The Suzaku Data Reduction Guide

–also known as the ABC Guide–

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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://suzaku.gsfc.nasa.gov/docs/suzaku/prop_tools/suzaku_td`.

This is only meant to be a brief guide to *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. 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 and 5, we explain how to analyze data from the X–Ray Imaging Spectrometer (XIS) and Hard X–Ray Detector (HXD) and explain the issues linked to the background in both analysis. 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. A suite of new programs has been added to `HEAsoft` to support the *Suzaku* mission, collectively called the "*Suzaku* FTOOLS." 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. Users should have installed `HEAsoft` version 6.1.1 or later, including the *Suzaku* FTOOLS.

Suzaku data analysis will be supported on major Unix architectures, such as Linux, Solaris and OS X. `HEAsoft` runs on Windows in principle, but not yet as smoothly as on Unix. Therefore, *Suzaku* users are strongly suggested to use one of the supported Unix systems, listed on the `HEAsoft` website.

Suzaku FTOOLS will evolve rapidly in the early stages of the mission, hence a shorter release cycle will be required. In order to keep up with the rapid development cycle, we are planning to release the "*Suzaku* add-on" package on a shorter interval ($\sim$ months) than the complete `HEAsoft` . Users will be able to install the *Suzaku* FTOOLS on top of their current `HEAsoft`. All the software required to calibrate *Suzaku* data are written by the instrument teams and released as FTOOLS so that the latest calibration by the instrument teams are promptly made available to general *Suzaku* users. Also, *Suzaku* users are able to recalibrate their data using the FTOOLS when new calibration information is made available. Readers who are interested in how the *Suzaku* FTOOLS are developed and maintained can find more detailed explanations at the following page, as well as the complete *Suzaku* FTOOLS list at `http://suzaku.gsfc.nasa.gov/docs/suzaku/analysis/suzaku_ftools.html`.

2.1 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` actually extracts the 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.

2.2 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`.

2.3 Profit

Profit is a new 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 the web page, `http://heasarc.gsfc.nasa.gov/docs/software/profit/profit.html`, for download 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 set, 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

The standard *Suzaku* "pipeline processing" products (encrypted for proprietary data) are available from the GSFC HEASARC archive at `http://suzaku.gsfc.nasa.gov/docs/suzaku/aehp_archive.html` or using the BROWSE system at `http://heasarc.gsfc.nasa.gov/docs/archive.html`. Users can also access the data at the ISAS DARTS site (for Japanese and European-based observers). Standard data formatting and calibration are carried out in the pipeline processing, and all *Suzaku* users should start scientific data analysis from the pipeline processing products.

3.1.1 Retrieving the data

This section is relevant for US PIs only

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://suzaku.gsfc.nasa.gov/docs/suzaku/aehp_archive.html`.

There are two options available for the download: FTP and `wget`.
To retrieve the data via FTP type:

```
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
```

To retrieve the data via `wget`[1], type:

```
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.

Once retrieved, the data have 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`.

3.1.2 Organization of the data

All *Suzaku* data (including ground calibration and test data) have unique 9-digit observation 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[2]. 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 orbital data (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.

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

[2] In the early stage of the mission, some calibration files may be ASCII files but these will eventually be converted into FITS format.

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) 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 4 and 5 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:

`aeXXXXXXXXXiii_N_mmmmmmmm_ll.ext.gz`

where

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

XXXXXXXXX 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 can take the values: "evt" (event files), "gti" (good time interval), "hk" (house keeping), "ghf" (gain history file), "lc" (light curve), "pi" (pulse invariant), "hltm", "log", "com", "att" (attitude file), "cat", "ehk", "mkf", "orb", "tim","img", "gif".

For more informations on file names of the products of the pipeline processing, please refer to the documentation that can be found at `http://suzaku.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

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

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.[3]

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) 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

[3]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.

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 4095, should be used for GSO spectral analysis. The PI vs. energy relationship is the following: E [keV] =2×(PI_SLOW + 0.5). 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).

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. 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 4 s (1/2 Window), 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 Nominal time resolution is 61μs, which corresponds to the HXD_WPU_CLK_RATE_HK parameter = 1 (Fine). A higher time resolution, 30.5μs is possible by commands, in which case HXD_WPU_CLK_RATE will be 2 (Super-Fine), although this is not user-selectable at this time.

	5x5	3x3	2x2	Timing
Super-High	985	1971	3942	9381
High	475	949	1899	4528
Medium	221	441	883	2114
Low	29	58	116	292

Table 3.2: Telemetry limits (in events/s) in different XIS modes

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[4]. Basically, a combination of the following three telemetry rates will be used for observations; High rate (262 kbps), Medium rate (131 kbps), or Low rate (33 kbps)[5]. 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 will be dependent on the bitrates.

3.6.3 Telemetry Limits

XIS The approximate XIS telemetry limits (events/s for four XIS combined) for different bitrates and observational modes will be the following:

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.

[4]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 it is expected that usually 10 Gbits/day raw data will be taken.

[5]In addition, there is Super-High rate (524 kbps), which may not be allowed for general observations.

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

XSELECT behavior for each mission is determined by the mission database file, usually located at $FTOOLS/bin/xselect.mdb[6]. The *Suzaku* entries in the mission database files enable the following:

- Common for all the instruments
  - Default light curve bin is 16 sec
  - "extractor" is used to extract products
  - WMAP[7] 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*.*, ae*xis1*.*, ae*xis2*.*, ae*xis3*.*, or ae*hxd wel*.*
  - The filter file has the name ae*mkf*, and is in the directory ../auxil relative to the event file directories
- XIS
  - Default image binning is 8 (makes a 384×384 image)
  - Default WMAP binning is 4 (256×256 WMAP)
  - "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 "rbnpha" when saving a spectral file, and rebins by a factor of 2 to reduce the number of channels from 4096 to 2048 linearly
- HXD

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

[7] 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.

- "PI_PIN' is the default energy column to make energy spectra (thus a PIN spectrum is the default). Users need to "set phaname PI_SLOW" to extract the GSO spectrum.
- The UNITID event 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 DET_TYPE event column is used in lieu of DETY, so that the WMAP is created with UNITID vs. DET_TYPE, which will be useful when creating ARFs and RMFs
- No binning for image and WMAP
- Spawns "rbnpha" when saving a spectral file, and rebins by a factor of 4 to reduce the number of channels from 4096 to 1024. For PIN, the number of original channels is 256, so users should answer "no" to this option when saving PIN spectra. The GSO response will be made with 1024 channels.

[8] For each HXD event, UNITID and DET_TYPE tells the Well unit-ID and the detector type. UNITID takes a value in the range of 0 to 15 corresponding to the 16 Well units. DET_TYPE = 0 corresponds to GSO, and 1 to 4 correspond to PIN0 to 3 respectively.

Chapter 4

XIS Data Analysis

4.1 Introduction

The XIS consists of four CCD detectors, three of which are "front-illuminated" (FI) and one "back-illuminated" (BI). The BI chip was a late addition to the XIS which increases the effective area of the entire system substantially at low ($< 1\,\mathrm{keV}$) energies with only a small decrease at higher energies. Although the detectors have seen significant improvements since the ASCA SIS, the data reduction is expected to be quite similar to that of ASCA SIS and Chandra ACIS.

Note to users: Some of the information below can be found at `http://suzaku.gsfc.nasa.gov/docs/suzaku/aehp_proc.html` or `http://www.astro.isas.jaxa.jp/suzaku/process`. Users are encouraged to contact us via the comment webpage at `http://heasarc.gsfc.nasa.gov/cgi-bin/Feedback`. Before attempting any analysis of XIS data, please check the *Suzaku* data analysis website (`http://suzaku.gsfc.nasa.gov/docs/suzaku/aehp_data_analysis.html`) for updates.

4.2 Current Issues with the XIS and XIS analysis

4.2.1 Contamination

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 shows that the contamination is increasing at a different rate for each sensor, from less than 0.3 to 0.9 mg cm^{-2} day^{-1} leading to an equivalent additional column density of C of 6×10^{18} cm^{-2} (as of April 2006; see Figure 4.1). There is some indication that the rate of accumulation has recently stopped increasing. 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. Recent studies suggest that the contaminant is DEHP ($C_{24}H_{38}O_4$, or C/O = 6 by number) although the XIS team is still investigating the material's exact composition.

The XIS design allows the CCDs to be warmed to room temperature by reversing the current in the thermoelectric coolers. Independently, the OBF temperatures can be raised by activating heaters on the heatpipes that cool the sensor housings in which the filters are mounted. Either or both may help to reduce or reverse the contamination.

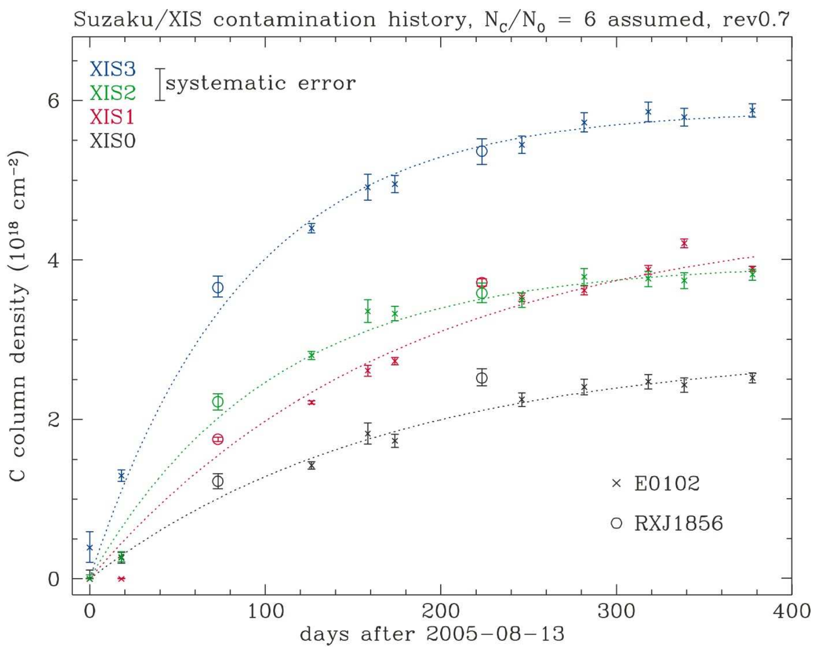

Figure 4.1: An empirical model for the on-axis contamination evolution, assuming DEHP (C24H38O4, or C/O = 6 by number) as contaminant. Crosses and open circles indicate the C column density of the contaminant derived from the E0102−72 and RXJ 1856 observations, respectively. Dotted lines indicate the best fit empirical model to the time evolution of the contamination for each sensor.

The newly released ARF generator simulation routine `xissimarfgen` contains the current information to take into account the contamination. `xissimarfgen` does have the broken line (as shown in the figure above) approximation of contamination built-in. Note, however, that the current calibration is probably inaccurate for more recent data (later than June 2006).

4.2.2 Imaging analysis

The software to produce exposure maps is not yet available

4.2.3 Timing modes

Currently timing mode data are not processed (nor distributed) and fine timing assignment (< 8 s) is not done when window/burst options are used.

The software to apply barycentric corrections is not yet available

4.3 Initial Processing

XIS data begins as part of the RPT telemetry downloaded from *Suzaku*, and is 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 (SFF), 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, lightcurves, and images, which are found in the directories "xis/event_cl" and "products". As the mission progresses, it is expected that these outputs will be the primary data for users. However, during the early stages of the mission we expect that the calibration applied by `mk2ndfits` will change frequently. The user should check the date of `mk2ndfits`, which is listed in the event file in the FITS keyword DATE. This can be compared again the list of calibration updates, found at `http://suzaku.gsfc.nasa.gov/docs/suzaku/aehp_proc.html`. If any substantial changes have occurred, the data should be reprocessed as needed, as described below. Users may want to create a new directory and run all the tasks from that new directory.

4.3.1 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 be either read from the header of the input event file or set manually.

Typically, users should not run this as it has been already run on the SFF file distributed in the event_uf directory. However, some user may want to rerun the command. In this case the command is:

