436` is imposed on the XIS data.

The two remaining criteria are recommended by the instrument teams to reduce the contamination from Earth's atmosphere. The first is applied to the elevation angle, `mkf` column `ELV`, the angle between the target and the Earth's limb. Only data with an elevation angle larger than 5 degrees should be considered. The second concerns the elevation angle from the day Earth rim and helps reduce contamination in the Nitrogen and Oxygen lines from X-rays scattered on the Earth's atmosphere. Users who can ignore the low energy part of their spectrum (below 0.6 keV) may want to explore the possibility of relaxing the cut on `DYE_ELV`.

Chapter 7

HXD Data Analysis

7.1 Introduction

The HXD significantly extends the spectral range of *Suzaku* (to 600 keV) and has the lowest background rate of any instrument ever operated in the 10–600 keV energy range. Because the HXD is a non-imaging instrument, the analysis of HXD data follows a different path from that used in XIS data analysis. It is much closer to the analysis flow of other collimated instruments, such as *Ginga* LAC and *RXTE* PCA. Users familiar with the analysis techniques for either will find much in common in what we describe below.

Users should also refer to the outstanding issues in HXD data analysis (chapter 5).

A peculiarity of the HXD that needs to be taken into account is that there are two independent detector systems. These are the Gadolinium Silicate (GSO) / Bismuth Germanate (BGO) phoswich counters and the PIN silicon diodes. The PIN diodes are sensitive below ~ 60 keV, while the GSO/BGO phoswich counters detect photons above ~ 30 keV. The energy resolution of the PIN diodes is ~ 3.0 keV, while the phoswich counters have a resolution of $7.6\sqrt{E}\%$ (FWHM) where E is the photon energy in MeV. There are a couple of things that users should know about the detectors, in order to understand better the HXD data and their organization:

The HXD sensor (HXD-S) is composed of 16 main detectors (well units) arranged as a 4×4 array (see top view in Fig. 7.1) and 20 surrounding crystal scintillators for active shielding. Each unit consists of four GSO/BGO phoswich counters, and four 2 mm-thick PIN silicon diodes located inside the well, but in front of the GSO scintillator. The configuration of the sensor units is shown in Fig. 7.2.

This means that the data ("well" data) do not initially differentiate between PIN and GSO. The distinction is made later on in the pipeline. For more information about the HXD detector, please see the *Suzaku* Technical Description at `http://heasarc.gsfc.nasa.gov/docs/suzaku/prop_tools/suzaku_td`.

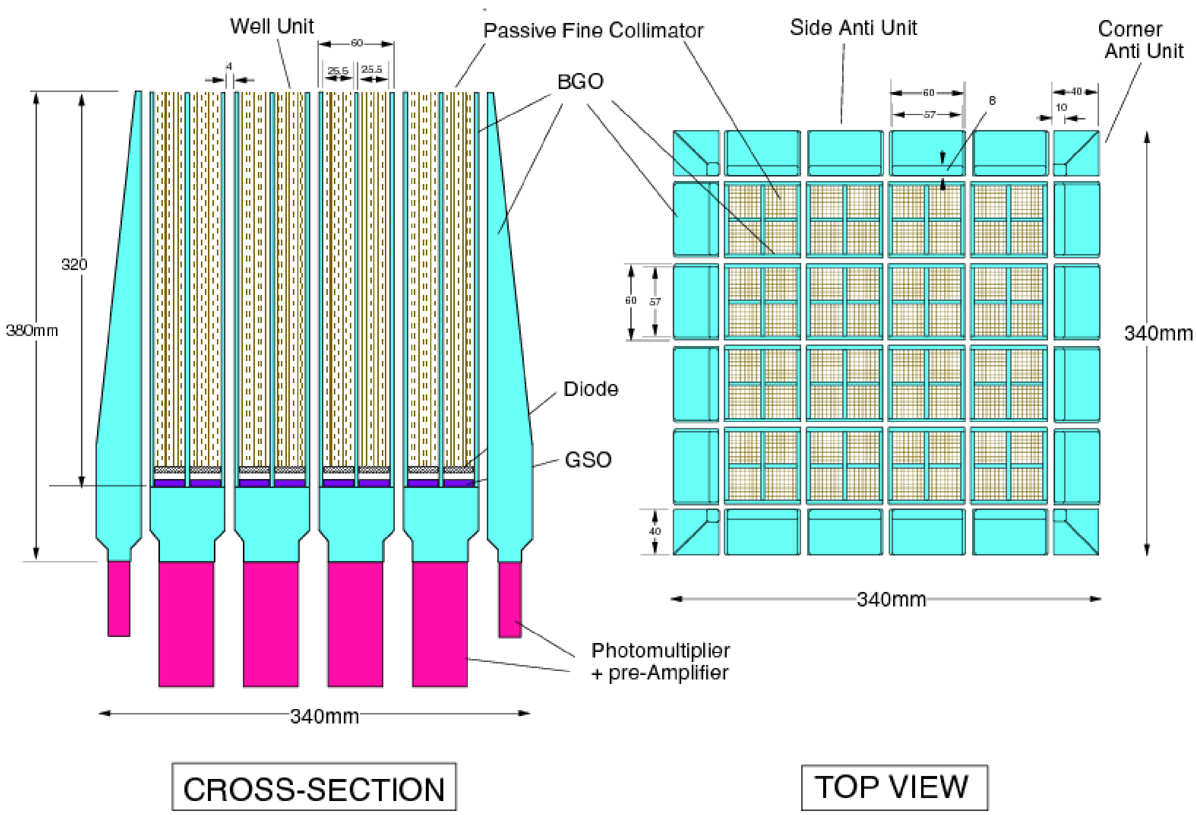

Figure 7.1: Schematic picture of the HXD instrument, which consists of two types of detectors: the PIN diodes located in the front of the GSO scintillator, and the scintillator itself.

7.2 Cleaned Event File Content

HXD data begin as part of the RPT telemetry downloaded from *Suzaku*, and are converted into a collection of FITS files by the `mk1stfits` routine at ISAS. `mk1stfits` does not reject any events or apply any calibration to the data but merely converts it to FITS files. Once the files have been processed through the pipeline, they are included in the standard data download in the directory `hxd/event_uf`.

The HXD `mk2ndfits` pipeline task is then run on the mk1stfits output to create filtered, calibrated output event files, which are placed in the `event_cl` subdirectory. The calibration steps are summarized in Table 7.1. If updates of any of these tools became available since the initial processing of a dataset; the user can reprocess the data, see section 7.3 and 7.4 for details.

In addition to the above calibration steps, the event files in the `event_cl` have been

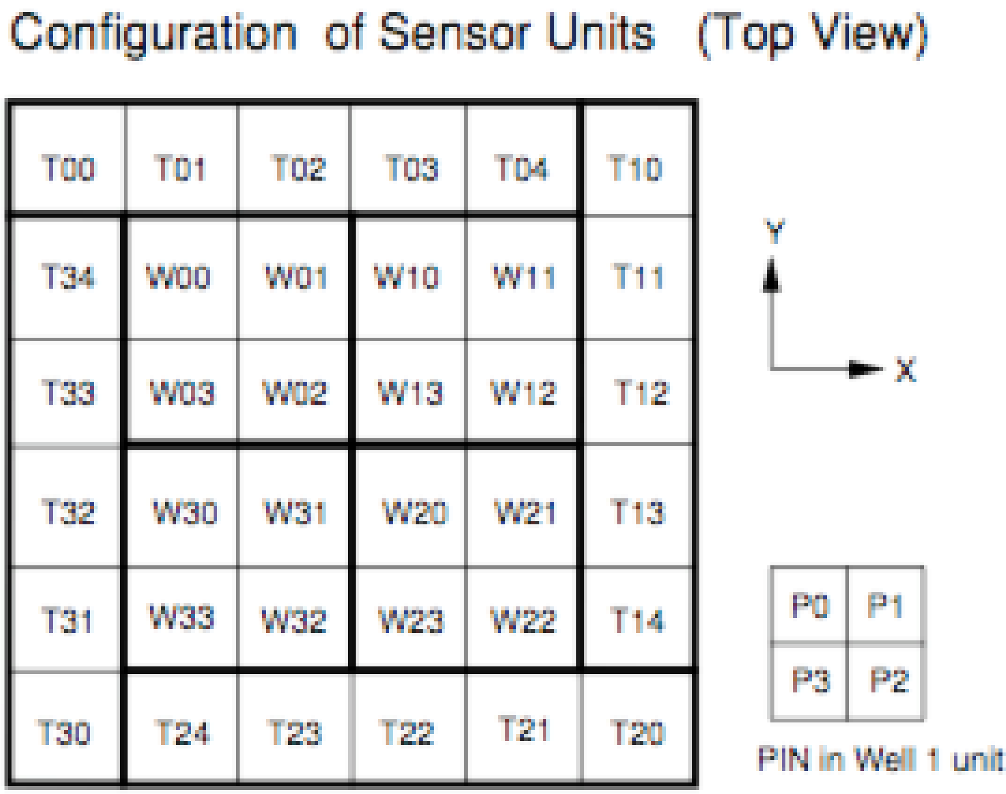

Figure 7.2: Numbering of the well- and anti-coincidence-units.

Calibration Item	Tool	Comments
Time Assignment	`hxdtime`	
Gain History Generation	-	Obtain latest from HXD team via `CALDB`
PI Assignment	`hxdpi`	
Grade assignment	`hxdgrade`	

Table 7.1: HXD calibration steps.

screened applying the criteria summarized in Table 7.2.

7.3 HXD Reprocessing and Screening: General Remarks

Reprocessing, especially the recalculation of the `PI` column of the unfiltered event file using the most up-to-date calibration, is required for all PIN data taken after 2007 July 28 and

Type	Criterion	Comments
Event by event	DET_TYPE=0	GSO events
	DET_TYPE=1	PIN events
	DET_TYPE=2	Pseudo events
GTI	AOCU_HK_CNT3_NML_P==1	Attitude control in pointing mode
	ANG_DIST<1.5	Instantaneous pointing within 1.5 arcmin of mean.
	HXD_HV_Wn_CAL>700	High voltage is not reduced
	HXD_HV_Tn_CAL>700	High voltage is not reduced
	SAA_HXD==0	Satellite is outside SAA
	T_SAA_HXD>500	Time since SAA passage >500 sec
	TN_SAA_HXD>180	Time to next SAA passage >180 sec
	COR>6	Cut-off Rigidity >6 GeV
	ELV>5	Pointing direction >5 deg above Earth
	HXD_DTRATE<3	GSO only
	Telemetry is unsaturated	`aeNNNNNNNNNhxd_0_tlm.gti`

Table 7.2: HXD screening criteria.

processed with pipeline Version 2.0.6.13 or earlier.

