The ASCA Data Reduction Guide

(Otherwise known as the ABC Guide)

Version 2.0

ASCA Guest Observer Facility

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Contents

Chapter 1

INTRODUCTION

1.1 Scope

This Guide describes how to reduce *ASCA* data. By reduce, we mean the preparation of data for analysis, a process which entails first screening your data and then selecting which parts of the screened data to extract as data products (i.e., spectra, light curves and images). Data analysis, i.e., the derivation of scientific results from the data products, is described in detail elsewhere, although the chapters on spectral, temporal and spatial analysis do show how to get started. This Guide assumes that the data have already been loaded, either from the original data tape, or obtained by FTP from the archive. Further details can be found in 'The Getting Started Guide' at the URL

`http://adfwww.gsfc.nasa.gov/asca/processing_doc/GS/getting_started.html`

and other on-line help accessible from the *ASCA* GOF WWW area at

`http://heasarc.gsfc.nasa.gov/docs/asca/ahp_proc_analysis.html`.

The principal tool for reducing *ASCA* data is a program called `XSELECT`. This Guide is suitable for users who are going to do their data reduction based entirely on `XSELECT`, as well as users who wish to use their own or preferred software package. Accordingly, the main focus of this Guide is on

- *ASCA* data files,
- the properties of the *ASCA* instruments and their modes, and
- the criteria for identifying good and bad data.

For general instructions on how to run `XSELECT`, users should refer instead to the `XSELECT` User's Guide available on the WWW at the URL

`http://heasarc.gsfc.nasa.gov/docs/software/ftools/xselect/xselect.html`.

However, `XSELECT` commands specific to *ASCA* are covered here in detail, while the appendix contains a set of `XSELECT` command sequences for accomplishing the basic reduction tasks.

1.2 The Basic Scheme

Between receiving *ASCA* data from ISAS and sending the data to Guest Observers, the *ASCA* Guest Observer Facility (GOF) converts the data to FITS format (see §2.2) and performs a set of standard calibrations. Also produced at this stage are `mkf` files, which contain the time-histories of various parameters to which good data can be referenced, identified and screened. The name `mkf` comes from the program `mkfilter` used to produce the files. *ASCA* data reduction, as performed by GOs, involves the manipulation of these FITS files by a set of tasks, called FTOOLS, which can be called from `XSELECT` by higher level tasks.

When screening data, `XSELECT` consults the events data files and the accompanying `mkf` files to produce a list of selected good time intervals (GTI). These good time intervals are used for extracting a list of screened events (in the same FITS format as before). The final stage, when the GO is happy with the screening, is the filtering (spatial, temporal or spectral) of the events list, which is then binned and projected appropriately for extraction, as data products in their own FITS formats. The products, usually spectra, light curves, or images, can be read into the data analysis programs `XSPEC`, `XRONOS` and `XIMAGE`, respectively, or into any others equipped to handle these formats. Since many of the basic `XSELECT` commands required to clean data are repetitive, a script called `ascascreen` has been produced to take care of this task. `ascascreen` is the usual starting point in the reduction of *ASCA* data.

1.3 Organization of this Guide

The second chapter is devoted to the RAW FITS data files (GIS and SIS) and the `mkf` files. Familiarity with the basic structure of these files, if not their detailed format, is important when reducing the data they contain.

The third and fourth chapters describe, respectively, those aspects of the GIS and SIS that pertain to data reduction and analysis. The special techniques required by the various instrument modes are described.

The fifth chapter describes what screening criteria have to be applied to the data before it can be analyzed.

The sixth chapter covers how to screen your data with these criteria using `XSELECT`, `ascascreen` or `tkascascreen`.

The seventh chapter covers the next stage of data reduction, how to filter subsets of your screened data before creating data products.

The eighth, ninth and tenth chapters describe, respectively, the extraction and formats of spectra, light curves, and images.

Further details can be found in the appendices. The appendix has a listing of acronyms used in this Guide, relevant WWW URLs, and a set of common `XSELECT` command sequence examples.