```
xiscoord infile=filename_uf.evt.gz attitude=DEFAULT pointing=KEY \
outfile=xiscoord_outfile.fits
```

where
`infile` is the XIS event fits file name.
`attitude` indicates where to get the attitude information
`pointing` indicates where to read the RA and Dec – a pointing set to KEY reads them from the header of the input event file
`outfile` is the name of the output file created – see caveat below
Users should be aware of the following points: 1) For each XIS, the script requires a teldef file which is input by the option "xis0_teldef=". If this option is omitted from the command line, the file needs to be visible from the directory in which the task is run (soft links are OK).
2) 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.
3) We have found that `xiscoord` does not produce output files on several unsupported plateforms (Mandrake 10,..). Users are advised to check the supported plateforms (see `http://heasarc.gsfc.nasa.gov/docs/software/lheasoft`) and run only on a supported platform.

4.3.2 Put Pixel Quality

`xisputpixelquality` runs on the output of `xiscoord`

In this case the command is:

```
xisputpixelquality infile=xiscoord_outfile.fits  badcolumn_file=CALDB_badcolum_file.fits \
calmask_file=CALDB_calmask_file.fits  outfile=xisputpixelquality_outfile.fits
```

where
`infile` is the XIS event fits file name (output from `xiscoord`)
`badcolumn_file` is the badcolumn file from CALDB
`calmask_file` is the calmask file from CALDB
`outfile` is the name of the output file created

Users may want to examine the differences (if any) between the input and the output files of `xisputpixelquality`.

4.3.3 Computing the PI for XIS events

As its name indicates, the `xispi` routine calculates the XIS PI and grades values from the PHAs. 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 which is the latest "makepi" file to be used. The command to run `xispi` is:

```
xispi infile=xisputpixelquality_outfile.fits
trcor_caldbfile=ae_xi[0-3]_makepi_YYYYMMDD.fits \
cticor_caldbfile=ae_xi[0-3]_makepi_YYYYMMDD.fits \
grade_caldbfile=ae_xi[0-3]_makepi_YYYYMMDD.fits \
pha2pi_caldbfile=ae_xi[0-3]_makepi_YYYYMMDD.fits \
pha2pi_hkfile=HKFILE.fits outfile=xispi_outfile.fits
```

where
`infile` is the XIS event fits file name.
`trcor_caldbfile` is the CALDB file for charge trail parameters
`cticor_caldbfile` is the CALDB file for Input file for CTI parameters
`grade_caldbfile` is the CALDB file for the spth parameter (not used by default)
`pha2pi_caldbfile` is the CALDB file for the gain parameters
`pha2pi_hkfile` is the House Keeping file located in the `xis/hk` directory. This is not the hk file from the `auxil` directory
`outfile` is the output file name.

4.4 User specific processing

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`. We explain the steps below.

4.4.1 Bad pixel filtering

The cleaning of hot and flickering pixels is done in `cleansis` and 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* : 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 from the command line cleansis chipcol=SEGMENT, give the input and output filenames and use the default values of the remaining parameters.

4.4.2 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 will assume GRADE 0,2,3,4, and 6. You may select only events with these grades (within the `xselect` task):
`select event ‘‘GRADE==0||GRADE==2||GRADE==3||GRADE==4||GRADE==6’’` or equivalently `filter grade‘‘0,2-4,6"`

4.5 Extracting Data within `xselect`

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. Some basic parameters to be used for common data screening are in the filter file. The "select mkf" command is used to screen the output of the badpixel filtering and grade selections. The *Suzaku* instrument teams recommend the following cuts be applied within `xselect`.

```
select mkf  "SAA==0  && T_SAA> 436 && COR > 6 && ELV> 10 && 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` on read events.
2) `select mkf` command creates a time filter of good times. To actually filter the events, users must then issue the command "`extract events`"

Satellites, such as *Suzaku* launched into low-Earth orbit pass through the South Atlantic Anomaly (SAA). During a passage, the high particle flux makes the instruments unusable. The `mkf` keyword SAA is set to 0 when the satellite is **not** in the SAA and so the selection condition is SAA==0. Even when the satellite emerges from the SAA, the background is still high, the `mkf` keyword T_SAA indicates the amount of time since an SAA passage. For the XIS, T_SAA 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>436 imposed on the XIS data. In addition to the SAA, there are still regions of high particle background where the geomagnetic rigidity is low. Data taken in regions of low rigidity (less than 6) should be discarded. We encourage the user to explore the effect of slightly different boundaries on their data.

The two last cuts are recommended by the instrument teams to reduce the contamination from the Earth's atmosphere. The first is applied to the elevation angle, `mkf` keyword ELV, the angle between the target and the Earth's limb. Only data with an elevation angle larger than 10 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.
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.

4.5.1 Region Selection

Sky regions

It often happens that users want to extract light curves or energy spectra from some specific regions on the sky. Such region selection can be done on the "SKY" image displayed by ds9/saoimage; select a region and create a region file to use for the xselect "filter region" command. Region files should be created in `ds9` using the `ds9/funtools` format and equatorial J2000 coordinate system. 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 may be selected using Detector coordinates. Use `set image det` command 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 on particular chip positions (such as extracting the calibration source spectra). `set image raw` followed by `extract image` will extract XIS ACT images. XIS performance will be 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 value 0, 1, 2, 3 and 4 respectively.

4.6 Generating RMF and ARF files

The first thing to do before running either `xisrmfgen` or `xissimarfgen` is to ensure that your `CALDB` variable is set properly because some of the hidden parameters of the task use the `CALDB` setup (users can issue the command `plist xisrmfgen` or `plist xissimarfgen` to see all the hidden parameters used by the tasks).