For GSO data users should check the `GSOGPT_F` and `GSOGPT_V` keywords in the FITS headers of the cleaned event (observed) and background (simulated) files. These keywords define which HXD GSO gain parameter table (GPT) was used in the processing. If the values match then there is no need to reprocess the GSO data (note: the files `ae_hxd_gsogpt_20091225.fits` and `ae_hxd_gsogpt_20100323.fits` are identical in content). If the values do not match the data have to be reprocessed. If these keywords are not present the data were processed with pipeline Version V2.4.12.27 or earlier corresponding to a different way of performing GSO calibration (using GHT [gain history table] instead of GPT type gain files) and should be reprocessed, preferentially using the new setup. For more details on the two different GSO setups see `http://heasarc.nasa.gov/docs/suzaku/analysis/gso_newgain.html`.

Please note that in general it is not necessary to run `hxdtime` again to perform the arrival time correction. This is because the only calibration item necessary for this process is the clock correction (or TIM) file, which, once generated, is not updated. Starting from the unfiltered event file the *Suzaku* `FTOOLS` `hxdpi` and `hxdgrade` have to be run (see section 7.11 for details). It is strongly recommended to uncompress the event file(s) before reprocessing.

The reprocessed event files should then be screened with the desired event selection criteria. For this the standard criteria used in Version 2 processing (Table 7.2) are available for the GSO (`http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/gso_mkf.sel`) and for the PIN (`http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/pin_mkf.sel`).

Users can edit these files to modify the criteria.

The FTOOL `aepipeline` described in the following section can be used to perform reprocessing (in this case including `hxdtime`) and rescreening.

7.4 Full HXD Reprocessing and Screening using `Aepipeline`

The powerful tool `aepipeline` (available since *Suzaku* FTOOLS version 14, i.e., HEAsoft v.6.8) duplicates the *Suzaku* processing pipeline. It allows the user to run all or part of the pipeline for XIS (detector selection available) and/or HXD (detector selection available) and to vary the calibration files used. A number of other pipeline processing parameters can also be changed. Please refer to the help text available, e.g., by typing "`fhelp aepipeline`".

The pipeline performs *calibration* – for the HXD this includes running `hxdgtigen`, `hxdtime`, `hxdpi`, and `hxdgrade` – as well as data *screening* – with defaults as given in Table 7.2 for the HXD. The screening criteria can be modified by changing the parameters `hxd_pin_expr` or `hxd_gso_expr` from their default values, e.g., in order to extraxt night Earth data. If the screened pseudo event data are used, e.g., instead of the unfiltered events for deadtime correction, `hxd_pse_expr` has to be used to apply the selected screening to those events as well.

The GTI file for telemetry un-saturated times created by `hxdgtigen` (`aeNNNNNNNNNhxd_0_tlm.gti`) is applied by `aepipeline`.

The following is an example of a simple call of `aepipeline`, performing recalibration (`stage 1`) and rescreening (`stage 2`) of the PIN data for a given observation or sequence number (here: 403049010) applying the default calibration and the default screening criteria. An example for GSO data, with an explanation of issues to consider in that case, is given in section 7.6.3.

```
> aepipeline indir=/scratch/403049010 \
outdir=/scratch/reprocessed/hxd \
steminputs=ae403049010 entry_stage=1 \
exit_stage=2 clobber=yes instrument=PIN
```

Warning:

(1) The `outdir` directory may not be a subdirectory of the `indir` directory. If it is, wrong results can be produced (double counting of events), especially in the case of multiple reprocessing runs. While the reporting will soon be improved, this currently happens without warning or error messages.

(2) The header keyword in the event files indicating the version of the processing pipeline used for reprocessing "`PROCVER`" is not updated by `aepipeline`. Check the log file produced by `aepipeline` for pipeline version information.

7.5 PIN Spectral Analysis

Since PIN is a collimated instrument, it is not possible to obtain background data from the observation data themselves. Instead, the HXD team has developed and run a model of the time-variable particle background, and made the results available.

Before describing the usage of these files, we should note the following:

1. The background model is still under development. The ultimate accuracy is limited by the amount of day and night Earth data that are used to calibrate the background model, and will slowly improve with time. The current uncertainty is estimated to be about 3.2% in the 15–40 keV range (see `ftp://legacy.gsfc.nasa.gov/suzaku/doc/hxd/suzakumemo-2007-09.pdf`). A more general estimate of 3%–5% is given in Table 3.2 of the Technical Description for AO-6 `http://heasarc.gsfc.nasa.gov/docs/suzaku/prop_tools/suzaku_td/suzaku_td/node6.html`.
2. The background files only model the particle background. The cosmic X-ray background must be evaluated separately, see section 7.5.4.

7.5.1 PIN Non X-Ray Background

The HXD background is distributed in the form of simulated event files tailored to each observation. Two different non X-ray background (NXB) models for the HXD/PIN are available, the *tuned* background ("`bgd_d`", `METHOD=LCFITDT`) from `ftp://legacy.gsfc.nasa.gov/suzaku/data/background/pinnxb_ver2.0_tuned/` and the *quick* background ("`bgd_a`", `METHOD=PINUDLCUNIT`) from `ftp://legacy.gsfc.nasa.gov/suzaku/data/background/pinnxb_ver2.0/` . Please note that both versions are dead time corrected. These files should only be used with Version 2 processed data, and vice versa. One important change from Version 1.x background files is that the new background files contain events from all units of PIN, regardless of whether the bias voltage for PIN is 500 V or 400 V.

These directories are divided into subdirectories by month. For example, background files for observations carried out in 2006 August can be found in the subdirectory `2006_08`. Within these monthly directories, individual background files are listed alphabetically. Note these files are named using the sequence number, e.g., `ae100005010hxd_pinnxb_cl.evt.gz`.

The tuned background is available for observations since 2005-08-17, except for the period 2006-05-24 to 2006-05-29, when one of 64 PIN diodes showed an unusually high event rate probably caused by radiation damage. For this period, users can use the quick background by applying the event selection criterion "`UNITID>3`".

The tuned background files cannot be produced until 1–2 months after the processing of the data. Once produced, they have estimated systematic uncertainties of about 3%, about half of the quick model, so we recommend the use of tuned background for publication-quality analysis. In any case it is strongly recommended to verify the reliability of the background estimate, by comparing the model spectrum and light curve with the "earth occulted data" (`ELV`< -5). Since the quick background files can be delivered a few weeks after processing, these can be used for quick-look purposes before the tuned background files become available.

Notes on using the PIN background files:

1. These files should only be used with Version 2.x processed data, and vice versa.
2. A dead time correction is not necessary for the PIN background files, regardless of whether they are "quick" or "tuned".
3. The event rate in the PIN background event files is 10 times higher than the real background to suppress the Poisson errors. Therefore, users should increase the exposure time of derived background spectra and light curves by a factor of 10 using, e.g., the `FTOOL` `fparkey`.
4. The background event files does not include the cosmic X-ray background (CXB). Since the CXB flux is about 5% of the background for PIN, you should take it into account after subtracting the background (see section 7.5.4).

Finally, note that the Version 2 PIN background files for (i) the initial operation phase of the HXD (launch through 2005 September 1) and (ii) the period 2006 March 23 – 2006 May 13, during which some GSO parameters were changed, show a systematic offset. The workaround is to use the Version 1 background files available at:
`http://www.astro.isas.jaxa.jp/suzaku/analysis/hxd/v1/pinnxb/pinnxb_ver1.2_d/`.

7.5.2 PIN Spectral Extraction

1. The background event files have a GTI extension (extension 2). The background estimation is performed only within the GTIs listed. For further filtering, you should make a new GTI by ANDing the GTI from your filtering criteria with the GTI extension of the background files. For example:

```
> mgtime "ae100005010hxd_0_pinno_cl.evt+2 ae100005010hxd_pinnxb_cl.evt+2" \
common.gti AND
```

2. Extract the source and background spectra, applying the GTI file as generated above. To do so in `xselect`:

```
xsel> filter time file common.gti
```

3. It is necessary to correct for the dead time of the observed spectrum to apply the background file correctly. The dead time correction tool (`hxddtcor`, included in the latest release of the *Suzaku* `FTOOLS`) updates the `EXPOSURE` keyword of the spectral file, by comparing the number of pseudo events injected by the analog electronics on-board with that found in the telemetry.

   A pseudo event file filtered with the same GTI as the cleaned event file can be found in the cleaned event file directory in data processed with version 2.x (`event_cl/aeNNNNNNNNNhxd_0_pse_cl.evt.gz`). This is the most convenient input to `hxddtcor`, if you are analyzing the cleaned event files. Otherwise, supply the unfiltered event file(s) to `hxddtcor`. The syntax is:

   ```
   > hxddtcor ae100005010hxd_0_pse_cl.evt ae100005010pin.pha
   ```

   Note that the `EXPOSURE` keyword value will be rewritten.

   Dead time correction is *not* necessary for the PIN background files.

4. The event rate in the PIN background event file is 10 times higher than the real background to suppress the Poisson errors. Therefore, users should increase the exposure time of derived background spectra and light curves by a factor of 10:

   ```
   > cp ae101005040hxd_wel_pin_bgd.pha ae101005040hxd_wel_pin_bgd_expcor.pha

   > fkeyprint infile=ae101005040hxd_wel_pin_bgd_expcor.pha \
   keynam=EXPOSURE

   # FILE: ae101005040hxd_wel_pin_bgd_expcor.pha
   # KEYNAME: EXPOSURE

   # EXTENSION:    0
   EXPOSURE= 1.755875832736492E+03 / Exposure time
   # EXTENSION:    1
   EXPOSURE= 1.755875832736492E+03 / Exposure time
   # EXTENSION:    2
   EXPOSURE= 1.755875832736492E+03 / Exposure time

   > fparkey value=1.755875832736492E+04 \
   fitsfile="ae101005040hxd_wel_pin_bgd_expcor.pha+0"\
   keyword=EXPOSURE

   > fparkey value=1.755875832736492E+04 \
   fitsfile="ae101005040hxd_wel_pin_bgd_expcor.pha+1" \
   keyword=EXPOSURE
   ```

```
> fparkey value=1.755875832736492E+04 \
fitsfile="ae101005040hxd_wel_pin_bgd_expcor.pha+2" \
keyword=EXPOSURE

> fkeyprint infile=ae101005040hxd_wel_pin_bgd_expcor.pha\
 keynam=EXPOSURE

# FILE: ae101005040hxd_wel_pin_bgd_expcor.pha
# KEYNAME: EXPOSURE

# EXTENSION:    0
EXPOSURE= 1.755875832736492E+04 / Exposure time
# EXTENSION:    1
EXPOSURE= 1.755875832736492E+04 / Exposure time
# EXTENSION:    2
EXPOSURE= 1.755875832736492E+04 / Exposure time
```

7.5.3 PIN Responses by Epoch

Now that spectral files have been extracted and exposure times have been corrected for the data and the background model, users need to obtain the appropriate response files. Due to the changes in instrumental settings (bias voltages used on-board and low energy threshold used in processing on ground), users must choose PIN response matrices that are appropriate for the epoch of observation, as listed in Table 7.3.