1.4 How to Use this Guide

If you are new to *ASCA* **data reduction**, then you should start at chapter two, and work your way down through the Table of Contents.

If you are familiar with *ASCA* **data reduction**, then the fastest way to find what you need is, again, from the Table of Contents.

On the WWW, each chapter, including this one, is headed by a set of buttons which link you to the other chapters. The sections within each chapter are listed at the beginning, after the introductory section, and are repeated at the end of the chapter. For convenience, the set of chapter buttons is also repeated at the end of each chapter.

1.5 New Releases, Bug Fixes, Other Updates

This version of the ABC Guide was written when the latest version of FTOOLS available was v3.6, and just before the release of v3.7. FTOOLS (including `XSELECT`) are typically released biannually, and users should check that they have the latest version. In addition to new releases of FTOOLS, *ASCA* users need to know about new releases of calibration files, improved screening criteria, bug reports, and other nuances in *ASCA* data analysis. We list below how to obtain the latest information.

1.5.1 *ASCA* GOF Homepage

The *ASCA* GOF home page is located at the URL

`http://heasarc.gsfc.nasa.gov/docs/asca/ascagof.html`

and the URL for 'Processing and Data Analysis' is

`http://heasarc.gsfc.nasa.gov/docs/asca/ahp_proc_analysis.html`.

The latest information on software and calibration is available from the *ASCA* GOF home page, particularly items under the heading of 'What's New', at the URL

`http://heasarc.gsfc.nasa.gov/docs/asca/whatsnew.html`.

In addition, both FTOOLS and XANADU have their own Web pages at the URLs

`http://heasarc.gsfc.nasa.gov/docs/software/ftools/ftools_menu.html`

and

`http://heasarc.gsfc.nasa.gov/docs/xanadu/xanadu.html`

respectively.

1.5.2 Ascanews

Information about software and calibration updates, bug fixes and enhancements is announced by means of the *'ascanews'* e-mail exploder. *Ascanews* is also used to distribute the short-term timelines. If you are not on the mailing list of this exploder, please send an e-mail to `listserv@athena.gsfc.nasa.gov` which should contain, in the text of the e-mail, the single line:

```
subscribe ascanews Eileen Collins
```

for the person Eileen Collins (please substitute your own name).

1.6 *ASCA* Newsletters

The *ASCA* GOF publishes *ASCANews* about once a year, a newsletter containing articles about *ASCA* by members of the *ASCA* Team. These are available on the WWW at the URL

`http://heasarc.gsfc.nasa.gov/docs/asca/newsletters.html`

or in paper form. To receive future/back issues of *ASCANews* contact: `ascahelp@athena.gsfc.nasa.gov`.

1.7 Calibration Uncertainties

The status of calibration of the *ASCA* instruments is documented and continuously updated in the 'Calibration Uncertainties' Web page, located at the URL:

`http://heasarc.gsfc.nasa.gov/docs/asca/cal_probs.html`.

Users are urged to become familiar and keep up-to-date with this document in order to fully understand the limitations and systematic errors of any results that they obtain from analysing *ASCA* data.

1.8 Obtaining Help and Information, Reporting Bugs, Submitting Comments

1.8.1 `ascahelp`

If you cannot find the answer to your question in this User's Guide, please send e-mail to `ascahelp@athena.gsfc.nasa.gov`. The *ASCA* GOF scientists and support staff will try to respond within one working day.

This is also the e-mail address to which you should send software problem reports. If you do encounter a problem, please:

1. Quit `XSELECT` or `ascascreen`.
2. Send an e-mail to `ascahelp`, explaining the problem.
3. Also include the file `xsel.log` which contains a log of your `XSELECT` or `ascascreen` session.

Please note that the `xsel.log` file will be overwritten if, after encountering the bug, you restart `XSELECT`. This means you should rename the file if you want to continue running `XSELECT` before sending `xsel.log` to `ascahelp`.