4.6.1 Generating RMF files using `xisrmfgen`

The newest version of the `HEASoft` package includes the RMF generator `xisrmfgen`. The program is relatively straightforward to use and we have included below an example.

```
> xisrmfgen
xisrmfgen version 2006-11-26
Name of input PI or IMAGE file or NONE[xis0-5b5w.pi] NONE
Name of output RMF[xis0-5b5w.rmf]
Instrument Name (XIS0,XIS1,XIS2,XIS3)[XIS0]
CCD clock mode (normal,psum)[normal]
Date of observation (yyyy-mm-ddThh:mm:ss.sss or Suzaku time)[2006-01-19T05:07:57.503289]
```

or

```
> 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]
```

If there is a PI file specified, the information concerning the instrument, clock mode and the date of observation is extracted directly from the header of the PI file given.

4.6.2 Extracting a calibrated spectrum

The XIS and XRT instrument teams have released their updated version of the `xissimarfgen` tool. The tool takes into account the contamination problem but at the time of this writing does not account for the attitude correction. You will find below hints and pointers on how to run the task. A description of the task is posted at `http://suzaku.gsfc.nasa.gov/docs/suzaku/analysis/xissimarfgen`.

The task can then be run by simply typing `xissimarfgen` and providing the input information requested by the program. A simple run input would look like:

```
> xissimarfgen
```

```
xissimarfgen version 2006-11-26
Written by Y.ISHISAKI (TMU)
Instrument Name (XIS0,XIS1,XIS2,XIS3)[XIS0]
source mode (SKYFITS,DETFITS,J2000,SKYXY,DETXY,UNIFORM)[J2000]
source position R.A. (deg)[16.027162]
source position DEC. (deg)[-72.025293]
number of ARF regions[1]
region mode (SKYFITS,DETFITS,SKYREG,DETREG,etc)[DETREG]
region file #1[./src-det.reg]
output arf file #1[src.arf]
limit mode (ACCURACY,NUM_PHOTON)[MIXED]
number of photons for each energy bin[100000]
calculation accuracy for each energy bin[0.005]
input pha file[src.pha]
XIS det-coordinates mask image file[ae_xi0_calmask_20051105.fits] none
input GTI file[e0102_init.fits]
input attitude file[ae100014010.att]
input rmf file[ae_xi0_20060213.rmf]
energy step file[estep-default.list] estep-test.list
```

Please note several potential pitfalls:

1) The program crashes if the image inputs have been rebinned. The input image should be 1536x1536 for region_mode=SKYFITS, while it must be 1024x1024 for region_mode=DETFITS.
2) Users should specify the `REGION MODE` using preferentially the "region file" option. If one **must** use the `DETFITS` option, please note that the normalization is computed using only the non-zero pixels. One consequence is that the input image should **not** be the image defined by your source region, but a **mask** of that same region ie a file with **only** 1's for the pixels in the region selected and 0's outside.
3) The number of ARF regions is an option that allow you to compute up to 200 **different** ARF files running only once. If you specify "N" ARF regions, the program will ask you for N region modes, N region files and N output ARF file names. Please note that your parameter file keeps the highest number of regions in memory (along with the list of the region modes, names, and the ARF output names) so if you want to avoid generating a very long parameter file, you should run the code several times instead of using that option.
4) The CALDB option does **not** work for the mask image and the RMF input files. Users should input the file names by hand. The rmf input file could the CALDB file or the one generated by the `xisrmfgen` code.
5) The options `phafile` and `attitude` parameters are not supported in the current version (ver. 2006-11-26) and should be set to "none".
6) The estep-default.list is an ascii file that contains the calculation steps, specified to take

into account the different edges.

```
cat estep-default.list
# Emin Emax Ebin
0.2     16.00 0.01
2.101 2.399 0.002
2.501 2.799 0.002
3.101 3.299 0.002
11.801 11.999 0.002
13.601 13.799 0.002
14.201 14.499 0.002
```

Please note that generating an ARF using this energy list can be quite long. If you are just experimenting and want to have a quicker run **not valid for spectral analysis**, you can use another file (with a coarser grid) as given by:

```
cat estep-test.list
# Emin Emax Ebin
0.0 0.5 0.1
0.0 8.0 0.5
8.0 12.0 0.5
12.0 17.0 1.0
```

7) The current version of `xissimarfgen` (ver. 2006-11-26) does not understand region files generated using version 4 of `ds9`.
8) For general information on `xissimarfgen` users can access `http://suzaku.gsfc.nasa.gov/docs/suzaku/analysis/xissimarfgen/`.

Chapter 5

HXD Data Analysis

5.1 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. Please check the *Suzaku* HXD data analysis website at `http://suzaku.gsfc.nasa.gov/docs/suzaku/aehp_data_analysis.html` for updates, before attempting any analysis of HXD data.

The HXD is significantly different from the XIS. First, it does not have any imaging capability, although it does have a collimator which makes it act as a "light bucket." Second, it has two independent detector systems. These are the GSO/BGO phoswich counters and the PIN silicon diodes. The PIN diodes are sensitive below $\sim 60\,\mathrm{keV}$, while the GSO/BGO phoswich counters detect photons above $\sim 30\,\mathrm{keV}$. The energy resolution of the PIN diodes is $\sim 3.0\,\mathrm{keV}$, 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 a composed of 16 main detectors (well units) arranged as a 4×4 array (see top view in Figure 5.1) and 20 surrounding crystal scintillators for active shielding.

Each unit actually consists of two types of detectors: Four GSO/BGO phoswich counters, and four 2 mm-thick PIN silicon diodes located inside the well, but in front of the GSO scintillator. One can see the configuration of the sensor units in Figure 5.2.

This means that the data ("well" data) do not initially differentiate between PIN and GSO. The distinction is made later on in the pipeline. This also means that the well units can be distinguished (this is done using the keyword `UNITID`, which ranges from 0 to 15) and analyzed separately to generate a rough *image* even if the HXD does

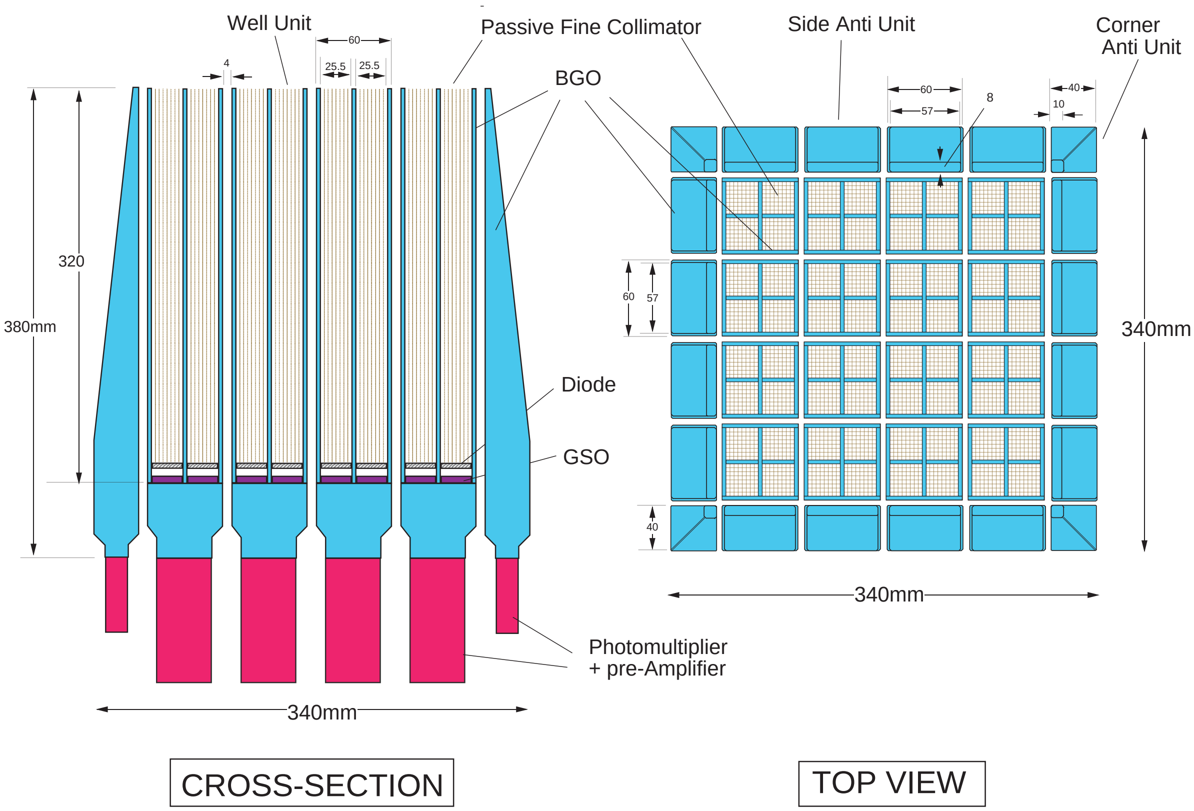

Figure 5.1: Schematic picture of the HXD instrument, which consists of two types of detectors: the PIN diodes located in the front of the GSO scintillator, and the scintillator itself.

not have imaging capabilities. For more information about the HXD detector, please see the *Suzaku* Technical Description at `http://suzaku.gsfc.nasa.gov/docs/suzaku/prop_tools/suzaku_td`.