In addition, the effective area of the PIN varies within the XIS FOV, because of the passive fine collimator that restricts the HXD FOV (see Figure 8.3 of the Technical Description at
`http://heasarc.gsfc.nasa.gov/docs/suzaku/prop_tools/suzaku_td/node11.html`).
Therefore, users need to select a response appropriate for the source location. For sources that are extended over ~5 arcmin or more, differential vignetting within the source region must be considered. The cosmic background can be considered to be flat over many degrees (ignoring the cosmic variance for the moment), which has to be accounted for using a special response that averages the fine collimator transmission over a wide area of the sky.

The original PI selected either the XIS nominal pointing (the target at the center of the XIS field of view) or the HXD nominal pointing (the target about 5 arcmin off-axis relative to the XIS, but at a point of maximum throughput of the HXD/PIN). The actual pointing can be determined by inspecting the `NOM_PNT` keyword in the FITS files. Responses are provided for point sources observed at these positions. In addition, we provide a "flat" response appropriate for large, extended sources such as the Cosmic X-ray background (CXB). Table 7.3 lists calibration epochs and corresponding response files. Refer to `http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/pinepochs.html` for the first announcement of new epochs.

Epoch	File(s)
2005 Aug 17 – 2006 May 13	ae_hxd_pinXXXXXe1_20080129.rsp
2006 May 13 – 2006 Oct 02	ae_hxd_pinXXXXXe2_20080129.rsp
2006 Oct 02 – 2007 Jul 28	ae_hxd_pinXXXXXe3_20080129.rsp
2007 Jul 28 – 2008 Aug 31	ae_hxd_pinXXXXXe4_20080129.rsp
2008 Sep 01 – 2009 Sep 30	ae_hxd_pinXXXXXe5_20080716.rsp
2009 Oct 01 – 2010 Jan 16	ae_hxd_pinXXXXXe6_20090826.rsp
2010 Jan 16 – 2010 Feb 02	ae_hxd_pinXXXXXe7_20100731.rsp
2010 Feb 2 – 2010 Apr 03	ae_hxd_pinXXXXXe8_20100731.rsp
2010 Apr 03 – 2010 Nov 30	ae_hxd_pinXXXXXe9_20100731.rsp
2010 Dec 01 – 2011 May 24	ae_hxd_pinXXXXXe10_20101013.rsp
2011 May 25 –	ae_hxd_pinXXXXXe11_20110601.rsp

Table 7.3: HXD/PIN response files by epoch; XXXXX=xinom, hxnom, flat.

These files are available from the Suzaku `CALDB` `http://heasarc.gsfc.nasa.gov/docs/heasarc/caldb/suzaku/`.

Now users can begin spectral fitting of the HXD/PIN data. In addition to the usual tasks of selecting the appropriate model etc., there are two steps that are needed here and that are described in the following two sections.

7.5.4 Cosmic X-Ray Background

The background event file does not include the cosmic X-ray background (CXB). Since the CXB flux is about 5% of the background for PIN, users need to take it into account after subtracting the non X-ray background. One method is to estimate the CXB level by using the PIN response for the flat emission distribution (see Table 7.3). It assumes uniform emission from a region of $2\,\mathrm{deg} \times 2\,\mathrm{deg}$.

A "typical" CXB spectrum is reported as follows, based on the *HEAO1* results (Boldt, 1987, `http://adsabs.harvard.edu/cgi-bin/nph-bib_query?bibcode=1987IAUS..124..611B`):

$$CXB(E) = 9.0 \times 10^{-9} \times (E/3\,\mathrm{keV})^{-0.29} \times \exp\left(-E/40\,\mathrm{keV}\right) \mathrm{erg\ cm^{-2}s^{-1}str^{-1}keV^{-1}}$$

Since the flat PIN response files are for 4 square degree field of view, we need to multiply this result by the appropriate ratio ($4\,\mathrm{deg}^2/1\,\mathrm{sr}$). Since $1\,\mathrm{sr} = 3283\,\mathrm{deg}^2$, this becomes

$$CXB(E) = 1.097 \times 10^{-11} \times (E/3\,\mathrm{keV})^{-0.29} \times \exp\left(-E/40\,\mathrm{keV}\right) \mathrm{erg\ cm^{-2}s^{-1}FOV^{-1}keV^{-1}}$$

Converting this into values appropriate for `xspec`, which assumes the power-law is normalized at 1 keV and is given in units of photons, not ergs, we obtain:

$$CXB(E) = 9.412 \times 10^{-3} \times (E/1\,\mathrm{keV})^{-1.29} \times \exp\left(-E/40\,\mathrm{keV}\right) \mathrm{photons\ cm^{-2}s^{-1}FOV^{-1}keV^{-1}}$$

Then we can simulate the CXB contribution to the PIN background with `xspec`. We fix the cutoff energie at the lower limit of the model ($E_{\mathrm{cutoff}} = 0.0001\,\mathrm{keV}$). The folding energy, E_{fold}, is 40 keV.

Note 1
This is the model of the CXB to be convolved with the "flat" response. To fit the observation with a model for the source, the simulated NXB spectrum, and the model for the CXB, a re-scaled version (using the ratio of XIS nominal or HXD nominal response vs. the flat response) of the model must be used. Although the effects of the CXB should be investigated independently for each observation, one can reproduce the observed counts from the diffuse CXB when using the HXD nominal position response matrix by using 8×10^{-4} as a normalization factor (instead of 9.412×10^{-3}) in the previous model.

Note 2
For the XIS nominal position, the amplitude of the powerlaw component should be increased by 10% to 8.8×10^{-4}, since the CXB is to first order position-independent while the HXD response to a point source at the XIS nominal position is reduced by 10%.

Note 3
The NXB background file and the simulated CXB `PHA` file can be added using `mathpha`, making sure that the resulting `EXPOSURE` keyword is the common value, i.e., the original NXB file exposure multiplied by a factor of 10 (and not the sum of both exposure times).

Note 4
The simulated CXB spectra generated by `hxdpinxbpi` (section 7.5.6) are based on the Boldt (1987) model and the parameters given here.

The `xspec` input for the flat response case thus looks like:

```
XSPEC12>model po*highecut

Input parameter value, delta, min, bot, top, and max values for ...
              1       0.01         -3         -2          9         10
1:powerlaw:PhoIndex>1.29
              1       0.01          0          0      1e+24      1e+24
2:powerlaw:norm>9.412e-03
             10       0.01     0.0001       0.01      1e+06      1e+06
3:highecut:cutoffE>0.0001
             15       0.01     0.0001       0.01      1e+06      1e+06
4:highecut:foldE>40
```

```
========================================================================
Model powerlaw<1>*highecut<2> Source No.: 1   Active/Off
Model Model Component  Parameter  Unit     Value
 par  comp
1    1       powerlaw   PhoIndex            1.29000      +/-  0.0
2    1       powerlaw   norm                9.41200E-03  +/-  0.0
3    2       highecut   cutoffE    keV      1.00000E-04  +/-  0.0
4    2       highecut   foldE      keV      40.0000      +/-  0.0
________________________________________________________________________

XSPEC12>
```

Once this has been set up, users can use the `fakeit none` command with the `pinflat` response matrix.

Please note that the level of the CXB and its point-to-point scatter are an active research topic. Other estimates of CXB spectrum can be converted to `xspec` models following the same steps as above.

7.5.5 Systematic PIN NXB Background Uncertainties

The accuracy of the PIN background model typically reaches as good as or better than 3–5% of the average background. It is strongly recommended to verify the reliability of the background model, though:

- By comparing light curves of the observation and the background model.
- By comparing the model spectrum with the Earth occultation spectrum, which can be obtained by screening with `ELV<-5`. Note, however, that in this case users need to start the analysis from the unfiltered event file.

7.5.6 `Hxdpinxbpi`

The `FTOOL` `hxdpinxbpi` automatizes the extraction steps described above, i.e., it produces the dead time corrected PIN source spectrum as well as the PIN background (NXB + CXB) spectrum.

The tool performs the following steps:

1. AND the GTIs from the NXB file(s) with the GTI in the `pin??_cl.evt` file(s) (or spectrum file) and any extra input GTI file(s) after ORing them together.
2. Extract the source spectrum using the GTI from step 1, if the PIN cleaned event file is input.

3. Extract the NXB background spectrum using the GTI from step 1.

4. Calculate a simulated CXB spectrum, if requested, the default exposure is that of the original NXB spectrum $\times 10$.

5. Adjust the EXPOSURE keyword in the NXB spectrum by a factor of 10.0 (background files are scaled up by 10.0 to suppress Poisson noise).

6. Apply dead time correction to the source spectrum using `hxddtcorr`.

7. Add the CXB spectrum to the NXB spectrum, if the CXB spectrum is created or given as input.

8. Optionally group the source spectrum.

7.6 GSO Data Analysis: General Remarks

The following duplicates some of the information given for the HXD in general in sections 7.2–7.4 above, but with special emphasis on the GSO.

This document refers to the GSO analysis setup available since `HEAsoft` v6.9, *Suzaku* `FTOOLS` Version 16. This version of the GSO analysis uses a new type of software and calibration files that implements a revised gain calibration of the HXD/GSO data. It extends the low energy limit of the usable GSO data from 70 keV down to 50 keV. For more details, see:
Yamada et al., 2011, PASJ 63, No. 5
`http://heasarc.nasa.gov/docs/suzaku/analysis/gso_newgain.html`
`http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/gso_newarf.html`

7.6.1 Revised GSO Gain Calibration: Backward Compatibility

To maintain backward compatibility of the new GSO analysis setup in *Suzaku* `FTOOLS` Version 16 with the earlier one, the following steps have been taken:

- The old version of `hxdpi` is available in the new release, under the name `hxdpi_old`, to enable reprocessing of data using the old calibration. This is based on the version of `hxdpi` available in `HEAsoft` v6.8, but now writes the new keyword `GSOOLDPI` set to `T` to indicate that the old GSO calibration has been applied.