It is commonplace for `ascahelp` questions to lead to exchanges of e-mails with a particular ascahelper. However, please send new questions (that are not direct follow-ups to an on-going dialog) to `ascahelp` rather than to an individual. This both helps to spread the load evenly among ascahelpers, and also is the best way to ensure that a question will be answered in a timely manner.

1.8.2 Ftoolshelp and Xanprobs

In general, most questions on FTOOLS or XANADU that arise in the course of *ASCA* data reduction and analysis should be sent to `ascahelp`. However, some technical questions, particularly those related to distribution and installation of these software packages, may be more appropriate for `ftoolshelp@athena.gsfc.nasa.gov` or `xanprob@athena.gsfc.nasa.gov` respectively. Questions sent to a 'wrong' e-mail address will be forwarded to the appropriate experts, but this may involve an additional delay in replying.

Chapter 2

DATA FILES

2.1 Introduction

The data files which contain events detected by *ASCA* have three key properties:

- They are in FITS format.
- They are time-ordered events lists.
- Each file contains data from only one of the four instruments and in only one instrument mode.

In *ASCA* data reduction, unwanted events are removed by screening, with files of the same type are merged together. The basic structure of the files is preserved, so that the data files input into an `ascascreen` session have the same structure as the single screened events list which `ascascreen` produces. To fully understand *ASCA* data reduction, it helps to be familiar with the basic structure. It also helps to know the names of the various columns which describe each event. This is what this chapter is about. Just as important are the filter files (called `mkf` files), also described here, which are used for screening based on the time history of various housekeeping parameters and derived parameters, such as elevation angle above the Earth.

2.2 FITS Files

2.2.1 Why FITS?

The format in which *ASCA* data are telemetered to the ground is very terse and compact. It is not intelligible without extensive documentation, nor is it machine independent. By contrast, files which conform to the The Flexible Image Transport System (FITS) standard are self-documenting and machine independent. For these reasons, the US *ASCA* Data Facility (ADF) converts the *ASCA* data it receives from ISAS into FITS as part of the initial processing. FITS is also a NASA-mandated standard which must be adhered to by NASA astrophysics missions.

2.2.2 FITS User's Guide

For newcomers to FITS, a helpful User's Guide is available in PostScript (`users_guide.ps`) and Tex formats (`users_guide.tex`) via anonymous FTP at `ftp://nssdc.gsfc.nasa.gov/`

in the directory `pub/fits`.

2.2.3 OGIP Standard

The FITS standard is so flexible that conformance to it does not immediately guarantee that files are readily usable. To establish a multi-mission FITS format for high-energy astrophysics, the Office of Guest Investigator Programs (OGIP), including the *ROSAT*, *ASCA*, and *RXTE* GOFs, and the HEASARC, has established a FITS working group (OFWG). OFWG has defined common keywords and classes of formats applicable to high-energy astrophysics research (e.g. light curves, spectra), and has examined and approved specific formats to be used for archival and current missions. OFWG does not work alone, it works in conjunction with the wider FITS community, and is in regular contact with other high-energy astrophysics groups that are writing FITS files for community use. All OGIP standards are published, either in /it Legacy or as internal memos, as appropriate. These memos are also available via anonymous FTP at `ftp://legacy.gsfc.nasa.gov/caldb/docs/`.

2.3 Data Processing Versions

The original 'pipeline processing' of *ASCA* data at GSFC is referred to as REV0 (symbolic for 'revision 0'). Subsequently, more sophisticated and updated versions were developed, namely REV1 and REV1+, and as of June 1997, REV2 processing began. Full REV2 reprocessing is expected to take about a year. The processing team at GSFC endeavor to run all the archival data through the very latest processing revision. Users who have data which was run through an older processing revision, are strongly advised to obtain data processed with the latest revision from the *ASCA* archive. Details of all of the changes in the different processing versions can be found at the URL

`http://adfwww.gsfc.nasa.gov/asca/processing_doc/proc/processing.html`.