5.2 Current Issues with HXD analysis

5.2.1 Background – I

The HXD background estimator is currently being tested by the instrument teams. At present the PIN background subtraction is accurate at the 5% level whereas the GSO background still has large uncertainties and GSO data should not yet be used for scientific purposes. Users should be aware of the fact that cosmic X-ray background is not included in the background models used by the HXD instrument team.

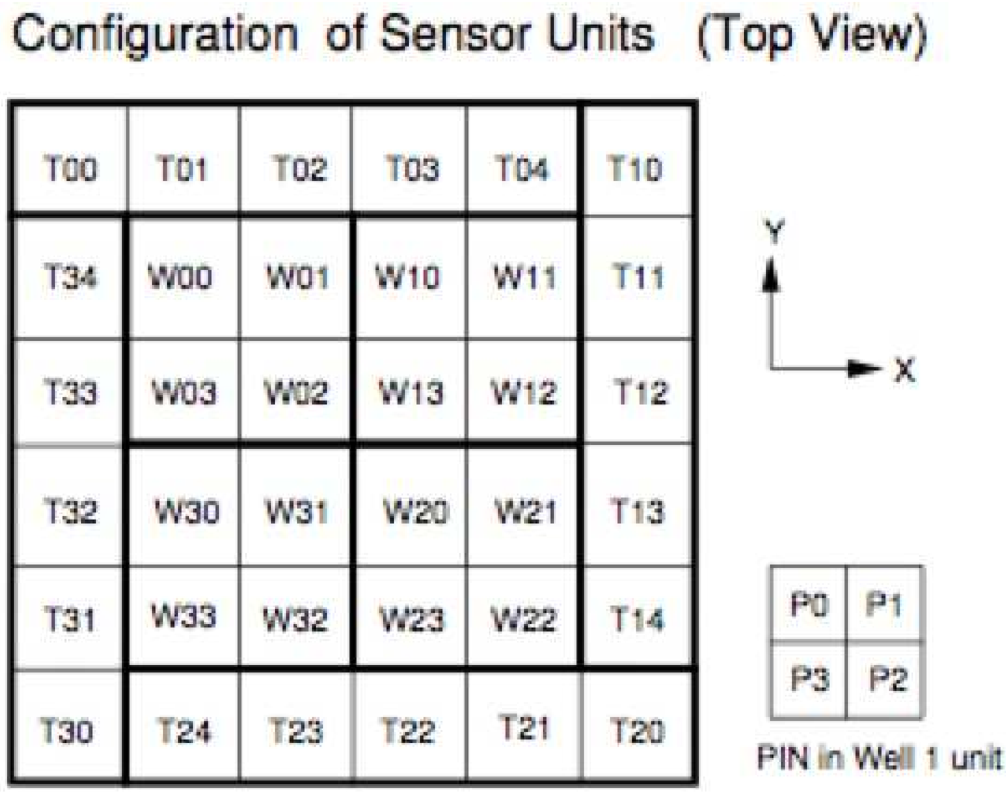

Figure 5.2: Numbering of the Well and Anti-counter units.

5.2.2 Background – II

Starting May 24, 2006, the HXD team has had to reduce the bias voltage from 500 V to 400 V on 16 of the 64 PIN units. This change has affected the energy response of these 16 PIN diodes , specially at high energy (above 15 keV). This effect is not yet implemented in the current PIN response matrices (version from 20060814) and the HXD team recommend to treat separately the diodes affected and those which aren't (i.e not to use the "standard" PIN analysis which treats all the diodes the same). We give in the guide below a way to separate between the two categories of diodes. For more information, please access `http://www.astro.isas.jaxa.jp/suzaku/analysis/hxd/hxdnxb`.

5.2.3 Energy range

The current response matrix cannot reproduce the Crab spectrum below 12 keV. The instrument team has been studying the energy scale of individual PIN diodes, in parallel with fine-tuning the response matrix but this study of the response is still ongoing.

5.2.4 Gain History File for the GSO

For data processed **before** February 2007, we recommend to reprocess your data following the recipe below as the Gain History File for the GSO used in the pipeline could be incorrect. We have shown in Figure 5.3), the potential difference in the GSO spectra derived using two different GSO Gain History Files. The black curve is wrong (note the extension of the energy range for the GSO) and could trigger bad scientific results.

5.3 Initial Processing

HXD data begins as part of the RPT telemetry downloaded from *Suzaku*, and is immediately 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. These files are included in the standard data download in the directory "hxd/event_uf".

The HXD `mk2ndfits` pipeline is then run on the `mk1stfits` output to create filtered, calibrated output event files, lightcurves, and images, which are found in the directories "hxd/event_cl" and "products". As the mission progresses, it is expected that this output will be the primary data for users. However, during the early stages of the mission the calibration applied by `mk2ndfits` may change rapidly. The user should check the date of `mk2ndfits`, which is listed in the event file in the FITS keyword DATE. This can be compared against the list of calibration updates, found at `http://suzaku.gsfc.nasa.gov/docs/suzaku/aehp_proc.html`. If any substantial changes have occurred, the data should be reprocessed as needed, as described below.

5.4 Processing description

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 have described the processing steps (in the recommended order) below. We will describe first the processing for the PIN and GSO, and address later the processing for the WAM. **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 just overwrite the existing files. To do so please type:

```
unix% mkdir event_cl2/; cd event_cl2/
```

```
unix% ln -s ../event_uf/aeNNNhxd_M_wel_uf.evt.gz .
unix% ln -s ../hk/aeNNNhxd_0.hk.gz .
unix% ln -s ../../auxil/aeNNN.tim.gz .
```

Also please make sure that your CALDB directory is set-up properly. CALDB files are needed for the processing.

5.4.1 Time Assignment

The first step is to calculate the HXD event arrival-time correction. The arrival time of each true event time (in column 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 to type:

```
hxdtime input_name=aeNNNhxd_M_wel_uf.evt create_name=aeNNNhxd_M_wel_uf2.evt \
leapsec_name=leapsec.fits hklist_name=aeNNNhxd_0.hk tim_filename=aeNNN.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 a file is simply known as leapsec.fits, whose contents depends on the version of HEAsoft; in the versions released after v6.1.1, it is identical to the 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 in principle)
grade_change=n (change GRADE_XX or not, no update in principle)
pi_pmt_change=n (change PI_SLOW, PI_FAST or not, no update in principle)
pi_pin_change=n (change PI_PIN or not, no update in principle)
gtimode=y (read and apply GTI extension or not)
gti_time=S_TIME (meaning of TIME in GTI, row level information)
time_convert_mode=4 (aste_ti2time function is used in calculation)
use_pwh_mode=n (use HXD_WEL_PWH extension in HXD HK FITS or not; always no)
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 or not)

5.4.2 Gain History Generation

After filling in the corrected event time, the next step is to adjust the detector gain for both HXD detectors. This is done by fitting a calibration line present in the detector as a function of time. In the case of the GSO, an intrinsic Gd line is used by the routine `hxdmkgainhist_gso`. For the PIN diodes, the gain drift is not yet known, so the gain history routine called `hxdmkgainhist_pin` is simply a placeholder until better calibration can be done. Once both tasks have been run, the task `hxdmkgainhist` converts **BOTH** ASCII output files into the final FITS files (one for each PIN and GSO detectors).

When and why run the `hxdmkgainhist`, `hxdmkgainhist_gso` and `hxdmkgainhist_pin` tasks?

In the processing, Gain History Files (FITS files) are used as input for the `hxdpi` task (see next section). The `hxdpi` needs **BOTH** Gain History Files (for the PIN and the GSO). Both Gain History files (PIN and GSO) computed with the method described below are delivered to the user in the `hxd/hk` directory as part of the standard processing. However, starting with processing v1.3 (Feb 2007), the instrument team recommends using the **CALDB GSO gain history file** (instead of the one generated by the tasks `hxdmkgainhist_gso` and `hxdmkgainhist`) if that CALDB file covers the observation date. The PIN gain history file used by `hxdpi` is the one generated by the task `hxdmkgainhist`.

The important point arises from the fact that `hxdmkgainhist` needs the input for **BOTH** `hxdmkgainhist_gso` and `hxdmkgainhist_pin` to run. This means that even though the Gain History CALDB file is used for the GSO for most of the cases (see exceptions below), users reprocessing their data need to run **BOTH** `hxdmkgainhist_gso` and `hxdmkgainhist_pin` before running `hxdmkgainhist`.

If the users are reprocessing their data entirely, it will mean, deriving the Gain History Files for the GSO and the PIN using the method described below (and the tasks `hxdmkgainhist_gso`, `hxdmkgainhist_pin` and `hxdmkgainhist`) even if they may **not** have to use the GSO Gain history file.

Note Users *can* skip this step and use in the task `hxdpi` the PIN Gain history file provided under the `hxd/hk` directory and either the CALDB GSO Gain History file or the file provided under the `hxd/hk` directory depending on whether or not the observation is not covered by the CALDB GSO Gain history file. We recommend **not** to and generate the gain history files according to the steps below and compare with the provided files.

GSO Gain History File

The `hxdmkgainhist_gso` routine calculates the time variation of the PMT gain for both SLOW_PHA and FAST_PHA data by fitting the intrinsic Gd line peak appearing in the background energy spectra. The tool makes GTIs for each Well unit using the high voltage value of the PMTs, "HXD_HV_Wn_CAL" (where n=0,1,2,3) in HK FITS, and then separates these into several epochs with period set by the `exposure` parameter. The fit process is performed using XSPEC for SLOW_PHA and FAST_PHA, and summarized in the output fitlog file *gs_fitlog_name*.