- `hxdgrade` uses the `GSOOLDPI` keyword to select the correct pulse shape discrimination file from the `CALDB` (e.g., `ae_hxd_gsopsd_20071010.fits` for the old GSO gain calibration). If the keyword is not present it assumes that the events were processed with the old GSO calibration.

- The background files for the old GSO calibration will continue to be available at `ftp://legacy.gsfc.nasa.gov/suzaku/data/background/gsonxb_ver2.0` for observations obtained on 2010 February 28 or earlier.

- The script `aepipeline` allows to reprocess data with both the old and new GSO gain calibration via the parameter `hxdpi_old`, which is set to no by default.

7.6.2 Data Reduction Differences between PIN and GSO

The user may be familiar with the HXD-PIN analysis. Although the analysis method of HXD-GSO is similar to that of HXD-PIN, there are some differences as listed below:

1. Reprocessing: The GSO cleaned event files need to be processed with the same version of the gain calibration table (gain parameter table in the `CALDB`, `ae_hxd_gsogpt_yyyymmdd.fits`) as used for creating the corresponding GSO non X-ray background (NXB) file. This will often be the case in the distributed data but should be checked, see section 7.3.

2. NXB deadtime correction: For the GSO a deadtime correction of the NXB is required, while for the PIN it is not.

3. `EXPOSURE` keyword: The exposure of the GSO-NXB does *not* need to be multiplied by a factor of 10, in contrast to that of the PIN-NXB.

4. Grouping: The distributed GSO-NXB is grouped, so GSO spectra have to be grouped accordingly, using the spectral binning given by "`gsobgd64bins.dat`", available from `http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/gsobgd64bins.dat`.

5. Arffile: An additional arffile is needed for the GSO spectral analysis ("correction arf"), in contrast to the requirements for the PIN spectral analysis (see `http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/gso_newarf.html`).

7.6.3 GSO Reprocessing and Screening

Reminder: This document refers to the GSO analysis setup available since `HEAsoft` v6.9, *Suzaku* `FTOOLS` Version 16. This new version of the GSO analysis uses a new type of software and calibration files that implements a revised gain calibration of the HXD/GSO data. It extends the low energy limit of the usable GSO data from 70 keV down to 50 keV. Please also see `http://heasarc.nasa.gov/docs/suzaku/analysis/gso_newgain.html`.

The gain of the GSO changes with time, which is corrected with the gain parameter table in the `CALDB` (`ae_hxd_gsogpt_yyyymmdd.fits`). GSO data need to be processed with the appropriate gain paramter table which has to be of the same version as that used for the GSO-NXB files. If the versions of the GSO cleaned event file and GSO-NXB file are inconsistent, a cleaned event file has to be created by reprocessing unscreened files (*hxd*uf.evt), using hxdpi and hxdgrade. There is no need to apply hxdtime again, which has been completed before publishing the data. hxdpi converts pulse height (PHA) into photon energy (or pulse height invariant – PI) data. The gain parameter table, ae_hxd_gsogpt_yyyymmdd.fits in the CALDB, is required by hxdpi. An orbit file, aeNNNNNNNNN.orb is also needed. Please make sure that the orbit file is set correctly. The current version of hxdpi creates output even without the orbit file, but the output file may not be correct.

After applying hxdpi and hxdgrade data screening is required, e.g., with the standard criteria (see Table 7.2).

For the GSO reprocessing and rescreening the aepipeline tool can be used, which allows the user to run all or part of the *Suzaku* pipeline processing and to vary the calibration files used. A number of other pipeline processing parameters can also be changed. The functionality of hxdgtigen, which generates a telemetry un-saturated GTI, is also included here.

Below is an example of a call of aepipeline. Please, read the help file carefully ("fhelp aepipeline") and set the parameters accordingly:

```
> aepipeline indir=NNNNNNNNN \
outdir=OUTPUT_DIR \
steminputs=aeNNNNNNNNN \
entry_stage=1 \
exit_stage=2 \
instrument=GSO \
attitude=../auxil/aeNNNNNNNNN.att \
housekeeping=../auxil/aeNNNNNNNNN.hk \
extended_housekeeping=../auxil/aeNNNNNNNNN.ehk \
makefilter=../auxil/aeNNNNNNNNN.mkf \
orbit=../auxil/aeNNNNNNNNN.orb \
timfile=../auxil/aeNNNNNNNNN.tim \
hxd_gsogpt=$CALDB/data/suzaku/hxd/bcf/ae_hxd_gsogpt_yyyymmdd.fits
```

Warning:

(1) The outdir directory may not be a subdirectory of the indir directory. If it is, wrong results can be produced (double counting of events), especially in the case of multiple reprocessing runs. While the reporting will soon be improved, this currently happens without warning or error messages.

(2) The header keyword in the event files indicating the version of the processing pipeline used for reprocessing "PROCVER" is not updated by aepipeline. Check the log file produced by aepipeline for pipeline version information.

7.7 GSO Spectral Analysis

The procedure for creating a GSO spectrum is mostly the same as that for the HXD-PIN, but, please, see section 7.6.2, item 2–5, for important differences to keep in mind.

7.7.1 GSO Non X-Ray Background

The GSO Non X-ray Background (NXB) files can be downloaded from `ftp://legacy.gsfc.nasa.gov/suzaku/data/background/gsonxb_ver2.5/` and `ftp://legacy.gsfc.nasa.gov/suzaku/data/background/gsonxb_ver2.6/`. The last part of section 5.6.2 explains the difference between these two versions of GSO background model events. The NXB files are available around one month after the actual observation date.

The accuracy of the current background model is as good as ∼3% of the averaged background. It is strongly recommended to verify the reliability of background, though, by comparing the model spectrum and light curve with the "earth occulted data" (`ELV`< -5).

The GSO background event files do not include the Cosmic X-ray Background. However, the CXB is less than 0.1% of the total background rate in the GSO, and thus it is negligible.

7.7.2 `Hxdgsoxbpi`

The `FTOOL` `hxdgsoxbpi` automatizes the GSO spectrum extraction steps, i.e., it produces the dead time corrected GSO source spectrum as well as the dead time corrected GSO background (NXB) spectrum.

The tool performs the following steps:

1. AND the GTI from the NXB file(s) with the GTI in `gso??_cl.evt` file(s) (or spectrum file) and any extra input GTI file(s) after ORing them together.

2. Extract the source spectrum using the GTI from step 1, if a cleaned GSO event file is input.

3. Extract the NXB background spectrum using the GTI from step 1.

4. Apply dead time correction to the source and background spectrum using `hxddtcorr`.

5. Optionally group the source spectrum.

Below an example of the usage of `hxdgsoxbpi` is given. Please, read the help file carefully ("`fhelp hxdgsoxbpi`") and set the parameters accordingly. The NXB files are delivered with a fixed grouping scheme, following the specific procedure of creating the

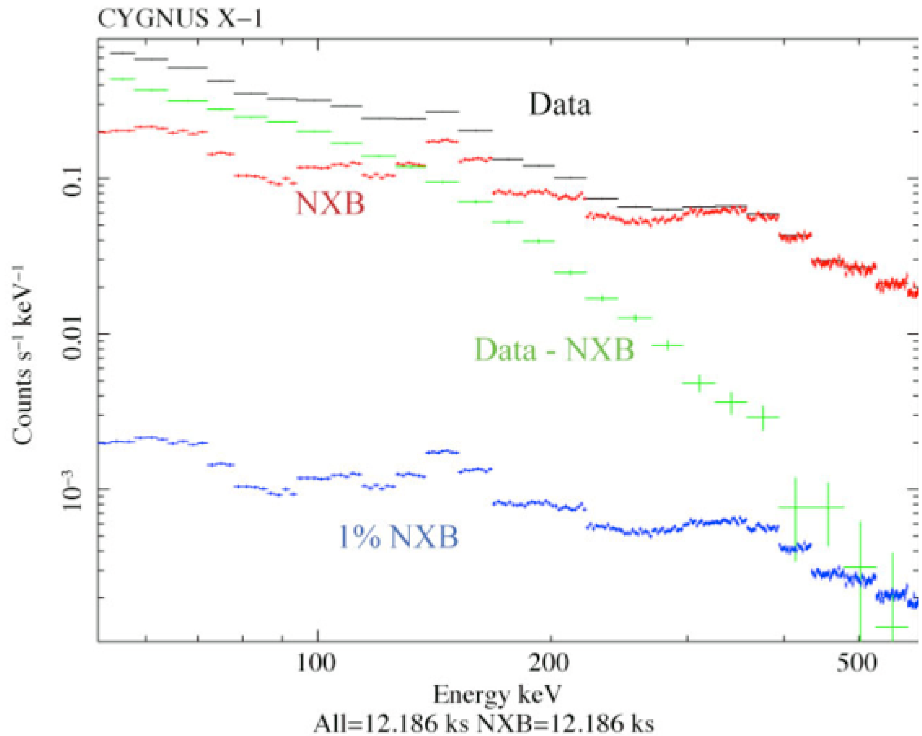

Figure 7.3: Example for a GSO spectrum as observed for Cygnus X-1 on April 8, 2009. The black, red, green, and blue data show the raw data, NXB, raw data − NXB, and 1% NXB spectrum, respectively. Since the systematic uncertainty of the NXB would be at most ∼3% at present, the source is clearly detected up to ∼300 keV.

NXB files.
Download `http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/gsobgd64bins.dat` in order to allow `hxdgsoxbpi` to group the source spectrum accordingly.

```
> hxdgsoxbpi input_fname=aeNNNNNNNNNhxd_0_gsono_cl.evt \
pse_event_fname=aeNNNNNNNNNhxd_0_pse_cl.evt \
bkg_event_fname=aeNNNNNNNNN_hxd_gsobgd.evt \
outstem=test \
gsonom_rsp=CALDB \
groupspec=yes \
groupfile=gsobgd64bins.dat
```

For the spectral analysis an additional GSO arffile (“correction arf”) is also required. This file can be downloaded from
`http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/gso_newarf.html`,

selecting the one appropriate for the aimpoint of the observation (i.e., `hxnom` or `xinom`).

7.8 Generating HXD ARF Files using `hxdarfgen`

Pre-calculated PIN and GSO response files, combining ARF and RMF effects, are provided through the *Suzaku* `CALDB` for observations at the HXD and XIS nominal positions and for large, extended sources, see e.g., Table 7.3 for PIN. In order to obtain ARFs for arbitrary offset pointings, the `FTOOL` `hxdarfgen` can be used.