2.4 Three Levels of *ASCA* Data Files

Although all *ASCA* data files share the same structure, they exist with three different levels of processing, on tapes and in the archive. These are as follows.

1. **UNSCREENED** These files are produced by merging raw files (obtained, for example, by running the program `FRFread` on the original telemetered data) which have the same instrument, mode and bit rate. A typical observation yields about a dozen unscreened files which, like the raw files, have not been screened. They have names like:

   `ad80003000g200170h.unf`

   The filename carries the sequence number of the observation (in this case 80003000), the instrument (s0, s1, g2 or g3) and the bit rate (l, m, h for LOW, MEDIUM and HIGH respectively). Users who wish to screen their own data can start with the unscreened files and run `XSELECT`, `ascascreen` or `tkascascreen` on them (see §5 and §6). Note that for SIS files the two digits immediately preceding the bit-rate letter have the following meaning.

   ```
   01 - FAINT mode
   02 - BRIGHT mode
   12 - BRIGHT2 mode
   ```

See §4 for details of these different SIS modes.

2. **SCREENED** For each unscreened file there is a screened file which has been subjected to the standard screening (see §5.5). They have the same names as the corresponding unscreened files, except that the filename extension is `.evt`, so that the screened file corresponding to the above example would be

   `ad80003000g200170h.evt`

   Users can read the screened files into `XSELECT` and proceed immediately to extract images, light curves and spectra.

3. **RAW** The availability of these files is discontinued for data processing revisions later than REV0, and the use of these files is being phased out. However we describe these files here for historical purposes only. Users who have only RAW files should instead obtain the `.unf` files from REV1 or later from the archive at GSFC. The number of RAW files per observation were numerous and cumbersome because a new file was written each time the mode or bit rate changed. A typical observation yields about 100 RAW files which, as the name suggests, have not been subjected to screening. RAW filenames began with '`ft`' followed by digits identifying the date of the observation, instruments were identified with the strings `S0, S1, G2, G3`, while bit rates were identified with the letters `L, M, H`. The filename extension was `.fits`. Thus a typical name would be `ft930920_0819_0630G200170M.fits`

For more information about the files on an *ASCA* data tape, please consult the `Getting Started Guide` which is available via anonymous FTP at `ftp://legacy.gsfc.nasa.gov/` in the directory `asca/doc` and called `start_guide_v6_1.tex` (Latex version) and `asca/doc/start_guide_v6_1.ps` (Postscript version). Alternatively, the HTML version can be found at the URL

`http://adfwww.gsfc.nasa.gov/asca/processing_doc/GS/getting_started.html`.

2.5 Basic File Structure

FITS files have:

1. a primary header,
2. a primary image array, and
3. optional extensions, each with a header.

In the case of the *ASCA* FITS files, the primary header contains information about the mission, the instrument, the observation and the initial processing. As with all FITS headers, this information is in the form of keywords with assigned values. The primary image array in *events* files is blank, i.e., it contains no data. The first extension, which is in the form of a binary table, is called EVENTS, and contains complete descriptions of the events themselves in the form of a time-ordered list of photon attributes (e.g. time, position and pulse-height information).

In REV0 processing the events files contained two good-time-intervals (GTI) extensions, called ALLGTI and STDGTI. The idea was that these GTI arrays would initially be identical to each other, containing the start and stop times of periods during which the respective instruments were switched on and collecting data. In the course of data reduction and analysis by the user, the STDGTI intervals would change, reflecting the data selections performed by the user, but the ALLGTI table would preserve its initial values so that the user would not lose this important information. The ALLGTI values are important for such operations as correcting instrument deadtime.

Since the RAW events files have been phased out, the ALLGTI table is no longer in the events files, because, events lists created by `XSELECT`'s `extractor` have only the STDGTI extension. However, the ALLGTI data will now be stored as an extension in the *ASCA* housekeeping (HK) files.