```
hxdmkgainhist_gso input_name=aeNNNhxd_M_wel_uf2.evt \
    hk_name=aeNNNhxd_0.hk gso_gd_fitlog_name=aeNNNhxd_gso_gd_ghf.tbl \
    gso_511_fitlog_name=aeNNNhxd_gso_511_ghf.tbl \
    gso_152gd_fitlog_name=aeNNNhxd_gso_152gd_ghf.tbl process_id=aeNNN \
    exposure=1000000 \
```

where
`input_name` is the HXD_WEL_FITS file input name
`hk_name` is the HXD_HK_FITS file list name
`gso_fitlog_name` is the name of the GSO fit log (ASCII output) – input of `hxdmkgainhist`
`gso_511_fitlog_name` is the HXD GSO 511 keV fitlog file name (output file) – input of `hxdmkgainhist`
`gso_152gd_fitlog_name` is the HXD GSO 152 Gd fitlog file name (output file) – input of `hxdmkgainhist`
`process_id` is the identifier for the observation
`exposure` in s - the program attempts to determine the gain every N s of exposure.

It is recommended that, for this usage, the `exposure` keyword be set high enough that only one gain history record per output file is written. Even so, `hxdmkgainhist_gso` can take a very long time to run (about 2 hours on a 1.5 GHz PowerPC G4 with 1.25 GB of RAM running Max OS 10.4)

Warning 1 If PGPLOT_TYPE is set to /xw it will (via `xspec`) generate plots on the user's computer screen and will leave 260 or so temporary files in a directory called aeNNN_hxdmkgainhist_tmp. Users should issue the command

```
setenv PGPLOT_TYPE /NULL
```

before running `hxdmkgainhist_gso`.

An output from such routine would look like:

```
hakatan-10-event_cl2: setenv PGPLOT_TYPE /NULL
hakatan-11-event_cl2: hxdmkgainhist_gso input_name=ae401100010hxd_1_wel_uf2.evt  \
hk_name=ae401100010hxd_0.hk gso_gd_fitlog_name=ae401100010hxd_gso_gd_ghf.tbl \
gso_152gd_fitlog_name=ae401100010hxd_gso_152gd_ghf.tbl \
gso_511_fitlog_name=ae401100010hxd_gso_511_ghf.tbl process_id=ae401100010 \
exposure=10000000

FFF = ae401100010hxd_1_wel_uf2.evt, HK = ae401100010hxd_0.hk
rm -rf ae401100010_hxdmkgainhist_tmp; mkdir ae401100010_hxdmkgainhist_tmp
maketime infile="ae401100010hxd_0.hk+1" outfile="ae401100010_hxdmkgainhist_tmp/total.gti"
expr="(HXD_HV_W0_CAL >= 700.0) && (HXD_HV_W1_CAL >= 700.0) && (HXD_HV_W2_CAL >=
700.0) && (HXD_HV_W3_CAL >= 700.0)" name=anything value=anything time=TIME compact=no
prefr=0.5 postfr=0.5
original GTI = ae401100010_hxdmkgainhist_tmp/total.gti
fdump infile="ae401100010_hxdmkgainhist_tmp/total.gti"
outfile="ae401100010_hxdmkgainhist_tmp/fdump.log" columns='START,STOP' rows=- prhead=no
pagewidth=100 showrow=no
fdump log = ae401100010_hxdmkgainhist_tmp/fdump.log
GTI LIST = ae401100010_hxdmkgainhist_tmp/gtilist
Exposure = 10000000

Making Non-selection fits file now.
fselect infile="ae401100010hxd_1_wel_uf2.evt" outfile="ae401100010_hxdmkgainhist_tmp/
tmp_ae401100010_0.fff" expr="(UNITID=="0")&&(TRIG==b0100000)&&(QUALITY_FLAGS==bxxxxxx1)"
```

(same output for the 15 others UNITID)

```
Making Hit Pattern 8 fits file now.
fselect infile="ae401100010hxd_1_wel_uf2.evt" outfile="ae401100010_hxdmkgainhist_tmp/
tmp_ae401100010_0_hitpat8.fff" expr="(UNITID==0) && (TRIG==b0100000) &&
(QUALITY_FLAGS==bxxxxxx1) && (((HIT_PATTERN_WELL & b0111000000000000) ==
(b0000000000000000)) && ((HIT_PATTERN_ANTI & b11100000000000000011) ==
(b00000000000000000000)))"
```

(same output for the 15 others UNITID) – This part is the longest to run

```
EVENT SELECTION
genrsp inrfil="none" rmffil="ae401100010_hxdmkgainhist_tmp/ae401100010dmy.rsp"
resol_reln="constant" resol_file="none" fwhm=0 disperse=no tlscpe="SUZAKU" instrm="HXD"
resp_reln="linear" resp_file="none" resp_low=-0.5 resp_high=255.5 resp_number=256
resp_break=-1.0 resp_bnumber=0 chan_reln="linear" chan_low=-0.5 chan_high=255.5
chan_number=256 chan_break=-1.0 chan_bnumber=0 efffil="none" detfil="none" filfil="none"
```

```
max_elements=100000 rsp_min=1.e-6 clobber=yes mode=ql
GENRSP vers 2.01  07/12/06.


...    256 channels in spectrum
...    256 energies in response
       100         1   9.90000E+01   9.90000E+01   0.00000E+00   1.00000E+00
       200         1   1.99000E+02   1.99000E+02   0.00000E+00   1.00000E+00
extractor filename="ae401100010_hxdmkgainhist_tmp/tmp_ae401100010_0.fff" eventsout="NONE"
imgfile="NONE" fitsbinlc="NONE" regionfile="NONE" phafile="ae401100010_hxdmkgainhist_tmp/
ae401100010_gso_w00_gti_0_slow.pha" timefile="ae401100010_hxdmkgainhist_tmp/
ae401100010_gti_0.gti" gtinam="GTI" tcol="TIME" ecol="PHA_SLOW" xcolh="UNITID"
ycolh="DET_TYPE" xcolf="UNITID" ycolf="UNITID"
extractor v4.71     22 Nov 2006
 No image X-axis TCRPX, set to 0
 No image Y-axis TCRPX, set to 0
 No image X-axis TCRVL, set to 0
 No image Y-axis TCRVL, set to 0
 No image X-axis TCDLT, set to 1
 No image Y-axis TCDLT, set to 1
 No wmap X-axis TCRPX, set to 0
 No wmap Y-axis TCRPX, set to 0
 No wmap X-axis TCRVL, set to 0
 No wmap Y-axis TCRVL, set to 0
 No wmap X-axis TCDLT, set to 1
 No wmap Y-axis TCDLT, set to 1
 Doing file: ae401100010_hxdmkgainhist_tmp/tmp_ae401100010_0.fff
100% completed
         Total      Good    Bad: Region      Time     Phase     Grade     Cut
        570784    570082              0       702         0         0         0
===============================================================================
   Grand Total      Good   Bad:  Region      Time     Phase     Grade    Cut
        570784    570082              0       702         0         0         0
   in 1.25152E+05 seconds
 Spectrum         has   570082 counts for  4.555     counts/sec
 ... written the PHA data Extension
extractor filename="ae401100010_hxdmkgainhist_tmp/tmp_ae401100010_0.fff" eventsout="NONE"
imgfile="NONE" fitsbinlc="NONE" regionfile="NONE" phafile="ae401100010_hxdmkgainhist_tmp/
ae401100010_gso_w00_gti_0_fast.pha" timefile="ae401100010_hxdmkgainhist_tmp/
ae401100010_gti_0.gti" gtinam="GTI" tcol="TIME" ecol="PHA_FAST" xcolh="UNITID"
ycolh="DET_TYPE" xcolf="UNITID" ycolf="UNITID"
extractor v4.71     22 Nov 2006
```