Description: The task `hxdarfgen` calculates the incident angle for each detector using the `teldef`, `pi/pha`, and `atti` files. The transmission rates onto PIN and GSO for various incident angles are summarized in the `CALDB` files named `ae_hxd_pinart_YYYYMMDD.fits` and `ae_hxd_gsoart_YYYYMMDD.fits`, respectively. The task reads these ARF tables to generate ARF file(s) for this observation.

Note: The output ARF file(s) should be coupled with the responses for the "hxdnominal" pointing position in both, the PIN and the GSO case.

Example: Calculate ARF file for merged for 64 PINs for spectral file `ae20050405_2000_2100_hxd.pha` using the `teldef` file `ae_hxd_teldef_20050908.fits` and the `arfdb` file `ae_hxd_pinart_20070611.fits` for pointing position (RA,DEC) = (274.0554, 49.8675):

```
hxdarfgen hxd_arf_pinid=64 hxd_arf_gsoid=17 \
   hxd_teldef="ae_hxd_teldef_20050908.fits" \
   attitude="attitude.fits" \
   hxd_arfdb_name="ae_hxd_pinart_20070611.fits" \
   input_pi_name="ae20050405_2000_2100_hxd.pha" \
   point_ra=274.0554 point_dec=49.8675
```

Note: Definition of input parameters `hxd_arf_pinid` and `hxd_arf_gsoid`:

```
hxd_arf_pinid
PIN ID (0...63 64:merged >64:UNDEFINED). Default set to 65.

hxd_arf_gsoid
GSO ID (0...15 16:merged >16:UNDEFINED). Default set to 16.
```

Note: Currently only point source ARFs can be produced, as can be seen from the definition of the optional imput parameters `hxdarf_point_yn` and `image_fname`:

```
(hxdarf_point_yn = y)
Input position is POINT or not. Default set to yes.
‘‘n’’ is not supported yet in this version.
```

```
(image_fname = NONE)
Input image file, required only when hxdarf_point_yn is no.
Default set to be 'NONE'.
Image input is not supported yet in this version.
```

7.9 PIN Timing Analysis

Users can also generate background-subtracted PIN light curves using these background files. In this process, users need to take the dead time into account, using the pseudo event files. Since pseudo events are generated by the HXD analog electronics every 4 seconds for each of the 16 units, we expect 16 counts/4 s=4.0 counts/s in the absence of dead time. Therefore, the live time is given by the measured pseudo event rate during the time bin divided by 4.

The following method for correcting for bin-by-bin dead time is recommended only for bins longer than 128 s, to ensure that the dead time estimate is statistically accurate enough.

1. Merge the GTIs (see first step of extracting PIN spectra, section 7.5.2).

2. Extract a pure pseudo event light curve (i.e., those pseudo events that have no coincidental trigger flags from the real detectors).

   ```
   > fselect infile=ae123456789hxd_0_pse_cl.evt+1 outfile=pseudo_pure.evt \
             expr="GRADE_HITPAT<=1&&GRADE_QUALTY==0" histkw=yes
   ```

   Extract a lightcurve from this "pure" pseudo event file, while applying the merged GTI file, and save it as `pin_pseudo.lc`, for example.

3. Extract the source light curve using the merged GTI file. If this file is called `pin_event.lc`, the following steps will allow you to create a new `RATE` column which includes the dead time corrected `RATE`.

   ```
   > fcalc pin_pseudo.lc+1 pin_pseudo_div4.lc DTCOR "RATE/4"
   > faddcol pin_event.lc+1 pin_pseudo_div4.lc+1 DTCOR
   > fcalc pin_event.lc+1 pin_event_dtcor.lc RATE "RATE/DTCOR"
   > fcalc pin_event_dtcor.lc+1 pin_event_dtcor.lc ERROR "ERROR/DTCOR" clobber=yes
   ```

   The above steps were: calculate the live time in the `DTCOR` column of a temporary file, `pin_pseudo_div4.lc`; copy that column into the light curve file, `pin_event.lc`; create a new light curve file `pin_event_dtcor.lc` in which the `RATE` column is dead time corrected; dead time-correct the `ERROR` column in that file.

4. Extract the background light curve, and divide it by 10.

```
> fcalc pin_bgd.lc+1 pin_bgd_div10.lc RATE "RATE/10"
> fcalc pin_bgd_div10.lc+1 pin_bgd_div10.lc ERROR "ERROR/10" clobber=yes
```

Note that, in addition to the contribution from this background light curve, the observed light curve contains the cosmic X-ray background component, which can be treated as a constant.

7.9.1 `Hxdpinxblc`

The `FTOOL` `hxdpinxblc` automatizes the extraction steps described above, i.e., it produces the dead time corrected PIN source with background light curve, as well as the PIN background (NXB + constant CXB) light curve, and the background subtracted light curve.

The tool performs the following steps:

1. AND the GTI from NXB file(s) with the GTI in the `pin??_cl.evt` file(s) (or input light curve file) and any extra input GTI file(s) after ORing them together.
2. Extract the pseudo event light curve from all input `pse_cl.evt` file(s) (or `wel_uf.evt` file(s)) using the GTI from step 1.
3. Extract source light curve using the GTI from step 1, if a cleaned PIN event file is input.
4. Extract the background light curve using the GTI from step 1.
5. Divide the background light curve RATE and ERROR by 10.0 (background files are scaled up by 10.0 to suppress Poisson noise).
6. Apply dead time correction to the source light curve (pseudo RATE/4.0) if not already applied.
7. Add a constant CXB component to background light curve, if supplied.
8. Optionally subtract the background light curve from the source light curve.

7.10 GSO Timing Analysis

The procedure for creating a GSO light curve is mostly the same as that for the HXD-PIN, but please see section 7.6.2, item 2 and 3, for important differences to keep in mind.

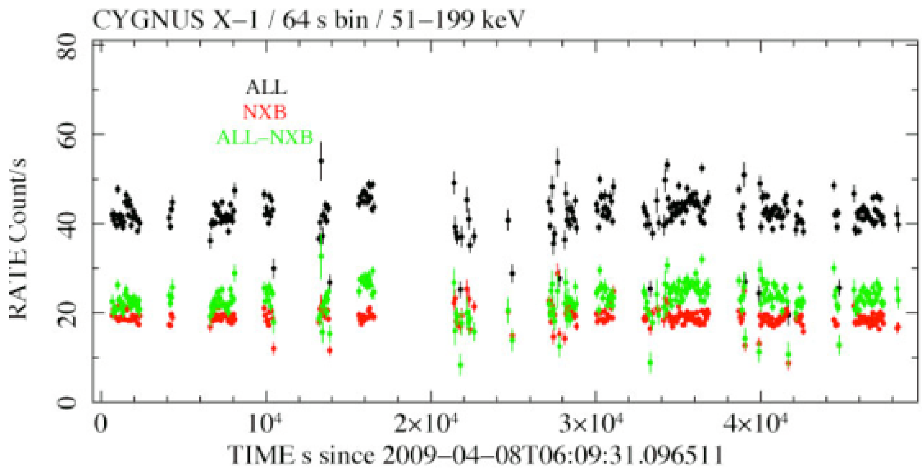

Figure 7.4: Example for a GSO light curve as observed for Cygnus X-1 on April 8, 2009. The black, red, and green data show the raw data, NXB, and raw data − NXB light curve, respectively. 20 counts/s is a typical count rate of Cyg X-1.

7.10.1 `Hxdgsoxblc`

The `FTOOL` **`hxdgsoxblc`** automatizes the GSO light curve extraction steps, i.e., it produces the dead time corrected GSO source with background light curve, as well as the GSO background (NXB) light curve, and the background subtracted light curve.

The tool performs the following steps:

1. AND the GTI from the NXB file(s) with the GTI in the **`gso??_cl.evt`** file(s) (or input light curve file) and any extra input GTI file(s) after ORing them together.

2. Extract the pseudo event light curve from all input **`pse_cl.evt`** file(s) (or **`wel_uf.evt`** file(s)) using the GTI from step 1.

3. Extract the source light curve using the GTI from step 1, if a cleaned GSO event file is input.

4. Extract the background light curve using the GTI from step 1.

5. Apply dead time correction to the source and background light curves (pseudo RATE/4.0) if not already applied.

6. Optionally subtract the background light curve from source light curve.

Below an example of the usage of **`hxdgsoxblc`** is given. Please, read the help file carefully (“**`fhelp hxdgsoxbc`**”) and set the parameters accordingly.

```
> hxdgsoxblc input_fname=aeNNNNNNNNNhxd_0_gsono_cl.evt \
pse_event_fname=aeNNNNNNNNNhxd_0_pse_cl.evt \
bkg_event_fname=aeNNNNNNNNN_hxd_pinbgd.evt \
outstem=test \
bkgsub=yes \
binlc=128.0
```

7.11 Initial Processing: Details

The remainder of this chapter describes the details of the initial processing for the HXD. These steps, already performed in the processing pipeline, can be repeated by users if necessary (section 7.3, section 7.4).

For the HXD, the standard pipeline processing starts with an unfiltered file which contains events from both the GSO and PIN detector. This file contains "`wel`" in its filename and the `DETNAM` keyword has the value "`WELL`". We describe the processing steps, in the recommended order, below. *Please note that users who only want a quick look at their data should not have to run these routines again but could use the files provided in the* `products` *directory.*

Users are also advised to create a second directory in which the newly processed files will be saved as some of the routines would otherwise overwrite the existing files:

```
unix% mkdir event_cl2/; cd event_cl2/
unix% ln -s ../event_uf/aeNNNNNNNNNhxd_M_wel_uf.evt.gz .
unix% ln -s ../hk/aeNNNNNNNNNhxd_0.hk.gz .
unix% ln -s ../../auxil/aeNNNNNNNNN.tim.gz .
```

7.11.1 Time Assignment

The first step is to calculate the HXD event arrival-time correction. The arrival time of each true event time (`TIME`) is calculated from the HXD internal detector time value and other detector corrections. The computed time is then converted to *Suzaku* time coordinates using four separate methods (selected using the input parameter "`time_convert_mode`"). In addition, the tool `hxdtime` measures the actual time resolution of "`TIME`" during the observation. The standard way to run the `hxdtime` tool is the following:

```
hxdtime input_name=aeNNNNNNNNNhxd_M_wel_uf.evt \
create_name=aeNNNNNNNNNhxd_M_wel_uf2.evt \
leapsec_name=leapsec.fits \
hklist_name=aeNNNNNNNNNhxd_0.hk \
tim_filename=aeNNNNNNNNN.tim
```

where
`input_name` is the name of the original unfiltered event file in the `hxd/event_uf` directory;
`create_name` is the name of the new (output) unfiltered event file name;
`leapsec_name` is the name of the latest leap seconds file located in the `CALDB` (under mission "`gen`", under the filename `leapsec_010905.fits`) and in the `HEAsoft refdata` area (where the file is called `leapsec.fits`, after `HEAsoft` v6.1.1, it is identical to `leapsec_010905.fits`);
`hklist_name` is the name of the HXD HK file found under `hxd/hk`;
`tim_filename` is the name of the TIM file, found in `auxil`.