The structure of any FITS file can be displayed using the FTOOL `fstruct`, as in this example:

```
> fstruct ft940213_1039_0612G203870H.fits
  No. Type     EXTNAME      BITPIX Dimensions(columns)      PCOUNT  GCOUNT

   0  PRIMARY                 32     0                           0       1
   1  BINTABLE EVENTS          8     30(12) 2                    0       1
   2  BINTABLE STDGTI          8     18(3) 1                     0       1
   3  BINTABLE ALLGTI          8     18(3) 1                     0       1
```

More documentation is available on FTOOLS and on FITS files at the URL

`http://heasarc.gsfc.nasa.gov/docs/software/ftools/ftools_menu.html`.

It is a good idea to familiarize yourself with GIS and SIS events files by running the FTOOL `fdump` on typical files. Most of the keywords are self-explanatory - one of the *raisons d'etre* of FITS - but some column names in the EVENTS extension require further comment. More details are given below.

2.6 Important Keywords and Columns in *ASCA* FITS Events Files

2.6.1 RAWX/Y, DETX/Y, X/Y Columns and RA/DEC_NOM Keywords

For the GIS PH mode data, the RAWX and RAWY columns contain the position of events detected in the GIS gas cell as determined by the on-board electronics, and recorded in the telemetry. Processing at the ADF corrects for instrument distortions, using ground and in-flight calibrations to produce the linearized DETX and DETY focal plane coordinates and linearized X and Y sky coordinate data. The data in each pair of columns are in units of pixels (0.25 mm/pixel; 1.00 mm = 0.98 arc-minutes).

For the SIS FAINT, BRIGHT and BRIGHT2 modes (see §4) the SIS RAWX and RAWY columns give the discrete CCD pixel location of each event flagged and processed by the on-board electronics. Each SIS can have up to four adjacent CCD chips active at one time; accordingly, the number in the CCDID column (0-3) indicates in which CCD chip the event occurred. Processing at the ADF corrects for the instrument distortions using ground and in-flight calibrations to produce the linearized DETX and DETY focal plane coordinates and linearized X and Y sky coordinate data. The data in each pair of columns are in units of pixels (0.027 mm/pixel; 1.00 mm = 0.98 arc-minutes).

In all cases, the images are in 'look up' orientation, with the Y-axis flipped relative to the spacecraft coordinate system, and follow the FITS image convention. The aspect solution is applied to the focal plane coordinates (i.e., DETX, DETY) to produce the sky coordinates (i.e., X, Y). Each event is projected back onto the sky on a tangent plane, and a binned sky image is formed with the X and Y axes oriented along RA and DEC, respectively. If no aspect solution is available for an event then it is assigned the sky coordinates (1,1).

Since each instrument has a unique pointing, and each telescope a unique optical axis, the mean instrument pointing is chosen as the common aspect point. This mean pointing is stored in all the headers as the values of the RA_NOM and DEC_NOM keywords.

2.6.2 TIME Column and TIMESYS, MJDREF, TSTART, TSTOP Keywords

For GIS PH mode, the time attached to each event, in the TIME column, is given in seconds after the reference time (midnight, January 1st, 1993). The reference time is specified by two keywords in the header of the EVENTS extension: TIMESYS, which gives the reference time in UT, and MJDREF which gives the same time in Modified Julian Days (i.e., 48988.0). The two keywords which give the start and stop times of the data in the file, TSTART and TSTOP, are also given in seconds with respect to the reference time. Note that the precision of the arrival times in the TIME column - i.e., the time resolution of the data - depends on the number of bits assigned to timing. This is described in more detail in §3 (GIS Issues).

The above applies also to the SIS, except that the meaning of the TIME column is different and depends on datamode (for explanations of the different SIS modes see §4).

- FAINT, BRIGHT, BRIGHT2 modes: For these imaging modes the values in the TIME column are the CCD read-out times at mid-exposure and *not* the photon arrival times. This means that successive events within the same readout can have the same time.
- FAST mode: The values in the TIME column are the photon arrival times with a precision of 4 s. The RAWY column contains a correction to this value which, when applied by `XSELECT` (using the FTOOL `fasttime`), increases the precision to 15.625 ms.