```
 No image X-axis TCRPX, set to 0
 No image Y-axis TCRPX, set to 0
 No image X-axis TCRVL, set to 0
 No image Y-axis TCRVL, set to 0
 No image X-axis TCDLT, set to 1
 No image Y-axis TCDLT, set to 1
 No wmap X-axis TCRPX, set to 0
 No wmap Y-axis TCRPX, set to 0
 No wmap X-axis TCRVL, set to 0
 No wmap Y-axis TCRVL, set to 0
 No wmap X-axis TCDLT, set to 1
 No wmap Y-axis TCDLT, set to 1
 Doing file: ae401100010_hxdmkgainhist_tmp/tmp_ae401100010_0.fff
extractor filename="ae401100010_hxdmkgainhist_tmp/tmp_ae401100010_0_hitpat8.fff"
eventsout="NONE" imgfile="NONE" fitsbinlc="NONE" regionfile="NONE"
phafile="ae401100010_hxdmkgainhist_tmp/ae401100010_gso_w00_gti_0_hitpat8_slow.pha"
timefile="ae401100010_hxdmkgainhist_tmp/ae401100010_gti_0.gti" gtinam="GTI" tcol="TIME"
ecol="PHA_SLOW" xcolh="UNITID" ycolh="DET_TYPE" xcolf="UNITID" ycolf="UNITID"
extractor v4.71     22 Nov 2006
 No image X-axis TCRPX, set to 0
 No image Y-axis TCRPX, set to 0
 No image X-axis TCRVL, set to 0
 No image Y-axis TCRVL, set to 0
 No image X-axis TCDLT, set to 1
 No image Y-axis TCDLT, set to 1
 No wmap X-axis TCRPX, set to 0
 No wmap Y-axis TCRPX, set to 0
 No wmap X-axis TCRVL, set to 0
 No wmap Y-axis TCRVL, set to 0
 No wmap X-axis TCDLT, set to 1
 No wmap Y-axis TCDLT, set to 1
 Doing file: ae401100010_hxdmkgainhist_tmp/tmp_ae401100010_0_hitpat8.fff
100% completed
          Total      Good    Bad: Region      Time     Phase     Grade     Cut
         231018    230715             0       303         0         0         0
===============================================================================
   Grand Total      Good   Bad:  Region      Time     Phase     Grade    Cut
        231018    230715             0       303         0         0         0
   in 1.25152E+05 seconds
 Spectrum         has   230715 counts for  1.843     counts/sec
 ... written the PHA data Extension
extractor filename="ae401100010_hxdmkgainhist_tmp/tmp_ae401100010_0_hitpat8.fff"
```

```
eventsout="NONE" imgfile="NONE" fitsbinlc="NONE" regionfile="NONE"
phafile="ae401100010_hxdmkgainhist_tmp/ae401100010_gso_w00_gti_0_hitpat8_fast.pha"
timefile="ae401100010_hxdmkgainhist_tmp/ae401100010_gti_0.gti" gtinam="GTI" tcol="TIME"
ecol="PHA_FAST" xcolh="UNITID" ycolh="DET_TYPE" xcolf="UNITID" ycolf="UNITID"
extractor v4.71     22 Nov 2006
 No image X-axis TCRPX, set to 0
 No image Y-axis TCRPX, set to 0
 No image X-axis TCRVL, set to 0
 No image Y-axis TCRVL, set to 0
 No image X-axis TCDLT, set to 1
 No image Y-axis TCDLT, set to 1
 No wmap X-axis TCRPX, set to 0
 No wmap Y-axis TCRPX, set to 0
 No wmap X-axis TCRVL, set to 0
 No wmap Y-axis TCRVL, set to 0
 No wmap X-axis TCDLT, set to 1
 No wmap Y-axis TCDLT, set to 1
```

Same for the other 15 UNITID. Then the code calls up `XPSEC` and fit the gaussian for the Gd line. The output is saved in the different log files.

PIN Gain History File

The `hxdmkgainhist_pin` routine calculates the gain history for the HXD WELL_PIN. As noted above, for the moment the routine simply creates an appropriately formatted output `pin_fitlog_name` file. Once the detector is better understood, this routine will be updated. The task needs to be run in order to create the input file necessary to run the `hxdmkgainhist` task.

```
hxdmkgainhist_pin input_name=aeNNNhxd_M_wel_uf2.evt\
hk_name=aeNNN\_hxd.hk pin_fitlog_name=aeNNN_pin_ghf.tbl process_id=aeNNN
```

where
`input_name` is the HXD WEL FITS file input name
`hk_name` is the HXD HK FITS file list name
`pin_fitlog_name` is the name of the PIN fit log (ASCII output) – input of `hxdmkgainhist`
`process_id` is the identifier for the observation

Because the task is essentially a space-holder, the output reads like:

```
hakatan-13-event_cl2: hxdmkgainhist_pin input_name=ae401100010hxd_1_wel_uf2.evt
```

```
hk_name=ae401100010hxd_0.hk.gz pin_fitlog_name=ae401100010hxd_pin_ghf.tbl
process_id=401100010

FFF= ae401100010hxd_1_wel_uf2.evt, HK= ae401100010hxd_0.hk.gz
TSTART 1.987591033276449E+08, TSOP 1.989102553064591E+08
hakatan-14-event_cl2:
```

Gain History Files

Once the gain drift for the two detector subsystems has been calculated, the `hxdmkgainhist` routine converts the output fitlog files created by the `hxdmkgainhist_gso` and `hxdmkgainhist_pin` routines into gain history FITS files.

The first thing to do is to prepare the GSO input file for the task. The outputs from the `hxdmkgainhist_gso` have to be concatenated in one file called here `aeNNNhxd_gso_ghf.list`. This is done with the `cat` command. Please note that the resulting file is just a **list** of the files to be used by the routine and that the **order** of the files is important.

```
cat > aeNNNhxd_gso_ghf.list <<EOF
aeNNNhxd_gso_gd_ghf.tbl
aeNNNhxd_gso_511_ghf.tbl
aeNNNhxd_gso_152gd_ghf.tbl
EOF
```

For example, we have:

```
hakatan-25-event_cl2: more ae401100010hxd_gso_ghf.list
ae401100010hxd_gso_gd_ghf.tbl
ae401100010hxd_gso_511_ghf.tbl
ae401100010hxd_gso_152gd_ghf.tbl
hakatan-26-event_cl2:
```

Then one can run the general `hxdmkgainhist` task using the following syntax:

```
hxdmkgainhist phaextractor_mode=n ghfwrite_mode=y \
   gti_time=S_TIME hxdmkgainhist_origin=HXD \
   input_name=aeNNNhxd_M_wel_uf2.evt pin_fitlog_name=aeNNNhxd_pin_ghf.tbl \
   gso_fitlog_name=@aeNNNhxd_gso_ghf.list valid_date=2005-08-15 \
   valid_time=11:00:00 pin_gainhist_name=aeNNNhxd_pin.ghf \
   gso_gainhist_name=aeNNNhxd_gso.ghf leapsec_name=leapsec.fits
```

where
`phaextractor_mode` is always set to "no" (the "yes" mode is used only in certain cases on FFFs)
`ghfwrite_mode` is set always set to "yes" when `phaextractor_mode` is set to "no"
`gti_time` is the name for one of the columns containing the time information of the event (raw packet telemetry data)
`hxdmkgainhist_origin` should be set to ISAS or GSFC (irrelevant in the running of the task itself)
`input_name` is the name of the event file
`pin_fitlog_name` is the name of the log output of `hxdmkgainhist_pin`
`gso_fitlog_name` is the name of the file created above – Please note the "@" in front to signal a list of files
`valid_date` is the date of validity as stored in the CALDB database
`valid_time` is the time of validity as stored in the CALDB database
`pin_gainhist_name` is the name of the output PIN gain history file to be created
`gso_gainhist_name` s the name of the output GSO gain history file to be created
`leapsec_name` is the name of the leap-seconds file located under the `HEAsoft` refdata area

`hxdmkgainhist_origin`, `valid_date`, and `valid_time` parameters affect keywords in the output FITS gain history files, but do not affect their content.

5.4.3 Pulse Height Corrections

Once the gain drift has been measured, the (time) invariant event pulse-heights (PI) values can be determined. For the HXD, `hxdpi` calculates the HXD PI columns (PIN[0-3]_PI, SLOW_PI, FAST_PI) 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 takes in the Gain History Files and use them to correct the PI values. Users should make sure that the Gain history file for the GSO (parameter called `gso_gainhist_name`) is the **CALDB file whenever possible**. Please also note that the CALDB files provided will change over time. It is the responsibility of the user to check that the files that are used are indeed the latest in the CALDB. We have shown in Figure 5.3, the potential error for the resulting GSO spectrum if the wrong Gain History File is used. The black curve shows the spectrum extracted after processing with the non-CALDB Gain History File (users should note the wrong energy range covered by the spectrum) and the red shows the same spectrum after using a gain file extracted from the CALDB.

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

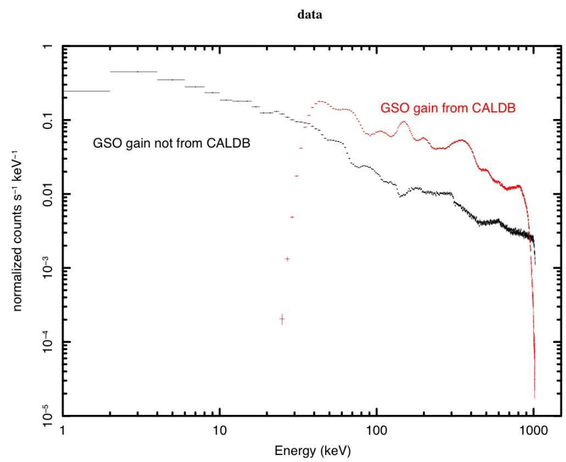

Figure 5.3: Shown are the different spectrum for two cases of gain history file used. In black is shown the result from the pipeline GSO gain computation using the tasks **hxdmkgainhist** and **hxdmkgainhist_gso** prior to version v1.3. The red curve is obtained using a gain file extracted from CALDB.