Users may wish to confirm the following hidden parameters:

`read_iomode=create` (a separate output file will be created)
`time_change=yes` (`TIME` column will be updated)
`grade_change=n` (no change of `GRADE_XX`)
`pi_pmt_change=n` (no change of `PI_SLOW, PI_FAST`)
`pi_pin_change=n` (no change of `PI_PIN`)
`gtimode=y` (read and apply GTI extension)
`gti_time=S_TIME` (meaning of `TIME` in GTI, row level information)
`time_convert_mode=4` (`aste_ti2time` function is used)
`use_pwh_mode=n` (no use of `HXD_WEL_PWH` extension of HXD HK FITS)
`num_event=-1` (control value for ANL routine; read all event if -1)
`event_freq=10000` (control value for ANL routine; frequency of messages)
`anl_verbose=-1` (control value for ANL routine; verbose level)
`anl_profile=yes` (control value for ANL routine; dump profile)

7.11.2 Gain History Generation

After filling in the corrected event times, the next step is to adjust the detector gain for both HXD detectors. In Version 2 processing, the gain history files are generated by the HXD team and provided to the `CALDB`. We have therefore discontinued the documentation regarding the generation of the HXD gain history.

7.11.3 Pulse Height Corrections

Once the gain drift has been measured, the (time) invariant event pulse-height (PI) values can be determined. For the HXD, `hxdpi` calculates the HXD `PI` columns (`PI_PIN[0,1,2,3]`, `PI_SLOW`, `PI_FAST`) based on the relevant `PHA` data, the gain history and other calibration data, such as non-linearity in the analog-to-digital conversion. The Gd edge effect is not included in `SLOW/FAST_PI`. The effect is included in the response matrix table for the GSO.

NOTE: This is the task that uses the gain history files to correct the PI values. Users should obtain/use the most up-to-date gain history file (GHF) for the PIN and the most up-to-date gain parameter table (GPT) for the GSO (GHF for the old GSO setup, i.e., with `hxdpi_old`) from the `CALDB`, where they are frequently updated by the calibration team.

The correct syntax to run the `hxdpi` tool is:

```
unix% cat > hk_file.list << EOF
../hk/aeNNNNNNNNNhxd_0.hk.gz
../../auxil/aeNNNNNNNNN.ehk.gz
EOF

unix% hxdpi input_name=aeNNNNNNNNNhxd_M_wel_uf2.evt\
create_name=hxd_picorr_evt.fits hklist_name=@hk_list.dat\
hxd_gsogpt_fname=CALDB hxd_gsolin_fname=CALDB \
hxd_pinghf_fname=CALDB hxd_pinlin_fname=CALDB
```

where
`input_name` is the HXD FITS file input name;
`create_name` is the output name (see below);
`hklist_name` should be used to pass the HXD HK file name and the extended hk file name using the @list syntax;
`hxd_gsogpt_fname` is the GSO gain parameter table from the `CALDB` (use `hxd_gsoghf_fname` with `hxdpi_old`);
`hxd_gsolin_fname` is the name of the `CALDB` file containing the GSO integrated non-linearity of the ADC;
`hxd_pinghf_fname` is the PIN gain history file from the `CALDB`;
`hxd_pinlin_fname` is the name of the `CALDB` file containing the PIN integrated non-linearity of the ADC.

Warnings:

1. For `hxdpi`, the hidden parameter `read_iomode` is set to overwrite by default, so the relevant columns of the input file will be modified. Optionally, select `read_iomode=create` and specify an output file name using the hidden parameter `create_name`. The other hidden parameters for this routine are similar to those of `hxdtime`.

2. Note that if the `CALDB` gain calibration file does not include the observation date of the event file, the tool will run silently without updating the file content. Users have to check that their observation date is covered by the `CALDB` file.

3. The hidden parameter `event_freq` is by default set to 10000. This is the event print-out frequency. Users may want to increase the value of this parameters to avoid long screen outputs. Look at the number of events in your initial event file to estimate a reasonable value.

Typical command line input to `hxdpi` is:

```
hxdpi input_name=ae401100010hxd_1_wel_uf2.evt read_iomode=create \
create_name=ae401100010hxd_1_wel_uf2-hxdpi.evt hklist_name=@hk_file.list \
hxd_gsogpt_fname=CALDB hxd_gsolin_fname=CALDB \
hxd_pinghf_fhame=CALDB hxd_pinlin_fname=CALDB \
event_freq=500000
```

7.11.4 Calculating Event Grade

HXD event files have 5 grade columns filled by the `hxdgrade` routine. The first column is called `GRADE_QUALTY` and stores the data quality. All events with a `GRADE_QUALTY` flag not equal to 0 should be ignored. The next two columns indicate the origin of the event. The column `GRADE_PMTTRG` is set to 1 for any PMT triggered event while the column `GRADE_PINTRG` is set for 1 for any PIN triggered event. Column `GRADE_PSDSEL` gives the GSO likelihood in the Slow/Fast diagram while the fifth column `GRADE_HITPAT` gives the hit pattern grade.

```
hxdgrade input_name=aeNNNNNNNNNhxd_M_wel_uf2.evt \
hxdgrade_psdsel_fname=CALDB \
hxdgrade_pinthres_fname=CALDB
```

where
`input_name` is the HXD FITS file input name;
`hxdgrade_psdsel_fname` is the name of the `CALDB` file containing the GSO PSD selection criteria (specify `CALDB` to pick the best file automatically; the file should have a name like `ae_hxd_gsopsd_20090812.fits`);
`hxdgrade_pinthres_fname` is the name of the `CALDB` file containing the PIN lower discriminator threshold (specify `CALDB` to pick the best file automatically; the file should have a name like `ae_hxd_pinthr_20101013.fits`).

Warning:
Just as for `hxdpi`, `hxdgrade` has the hidden parameter `read_iomode` set to overwrite by default, so the relevant columns of the input file are modified. Users may want to set `read_iomode=create` and specify an output file name using the `create_name` option.

Up until this step the files contain both GSO and PIN ("`WELL`") data. As described in the next section, a series of further screening procedures can be performed before separating the PIN and GSO data.

7.12 Extracting Data

Before extracting data products like spectra and lightcurves one can select events for given criteria, either directly from the FITS file using the `FTOOL` `fselect`, or within `xselect`. Here we show how to proceed within `xselect`. The default parameters used for data screening can be found in the filter file. The "`select mkf`" command applies filter file based data screening. This translates the selection criteria into a boolean expression and calculates the corresponding Good Time Intervals (GTI). Additional selections, e.g., for user-defined times or particular event flags, can be applied. Within `xselect` the filtered events can then be used to create a (binned) spectrum (as well as responses) or a lightcurve.

7.12.1 Standard and Additional Screening

The current cuts applied within the standard processing of the data read:

```
SAA_HXD==0 && T_SAA_HXD>500 && ELV>5 && ANG_DIST<1.5 && HXD_DTRATE<3 &&
 AOCU_HK_CNT3_NML_P==1 && COR>6 &&
 HXD_HV_W0_CAL>700 && HXD_HV_W1_CAL>700 && HXD_HV_W2_CAL>700 &&
 HXD_HV_W3_CAL>700 && HXD_HV_T0_CAL>700 && HXD_HV_T1_CAL>700 &&
 HXD_HV_T2_CAL>700 && HXD_HV_T3_CAL>700
```

where
`SAA_HXD==0` selects intervals during which *Suzaku* was outside of the SAA, using a map of the SAA determined empirically by the HXD team (**not to be changed or omitted**);
`T_SAA_HXD>500` sets the minimum time after SAA passages (**standard value but can be experimented with**);
`ELV>5` constrains the elevation of the target above the Earth's limb to at least 5 degrees (**standard value but can be experimented with**);
`ANG_DIST<1.5` constrains the pointing to be within 1.5 arcmin of the mean (**standard value but can be experimented with**);
`HXD_DTRATE<3` excludes intervals during which the data rate was low, since this means that the telemetry is saturated due to background events (**not to be changed or omitted**);
`AOCU_HK_CNT3_NML_P==1` indicates normal pointing operation (**not to be changed or omitted**);
`COR>6` selects the geomagnetic cut-off rigidity to be at least 6 GeV/c (**standard value but can be experimented with**);
`HXD_HV_Wn_CAL` and `HXD_HV_Tn_CA` select for the HXD operating with the usual setting (**not**

to be changed or omitted).

In particular, it is possible to create your own Night Earth HXD data by replacing `ELV>5` with appropriate expressions involving `ELV`, `DYE_ELV` (elevation above the sunlit limb of the Earth), and `NTE_ELV` (elevation above the night Earth).