```
hxdpi input_name=aeNNNhxd_M_wel_uf2.evt\
create_name=hxd_picorr_evt.fits hklist_name=@hk_list.dat\
pin_gainhist_name= ae_hxd_pinghf_date.fits\
gso_gainhist_name=ae_hxd_gsoghf_date.fits\
hxdpinlin_fname=CALDB/ae_hxd_pinlin_date.fits\
hxdgsolin_fname=CALDB/ae_hxd_gsolin_date.fits
```

where
`input_name` is the HXD FITS file input name
`create_name` is the output name (see below)
`hklist_name` is the HXD HK FITS file list name or input as @hk file list
`pin_gainhist_name` is the PIN gain history file either from CALDB or derived from the previous task
`gso_gainhist_name` is the GSO gain history file either from CALDB or derived from the previous task
`hxdpinlin_fname` is the name of CALDB file containing the PIN integrated non-linearity of ADC
`hxdgsolin_fname` is the name of CALDB file containing the GSO integrated non-linearity

of 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 others hidden parameters for this routine are similar to that of `hxdtime`.

2) In the above, please note that if the CALDB Gain History File does not include the observation date of the event fits file, the tool will run silently without updating the file content. Users are **urged** 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 too long screen outputs. Look at the number of events in your initial event file to estimate a reasonable value for that parameter.

The command line would look like:

```
hxdpi input_name=ae401100010hxd_1_wel_uf2.evt read_iomode=create
create_name=ae401100010hxd_1_wel_uf2-hxdpi.evt hklist_name=ae401100010hxd_0.hk.gz
pin_gainhist_name=ae401100010hxd_pinghf.fits gso_gainhist_name=ae_hxd_gsoghf_20061226.fits
hxdpinlin_fname=ae_hxd_pinlin_20060724.fits hxdgsolin_fname=ae_hxd_gsolin_20051209.fits
event_freq=500000
```

Note how in this example, we are using the CALDB file for the GSO Gain History file but not for the PIN Gain History file.

5.4.4 Calculating Event Grade

HXD event files have 5 grade columns filled by the `hxdgrade` routine. The first column is simply `GRADE_QUALTY` which stores the data quality. All events with a `GRADE_QUALTY` flag not equal to 0 should be ignored. The two next 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=aeNNNhxd_M_wel_uf2.evt \
hxdgrade_psdsel_fname=CALDB/ae_hxd_gsopsd_YYYYMMDD.fits \
hxdgrade_pinthres_fname=CALDB/ae_hxd_pinthr_YYYYMMDD.fits
```

where
`input_name` is the HXD FITS file input name

`hxdgrade_psdsel_fname` is the name of CALDB file containing the GSO PSD selection criteria
`hxdgrade_pinthres_fname` is the name of CALDB file containing the PIN lower discriminator threshold

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

The command line would look like:

```
hxdgrade input_name=ae401100010hxd_1_wel_uf2-hxdpi.evt read_iomode=create
create_name=ae401100010hxd_1_wel_uf2-hxdgrade.evt event_freq=500000
hxdgrade_psdsel_fname=ae_hxd_gsopsd_20060620.fits
hxdgrade_pinthres_fname=ae_hxd_pinthr_20060727.fits
```

Note as we use the latest CALDB file copied in the local directory. Any path to the files would also work but not the option "CALDB" as this option is not implemented yet in most of the HXD tasks.

Up until this step the file contain both GSO and PIN data (WELL data) and have not been separated yet. One can first do a series of cleaning procedures before separating the PIN and the GSO data.

5.5 Extracting Data

One can select for any criteria directly from the FITS file using the tool `fselect` part of the FTOOLS delivery or within `xselect` as described in Chapter 4. We show here how to proceed within `xselect`, as it can apply filters which select user-defined times, 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. Some basic parameters to be used for common data screening are in the filter file. The ``select mkf'' command will be used to carry out filter file based data screening, by specifying boolean expression of the parameters and calculating corresponding Good Time Intervals (GTI).

5.5.1 General Selection criteria

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>8 && \
```

```
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 the SAA, using a map of the SAA determined empirically by the HXD team (**not to be changed or omitted**)
T_SAA_HXD selects for the minimum time after the SAA passages (**standard value but can be experimented with**)
ELV selects the elevation of target above Earth limb to at least 5 degrees (**standard value but can be experimented with**)
ANG_DIST selects the pointing to within 1.5 arcmin of the mean (**standard value but can be experimented with**)
HXD_DTRATE excludes intervals during which the data rate low, since this means that the telemetry is saturated just with background events (**not to be changed or omitted**)
AOCU_HK_CNT3_NML_P==1 means normal pointing operation (**not to be changed or omitted**)
COR selects the geomagnetic cut-off rigidity to be at least 8 GeV/c (**standard value but can be experimented with**)
HXD_HV_Wn_CAL and HXD_HV_Tn_CA selects 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 changing 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` the input would look like:

```
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>8
&&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 >
```

NOTE For data taken between March 14th 2006 to May 13th 2006, the GTI used in all the processing versions before v1.3 do not accurately represent the contamination of the data. The HXD team recommends users to use the GTI intervals they have generated using the processing v1.3 and made available for affected users. For more information, please access `http://www.astro.isas.ac.jp/suzaku/analysis/hxd/hxdgti/`.

5.5.2 Separating PIN and GSO data

At this point, both GSO and PIN are still in the file (even if `xselect` is reading is as WELL_PIN and this is the time to separate the two detectors. To do this, we will select on the column called DET_TYPE. DET_TYPE==1 selects PIN events while DET_TYPE==0 selects only GSO events.

5.5.3 Selecting PIN data

At the same time that the selection is made between PIN and GSO, we can also select the PIN diodes with the correct voltage. As noted at the beginning of this chapter, the HXD team reduced the voltage on 16 of the PIN diodes starting May 24, 2006. For data taken after this date, only the part with the unchanged diode voltage should be used (for more information see the website at `http://www.astro.isas.jaxa.jp/suzaku/analysis/hxd/hxdnxb`).

To select the events to be used further down in the analysis, xselect input should read:

```
abc-guide:SUZAKU-HXD-WELL_PIN > filter column
> Enter filter on column(s) in the event file >[] DET_TYPE==1 && UNITID>3
abc-guide:SUZAKU-HXD-WELL_PIN > extract events
extractor v4.71     22 Nov 2006
 No image X-axis TCRPX, set to 0
 No image Y-axis TCRPX, set to 0
 No image X-axis TCRVL, set to 0
 No image Y-axis TCRVL, set to 0
 No image X-axis TCDLT, set to 1
 No image Y-axis TCDLT, set to 1
 Doing file: v1.2.2.3/401100010/hxd/event_cl2/ae401100010hxd_1_wel_uf2-hxdgrade.evt
100% completed
          Total      Good    Bad: Region      Time     Phase     Grade     Cut
       13260720   6232606              0   7028113         0         0         1
 Writing events file
6232606 events written to the output file
===============================================================================
   Grand Total      Good   Bad:  Region      Time     Phase     Grade    Cut
      13260720   6232606              0   7028113         0         0         1
   in  48599.     seconds
abc-guide:SUZAKU-HXD-WELL_PIN >
```

NOTE 1 After October 3, 2006, another set of HXD PIN had to be taken to a lower voltage. For data taken after that date, please apply the criteria **DET_TYPE==1 &&**

UNITID>7

NOTE 2 Although HXD is not an imaging instrument, one can create HXD pseudo-images, which may have some use using the UNITID for this purpose. In this case the selection criteria should read DET_TYPE==1 && UNITID==N where N is a number between 0 and 15 for data taken before May 24, 2006, 4 and 15 for data taken between May, 24 and Oct 3 2006 and between 8 and 15 for data taken after Oct 3, 2006. The extracted images from the selection above can be used to build pseudo-PIN images.

NOTE 3 A couple of keywords need to be modified in the final PIN event file created. First, the DETNAM keyword should be changed to WELL_PIN; second, the TIMEDEL keyword should be created (usually with the value 6.1x10^{-5}, or 61 microseconds - users should check the value in the event_cl directory version).

5.5.4 Selecting GSO data

After the save events command, to select for the GSO, we recommend to issue a `clear all` command and re-read in the initial event file to restart with the GSO selection process. All is almost identical, except the selection criteria which reads:

DET_TYPE==0 && GRADE==N

where N is a column which shows the legitimacy of the GSO events. For example, for spectral analysis, the HXD team may provide standard GSO responses which are valid only for some limited `GRADE` values; only events which have such `GRADE` values should be selected. On the other hand, for light curve analysis, the `GRADE` selection criterion may be loosened.

NOTE 1 As in the case of the PIN, a couple of keywords need to be modified in the final GSO event file created. The DETNAM keyword should be changed to WELL_GSO and the TIMEDEL keyword should be created – again users should check the value in the event_cl directory version).

5.5.5 Response Generation

Currently response files are available through CALDB. The HXD team has released the response matrices to be used for the PIN diodes at the nominal voltages. Users are invited to check regularly for updates at the `http://www.astro.isas.jaxa.jp/suzaku/analysis/hxd/`website.

5.5.6 Background Generation

Users should note that because background files do not have the UNITID keyword (no similar cut possible) there is no UNITID cut to be applied to the background files. Users can access the background files associated with their observations at `http://www.astro.isas.jaxa.jp/suzaku/analysis/hxd/`.

PIN background

The background to be used in the analysis has two components: the internal background and the Cosmic X-ray Background (CXB). The files released at the `http://www.astro.isas.jaxa.jp/suzaku/analysis/hxd/`website contain the internal background only. Before modeling the background in XPSEC for a given observation, users have to combined both backgrounds.

Internal background

These files are provided by the instrument team (there may be some delay between the delivery of the data and that of the background associated. If that delay is more than one month, please contact the GOF). Select the background file appropriate for your observation. This file should be filtered using the same GTI as the one used to extract the data spectrum. In addition, the files provided all have an EXPOSURE keyword **WRONG** by a factor 10. Users are warned to correct that keyword before proceeding with any analysis. More explanations are given at `http://www.astro.isas.jaxa.jp/suzaku/analysis/hxd/`. Lastly, users should note that the files provided are not deadtime corrected.

Cosmic X-ray background

The CXB is obtained by faking a CXB spectrum using a model and the `fakeit` command in XSPEC run with the PIN response for a flat emission. Such a response file (with a name like ae_pinflat_YYYYMMDD.rsp.gz) is made available by the HXD instrument team and is available at `http://www.astro.isas.jaxa.jp/suzaku/analysis/hxd/`or through CALDB. This response assumes that the uniform emission region is 2×2 deg^2. The typical CXB spectrum is modeled as:

$9\ 10^{-9}\times(E/3\ \mathrm{keV})^{-0.29}\times\ \exp^{-(E/40\ \mathrm{keV})}$ erg cm^{-2} s^{-1} str^{-1} keV^{-1} as defined by Boldt (1987, IAUS, 124, 611). Users are welcome to use more recent (or their favorite) models for the CXB. Please note that the Boldt's model has to be changed for a proper input in XSPEC. First, the model is normalized per steradian and the flat response assumes a uniform source on 4 deg^2, so we need to normalized it by the appropriate ratio of 4 deg^2/1 str or (4/3283)= 0.00121.

The model becomes: $1.097\times10^{-11}\ \ (E/3\ \mathrm{keV})^{-0.29}\times\ \exp^{-(E/40\ \mathrm{keV})}$ erg cm^{-2} s^{-1} keV^{-1} on the region assumed for the response.

This model is normalized at 3 keV and not at 1 keV as required by XSPEC. In addition, the model unit is erg whereas XSPEC expects photons. Once this is taken into account, we get: $9.412\times10^{-3}\ \ (E/1\ \mathrm{keV})^{-1.29}\times\ \exp^{-(E/40\ \mathrm{keV})}$ photons cm^{-2} s^{-1} keV^{-1} At this point, the `fakeit` command can be used, with the input model selected as po*highecut. The

`highecut` model can be written as:
$M(E) = e^{(E_c - E)/E_f}$ for $E > E_c$
$M(E) = 1$ for $E < E_c$
In our case, we take E_c at the lower limit of the model (E=0.0001 keV) and fix it there. E_f is 40 keV. The input to XSPEC 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` command using the `pinflat` response matrix.

NOTE 1

This model is NOT appropriate when using the point source PIN response matrix, since the normalization of that matrix is different. 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 ae_hxd_pinhxnom_20060814.rsp 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 power law 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 **two background PHA** files have then to be **combined** – paying attention that the EXPOSURE keyword should be the common value (and not the sum of both exposure times).

GSO background

This section is not yet available.

5.6 WAM Processing

The HXD Wideband All-Sky Monitor (WAM) utilizes the BGO anti-coincidence detectors to create an all-sky monitor. Although from the same detector, these data are processed independently. There should be no need for the user to reprocess the data from the WAM (the HXD team will analyze the WAM data and make the results public) but we have included the description of the processing pipeline for completeness.

5.6.1 `hxdwamtime`

The `hxdwamtime` routine compute the HXD event arrival-time correction. The arrival time for events detected in the WAM is computed in a manner similar to the `hxdtime` routine, where the conversion to *Suzaku* time coordinate is done using one of four methods to be specified by the parameter `time_convert_mode`.

```
 hxdwamtime input_name=aeNNN_hxd_wam.fff  create_name=aeNNN_hxd_wam.uff \
hklist_name=@hk_list.dat leapsec_name=leapsec.fits tim_filename=aeNNN.tim
```

where
`input_name` is the HXD_WAM_FITS file name to archive the time correction
`created_name` is the HXD_WAM_FITS output name
`hklist_name` is the HXD_HK_FITS file list name or input as @hk file list
`leapsec_name` is the name of the leap-seconds file located under the `HEAsoft` refdata area
`tim_filename` is the name of the TIM file.

5.6.2 hxdmkwamgainhist

This routine produces a gain history file for the WAM FITS, where gain-correction factor is given as a function of time. It is determined by fitting the data of the 511 keV line, much as the gain histogram is calculated for the HXD GSO from the Gd line. The fitting results are recorded in a log file. The gain history file will be used as input for **hxdwampi**.

```
hxdmkwamgainhist input_name=aeNNN_hxd_wam.uff trn_fitlog_name=aeNNN_hxd_wam_fit.log \
trn_gainhist_name=aeNNN_hxd_wamghf.fits  leapsec_name=leapsec.fits
```

where
input_name is the HXD WAM FITS file name
trn_fitlog_name is the name of the log (ASCII output)
trn_gainhist_name is the name of the gain history file (output) to be used as input for **hxdwampi**
leapsec_name is the name of the leap-seconds file located under the HEADAS ref area

5.6.3 hxdwampi

The **hxdwampi** routine calculates the time-invariant pulse-height value for each HXD WAM event, which is stored in the TRN_PI column. By default, the input file is used as the output, although this can be modified by setting the create_name parameter. The gain drift is not corrected in the current **hxdwampi**, but instead is considered in the response matrix. The task expands the reduced PH table via HXD-DE on-board process. The setting is identified by the column "TRN_TBL_ID", which is defined in the caldb FITS file named "ae_hxd_wampht_YYYYMMDD.fits" (currently "ae_hxd_wampht_20050916.fits").

```
 hxdwampi input_name = aeNNN_hxd_wam.uff  hklist_name = @hk_list.dat\
 trn_bintbl_name =   CALDB/ae_hxd_wampht_20050916.fits \
trn_gainhist_name = aeNNN_hxd_wamghf.fits
```

where
input_name is the input HXD WAM file name
hklist_name is the HXD HK FITS file list name or input as @hk file list
trn_bintbl_name is the name of the CALDB file associated with the PH compression process
trn_gainhist_name is the file name of the gain history file output of hxdmkwamgainhist.

5.6.4 hxdwamgrade

This routine calculates the event grade for a WAM event, much as the `hxdgrade` tool does for a standard HXD event. As with the `hxdwampi` tool, by default the input event file is also used as the output file, simply modifying the QUALITY column.

```
hxdwamgrade input_name=aeNNN_hxd_wam.uff  hklist_name=aeNNNhxd_0.hk
```

where
`input_name` is the input HXD WAM file name
`hklist_name` is the name of the input HK file

5.6.5 hxdbsttime

Fill the "BST_FRZD_TM" keyword in the header of the BURST FITS.

```
hxdbsttime input_name=aeNNN_hxd_bst_0.fff create_name=aeNNN_hxd_bst_0.uff\
 hklist_name=@hk_list.dat  leapsec_name=leapsec.fits  tim_filename=aeNNN.tim
```

where
`input_name` is the HXD WAM FITS file name
`create_name` is the HXD WAM FITS output name
`hklist_name` is the HXD HK FITS file list name or input as @hk file list
`leapsec_name` is the name of the leap-seconds file located under the `HEAsoft` refdata area
`tim_filename` is the name of the TIM file.

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
	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