Within `xselect` screening is performed as follows:

```
hakatan-91-event_cl2: xselect

                         **  XSELECT V2.4   **

> Enter session name >[xsel]  abc-guide
 Setting plot device to /NULL
abc-guide:SUZAKU > read events
> Enter the Event file dir >[./]
> Enter Event file list >[] ae401100010hxd_1_wel_uf2-hxdgrade.evt

 Notes: XSELECT set up for      SUZAKU
 Time keyword is TIME       in units of s
 Default timing binsize =   16.000

Setting...
 Image  keywords   = UNITID     UNITID      with binning =    1
 WMAP   keywords   = UNITID     PIN_ID      with binning =    1
 Energy keyword   = PI_PIN                 with binning =    1

Getting Min and Max for Energy Column...
Got min and max for PI_PIN:     0    255

could not get minimum time resolution of the data read
MJDREF =  5.1544000742870E+04 with TIMESYS = TT
 Number of files read in:  1

******************** Observation Catalogue ********************

Data Directory is:
/Volumes/Maison/Directories/Suzaku/MySuz/1E1841-045/v1.2.2.3/401100010/hxd/event_cl2/
HK Directory is:
 /Volumes/Maison/Directories/Suzaku/MySuz/1E1841-045/v1.2.2.3/401100010/hxd/event_cl2/
```

```
          OBJECT      DETNAM      DATE-OBS    DATE-END
        1 1E 1841-045 WELL        2006-04-19T 2006-04-22T

abc-guide:SUZAKU-HXD-WELL_PIN >
abc-guide:SUZAKU-HXD-WELL_PIN > filter mkf
> Boolean expression for filter file selection >[ ] SAA_HXD==0 && T_SAA_HXD>500 &&
ELV>5 && ANG_DIST<1.5 && HXD_DTRATE<3 && AOCU_HK_CNT3_NML_P==1 && COR>6 &&
HXD_HV_W0_CAL>700 && HXD_HV_W1_CAL>700 && HXD_HV_W2_CAL>700 &&
HXD_HV_W3_CAL>700 && HXD_HV_T0_CAL>700 && HXD_HV_T1_CAL>700 &&
HXD_HV_T2_CAL>700 && HXD_HV_T3_CAL>700
> Enter the filter file directory >[./] ../../auxil
PREFR keyword found in header, using prefr =   0.0
POSTFR keyword found in header, using postfr = 1.0
abc-guide:SUZAKU-HXD-WELL_PIN >
```

7.12.2 Separating PIN and GSO Data

At this point, both GSO and PIN events are still taken into account. Users can now select events from either one of these detectors by selecting on the column called `DET_TYPE`. `DET_TYPE==1` selects PIN events and `DET_TYPE==0` selects GSO events; e.g., for PIN:

```
abc-guide:SUZAKU-HXD-WELL_PIN > filter column
> Enter filter on column(s) in the event file >[] DET_TYPE==1
abc-guide:SUZAKU-HXD-WELL_PIN > extract events
```

7.13 WAM Data Analysis

7.13.1 Introduction

The WAM is the lateral BGO (= $Bi_3Ge_4O_{12}$ crystal) anti-coincidence shield of the Hard X-ray Detector (HXD). It consists of 4 identical walls (referred as WAM 0, 1, 2 and 3), which are further composed of 5 anti-counter units for each wall. The primary role of the WAM is the background rejection for the HXD-PIN and GSO, but the WAM can observe bright gamma-ray transients such as gamma-ray bursts (GRBs) and soft gamma repeaters (SGRs) in the range of $50 - 5000\,\mathrm{keV}$.

The WAM data consist of two types: Gamma burst (BST) and Transient (TRN) data (Table 7.4). The BST data are available only when the onboard GRB trigger occurs. They have time history (TH) data with a fine time resolution (1/32 or 1/64 s) in four energy ranges and the 55 channel pulse height (PH) histogram data with coarse time resolution (1/2 or 1 s) during finite time intervals (64 or 128 s). On the other hand, the TRN data cover the whole time with 1 s time resolution for monitoring the background. They have 55 channel pulse-height histogram data.

Details of the WAM instrumentation are described in Yamaoka et al., 2009, PASJ 61, S35. The spectral cross-calibration with Swift/BAT and Konus/Wind is described in Sakamoto et al., 2011, PASJ 63, 215.

Table 7.4: Characteristics of the BST and TRN WAM data.

Data	Energy	Epoch	Time resolution	Time coverage
BST	4 channels	2005 Aug. 22 – 2006 Mar. 20	1/32 s (TH)	128 s (16 s before and
	55 channels		1 s (PH)	112 s after the trigger)
	4 channels	2006 Mar. 20 – present	1/64 s (TH)	64 s (8 s before and
	55 channels		0.5 s (PH)	56 s after the trigger)
TRN	55 channels	2005 Aug. 22 – present	1 s (PH)	Always transferred to the telemetry every 1 s

7.13.2 WAM Event File Content

Cleaned event files are not provided for the WAM data because the PHA to PI conversions and the event grade selection are not performed for the raw data. Therefore the WAM data extraction starts with the second FITS files in the `hxd/event_uf` directory. This directory contains three types of WAM FITS files: the BST event files (`aeNNNNNNNNNhxd_y_bstzz_uf.evt.gz`), the TRN event files (`aeNNNNNNNNNhxd_y_wam_uf.evt.gz`), and BSTID table files (`aeNNNNNNNNNhxd_y_bstidt.fits.gz`) where `NNNNNNNNN` is the *Suzaku* observation ID, `y` is the RPT file number which ranges from 0 to 9, and `zz` is the sequential number of the BST data.

For example:

```
ae903005010hxd_1_bst01_uf.evt.gz
ae903005010hxd_1_bstidt.fits.gz
ae903005010hxd_1_wam_uf.evt.gz
ae903005010hxd_2_bstidt.fits.gz
ae903005010hxd_2_wam_uf.evt.gz
```

The BSTID table files are temporal files for the time assignment in the standard pipeline processing, they are not used for the data analysis. The BST data have to be reprocessed because wrong times are sometimes assigned for the BST data in the standard pipeline process (about 10% of all BST data). In order to check whether the time assignment is correct or not the following command can be used:

```
fkeyprint infile=ae903005010hxd_1_bst01_uf.evt.gz keynam=TIMECORR
```

The `TIMECORR` keyword can have the value F or T. F means that the time assignment has failed, so reprocessing is required. The way to reprocess the BST data is explained in section 7.13.6. After reprocessing the BST data it should be checked that the `TIMECORR` keyword has changed from F into T.

7.13.3 WAM `HEAsoft` Tools

There are currently (`HEAsoft` v6.10) seven tools available for the WAM data analysis (Table 7.5). Versions earlier than `HEAsoft` v6.9 should not be used for the WAM analysis.

Please note that the deadtime correction for TH light curves and TH spectra is not yet supported in `hxdmkbstlc` and `hxdmkbstspec` (Table 7.6). Correction tools are being developped by the WAM team.

Table 7.5: WAM tools in the `HEAsoft` package.

Tool Name	Role
`hxdbsttime`	Time assignment for the BST data
`hxdmkbstlc`	Creation of a light curve (PH and TH data) from BST data
`hxdmkbstspec`	Creation of an energy spectrum (PH and TH data) from BST data
`hxdwambstid`	Creation of a BSTID table from the TRN data
`hxdwamtime`	Time assignment for the TRN data
`hxdmkwamlc`	Creation of a light curve (PH data) from TRN data
`hxdmkwamspec`	Creation of an energy spectrum (PH data) from TRN data
`hxdbstjudge`	Search for a burst in the light curve FITS

Table 7.6: Deadtime correction support of WAM light curves and spectra in `HEAsoft` v6.9.

Data	Type	LC or SPEC	Tool Name	Deadtime Correction
BST	PH	LC	`hxdmkbstlc`	yes
		SPEC	`hxdmkbstspec`	yes
	TH	LC	`hxdmkbstlc`	no
		SPEC	`hxdmkbstspec`	no
TRN	PH	LC	`hxdmkwamlc`	yes
		SPEC	`hxdmkwamspec`	yes

7.13.4 WAM Timing Analysis

WAM light curve FITS files can be produced with `hxdmkbstlc` for the BST PH and TH data and with `hxdmkwamlc` for the TRN data. After producing these files (∗`.lc`) you can proceed with the timing analysis using, e.g., the XRONOS package.

The `TIME` column in the FITS file is usually given in `ASTETIME`, i.e., time in seconds since 2000-01-01 00:00:00 (UTC). You can convert `ASTETIME` into `UTC` using the `FTOOL` `aetimecalc`, e.g.:

```
aetimecalc input=mission mission=1.8e8
```

or with the date converter on the `HEASARC` web site (`http://heasarc.gsfc.nasa.gov/cgi-bin/Tools/xTime/xTime.pl`).

TRN Light Curve Extraction

For the TRN (PH) data, the energy channels (`min_channel` and `max_channel`) have to be specified. The WAM energy channels range from 0 to 54, and are compressed from the original flash ADC channels (0 to 63 plus one overflow bit).

Table 7.7: Bit-compression for 6-bit flash ADC channels.

Compressed Channels	ADC Channels	Binning
0–47	0–47	1
48–51	48–55	2
52–53	56–63	4
54	Overflow bit(≈64–150)	1

The approximate energy channels are calculated by:

```
Energy (keV) = ADC Channel x 511/15
```

Note that this equation depends on the gain of the detector, which varies with time and operation.

The PH light curves have to be deadtime corrected using the dt_cor option (`dt_cor=yes`). To create a light curve for the full WAM energy band select `min_channel=2` and `max_channel=54` (channels 0 and 1 [<∼50 keV] are affected by the low energy threshold and provide noisy light curves).

```
hxdmkwamlc input_name=ae903005010hxd_1_wam_uf.evt.gz \
  outroot=ae903005010hxd_1 \
  leapfile=CALDB min_channel=2 max_channel=54 dt_cor=yes
```

BST Light Curve Extraction

In order to obtain the BST TH light curve set the `th_mode` option to 1. Deadtime correction is not currently supported (dt_cor=no):

```
hxdmkbstlc input_name=ae903005010hxd_1_bst01_uf.evt.gz \
  outroot=ae903005010hxd_1_bst01 \
  tpu_board=-1 th_mode=1 dt_cor=no energy_mode=-1
```

In order to obtain the BST PH light curve set the `th_mode` option to 0 and specify the energy range with `min_channel` and `max_channel`:

```
hxdmkbstlc input_name=ae903005010hxd_1_bst01_uf.evt.gz \
  outroot=ae903005010hxd_1_bst01 tpu_board=-1 th_mode=0 energy_mode=1
  min_channel=2 max_channel=54 dt_cor=yes
```

7.13.5 WAM Spectral Analysis

In order to produce spectral FITS files (`*.pha`) use `hxdmkbstspec` for the BST data and `hxdmkwamspec` for the TRN data, correct for detector deadtime using the `dt_cor` option (`dt_cor=yes`), and give the start time (`time_min`) and end time (`time_max`) for spectral integration in `ASTETIME`:

```
hxdmkbstspec input_name=ae903005010hxd_1_bst01_uf.evt.gz \
  outroot=ae903005010hxd_1_bst01 tpu_board=-1 th_mode=0 \
  time_min=276787164 time_max=276869264 dt_cor=yes

hxdmkwamspec input_name=ae903005010hxd_1_wam_uf.evt.gz \
  outroot=ae903005010hxd_1 tpu_board=-1\
  time_min=276787164 time_max=276869264 dt_cor=yes
```

Background spectra can be derived by 1) integrating a few 10–100 seconds before and after the bursts if the background level is almost constant or, in principle, 2) modeling of the background (not supported yet).

The response generator, `wamrspgen`, will not be made publicly available due to its complex structure. The WAM team will make response matrices for certain GRBs publicly available on the web site. If you want response matrices for other GRBs, please contact the WAM team via their e-mail adress (`suzaku-wam@astro.isas.jaxa.jp`).

You can then proceed with spectral fitting using, e.g., XSPEC:

```
XSPEC12>data 1:1 wam0_grb.pha (GRB spectrum)
XSPEC12>backgrnd 1 wam0_bg.pha  (Background spectrum)
XSPEC12>response 1 wam0_grb.rsp (Response file)
```

Many GRBs are detected by more than one WAM detector. To constrain the spectral parameters more tightly, you can perform joint fitting of several WAM detectors, e.g., for two:

```
XSPEC12>data 2:2 wam1_grb.pha
XSPEC12>backgrnd 2 wam1_bg.pha
XSPEC12>response 2 wam1_grb.rsp
```

The current responses have systematic uncertainties at low energies (below $\sim$150 keV). It is recommended to ignore channels $0-4$ in spectral fitting:

```
XSPEC12> ignore **-4
```

The upper energy channel limit depends on photon statistics. Note that there are typically calibration uncertainties of 20% in the absolute flux. For the calibration status please see Yamaoka et al., 2009, PASJ 61, S35 and Sakamoto et al., 2011, PASJ 63, 215.

Notes

Please note that the WAM data in the current data archive are not screened according to criteria such as SAA times and performance of calibration tasks. Figure 7.5 shows a typical one-day light curve in the $50-5000$ keV range.

The high voltages are shut down during the SAA passage (about 10 times per day), so the light curve shows a zero value at these times. Also a gain check operation for each unit is performed during 10 minutes every day and the light curve shows about one quarter of the original count rate during this operation (at ~ 85000 s in Figure 7.5). If the burst occured during and near the SAA and the gain operation, please be careful not to use data during these periods.

7.13.6 Standard Processing

Time Assignment

First list the HXD HK files in ASCII format in a file, `hk.list`. For example, `hk.list` may contain:

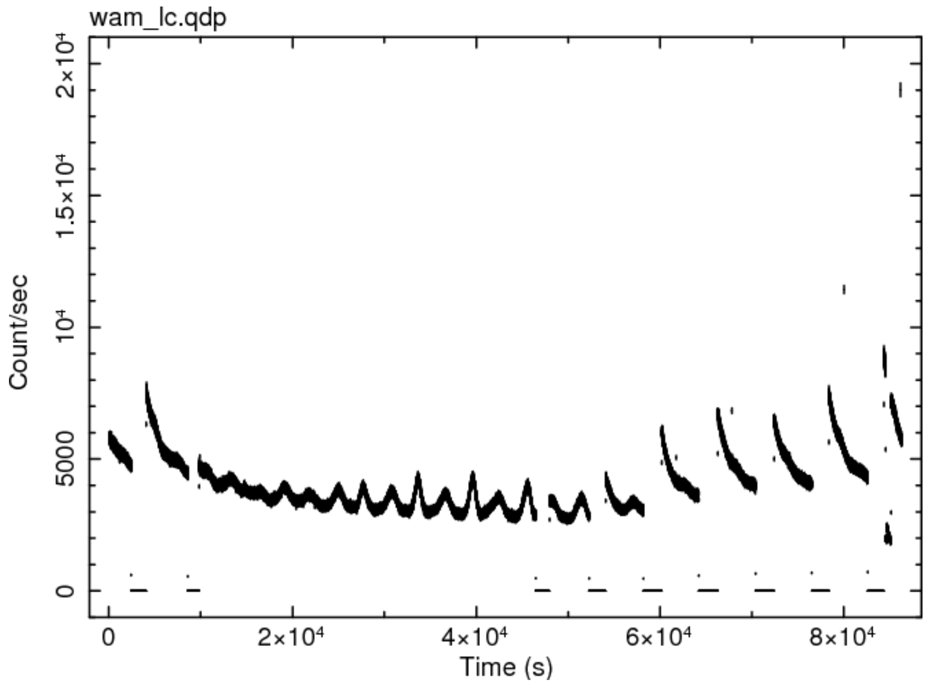

Figure 7.5: Typical one-day WAM light curve.

```
ae903005010_0.hxd.hk
ae903005010_1.hxd.hk
```

If there is only one HK file in the data archive it can be provided directly with `hklist_name=ae903005010_0.hxd.hk`.

For the TRN data:

```
hxdwamtime read_iomode=overwrite \
  input_name=ae903005010hxd_1_wam_uf.evt \
  leapfile=CALDB hklist_name=@hk.list \
  tim_filename=ae903005010.tim
```

For the BST data:

```
hxdbsttime read_iomode=overwrite \
input_name=ae903005010hxd_1_bst01_uf.evt \
hklist_name=@hk.list leapfile=CALDB \
tim_filename=ae903005010.tim  bstidt_fname=CALDB
```

7.13.7 Useful WAM Websites

0) The primary WAM web page:
`http://www.astro.isas.jaxa.jp/suzaku/HXD-WAM/WAM-GRB`

1) The WAM GRB (Gamma-Ray Burst) table:
Triggered events
`http://www.astro.isas.jaxa.jp/suzaku/HXD-WAM/WAM-GRB/grb/trig/grb_table.html`
Un-triggered events
`http://www.astro.isas.jaxa.jp/suzaku/HXD-WAM/WAM-GRB/grb/untrig/grb_table.html`

2) The WAM SGR (Soft Gamma Repeater) table:
Triggered events
`http://www.astro.isas.jaxa.jp/suzaku/HXD-WAM/WAM-GRB/sgr/trig/sgr_table.html`
Un-triggered events
`http://www.astro.isas.jaxa.jp/suzaku/HXD-WAM/WAM-GRB/sgr/untrig/sgr_table.html`

3) The WAM solar flare table:
Triggered events
`http://www.astro.isas.jaxa.jp/suzaku/HXD-WAM/WAM-GRB/solar/trig/solar_table.html`
Un-triggered events
`http://www.astro.isas.jaxa.jp/suzaku/HXD-WAM/WAM-GRB/solar/untrig/solar_table.html`

4) The WAM event candidate list:
`http://www.astro.isas.jaxa.jp/suzaku/HXD-WAM/WAM-GRB/list/wam_eventlist.html`

7.13.8 Contact

If you have any questions and comments about the WAM data analysis and software, please don't hesitate to send an e-mail to:

`suzaku-wam@astro.isas.jaxa.jp`

Appendix A

Acronyms

The following table lists acronyms used in this document.

Chapter	Acronym	Definition
	ADC	Analogue to Digital Converter
	ARF	Ancillary Response File
	ASCA	Advanced Satellite for Cosmology and Astrophysics
	ASCII	American Standard Code for Information Interchange
	ATOMDB	ATOMic DataBase
	BGO	Bismuth Germanate
	BI	Back-Illuminated
	CALDB	CALibration DataBase
	CCD	Charge-Coupled Devices
	CIAO	Chandra Interactive Analysis of Observations
	Co-I	Co-Investigator
	CXB	Cosmic X-ray Background
	DARTS	Data ARchive and Transmission System
	DEC	Declination
	DET	DETector (coordinates DETX and DETX)
	EEF	Encircled Energy Function
	FI	Front-Illuminated
	FITS	Flexible Image Transport System
	FFF	First FITS Files
	FOC	FOCal plane (coordinates FOCX and FOCY)
	FTOOLS	FITS Tools
	FW	Filter Wheel (on XRS)
	FWHM	Full-Width at Half-Maximum
	GHF	Gain History File
	GPT	Gain Parameter Table
	GHT	Gain History Table
	GIF	Graphics Interchange Format
	GO	Guest Observer

Chapter	Acronym	Definition
	GOF	Guest Observer Facility
	GRB	Gamma-Ray Burst
	GSFC	Goddard Space Flight Center
	GSO	Gadolinium Silicate
	GTI	Good Time Interval
	HEA	High Energy Astrophysics
	HEASARC	High Energy Astrophysics Science Archive Research Center
	HK	House Keeping
	HPD	Half-Power Diameter
	HTML	HyperText Markup Language
	HXD	Hard X-Ray Detector
	ISAS	Institute of Space and Astronautical Science
	JAXA	Japan Aerospace Exploration Agency
	NRA	NASA Research Announcement
	NASA	National Aeronautics and Space Administration
	NXB	Non X-ray Background
	OBF	Optical Blocking Filter
	OS	Operating System
	PDMP	Project Data Management Plan
	PHA	Pulse Height Amplitude
	PI	Principal Investigator
	PI	Pulse Invariant
	PIN	Positive Intrinsic Negative
	PMT	Photon Multiplier Tube
	QDE	Quantum Detection Efficiency
	RA	Right Ascension
	RDD	Residual Dark-current Distribution
	RMF	Redistribution Matrix File
	ROSAT	RÖntgen SATellite
	RPT	Raw Packet Telemetry
	RXTE	Rossi X–ray Timing Explorer
	SAA	South Atlantic Anomaly
	SAX	Satellite per Astronomia X
	S/C	Spacecraft
	SFF	Second FITS Files
	SIS	Solid-state Imaging Spectrometers
	SWG	Science Working Group
	TAI	Temps Atomique International
	TOO	Target Of Opportunity
	USC	Uchinoura Space Center
	UTC	Universal Time Coordinated

Chapter	Acronym	Definition
	WAM	Wideband All-sky Monitor
	WPU	Well Processing Unit
	XIS	X–Ray Imaging Spectrometer
	XMM	X–Ray Multi-Mirror Mission
	XRS	X–Ray Spectrometer
	XRT	X–Ray Telescope
	XRT-I	X–Ray Telescope for one of the four XIS detectors
	XRT-S	X–Ray Telescope for the XRS detector

Appendix B

Important Web/E-mail Addresses

Primary Suzaku Sites

Japan:
http://www.astro.isas.jaxa.jp/suzaku/
http://darts.isas.jaxa.jp/

US : http://suzaku.gsfc.nasa.gov/
ESA: http://www.rssd.esa.int/Astro-E2/

Questions:

The US GOF can be reached using the web form available at
http://suzaku.gsfc.nasa.gov/docs/suzaku/astroe_helpdesk.html

Tools:

Viewing	http://heasarc.gsfc.nasa.gov/Tools/Viewing.html
PIMMS	http://heasarc.gsfc.nasa.gov/docs/software/tools/pimms.html
MAKI	http://heasarc.gsfc.nasa.gov/Tools/maki/maki.html
XSPEC	http://heasarc.gsfc.nasa.gov/docs/xanadu/xspec/index.html
WebPIMMS	http://heasarc.gsfc.nasa.gov/Tools/w3pimms.html
WebSPEC	http://heasarc.gsfc.nasa.gov/webspec/webspec.html
XSelect	http://heasarc.gsfc.nasa.gov/docs/software/lheasoft/ftools/xselect/xselect.html