2.6.3 GIS PHA, PI Columns

The PHA (Pulse Height Analyzer) column contains the spectral information associated with each event. Processing at the ADF corrects for the spatial and temporal variations of the detector gain to produce the data in the Pulse Invariant (PI) column. In the case of the GIS, the accumulation of events for spectral analysis should be done using the PI data (this has always been the default in `XSELECT`).

2.6.4 GIS RISE_TIME, RTI Columns

After entering the GIS through a Beryllium (Be) window, X-ray photons ionize Xenon atoms, and the photoelectrons are accelerated by a strong electric field to excite Xenon atoms. When the atoms de-excite, UV scintillations are produced with intensity proportional to the energy of the original X-rays. These scintillations are then detected by the position-sensitive phototube where the energy of the original photon is ultimately manifested as a pulse of charge.

Each electrical pulse has a characteristic rise-time, which is stored in the RISE_TIME column in the GIS science file. Rise-time has a small positional dependence on the detector, and the RTI (Rise Time Invariant) columns give the rise-time values after this position dependence is corrected.

High-energy particles also produce charges in the phototube, but because they interact with the detector differently from X-rays, they have different rise-times (usually shorter than those of X-rays). Using this fact, background particles can be rejected by applying a rise-time filter. The on-board RISE_TIME window, whose lower and upper boundaries do not depend on the position and PHA, was fixed early in the PV phase of the mission, and only events whose RISE_TIME values fall in the window are telemetered to ground. By applying a stricter, PHA-dependent RTI window in the course of data analysis, background events are more effectively rejected (this is a standard practice, and is carried out with the `gisclean` command in `XSELECT`).

When standard bit-assignment is changed to increase time resolution (section 3.2.1), rise-time information may not be available. In this case, RTI based screening is not available, which slightly changes detector efficiency. In spectral analysis, this effect is taken into account by `ascaarf` to create ARFs which match the efficiency without the RTI screening. It is also important to use the background spectra without RTI screening in this case.

2.6.5 GIS MPC Mode Files

For GIS MPC mode, a non-imaging mode used only for bright sources, there are no PHA and PI columns. Instead, the primary extension, which is called SPECTRUM rather than EVENTS, contains the columns TIME, X, Y, and PHAS. The TIME column is defined in the same way as for PH mode, while the X and Y columns contain only zeroes, since MPC mode has no position information. (Nevertheless, MPC mode data files have X and Y columns lest future software require them, say, to perform a statistically based positional gain correction). For the same reason, MPC mode files do not have RAWX/Y nor DETX/Y columns. For each time bin, the PHAS column contains the integrated 256-channel PHA spectrum, or histogram. The values in the PHAS column are not corrected for the positional dependence of the gain. MPC mode data is much like traditional proportional-counter data.

2.6.6 SIS PHA, PHAS, GRADE, PI Columns

The meaning of the SIS PHA (pulse height analyzer) column depends on the datamode.

- FAINT: Each PHA entry is actually a vector containing the PHA values of each of the nine pixels in the 3 x 3 square-pixel grid encompassing the brightest pixel. In this case, the PHA column is called PHAS.
- BRIGHT, BRIGHT2, FAST: Each PHA entry is a single number occupying the column PHA and accompanied by an additional column called GRADE which describes the shape of the event. For conventional spectral analysis, FAINT mode data must first be converted to BRIGHT or BRIGHT2 mode data before further analysis is possible. The difference between onboard and converted BRIGHT or BRIGHT2 mode data is in the algorithm. More details can be found in §4 (SIS Issues).

Like the GIS, the SIS also has a PI (Pulse Invariant) column for gain-corrected PHA values, but only for BRIGHT and BRIGHT2 mode. In REV0 data files, the PI column is present, but not filled. In REV1 and later data files, however, the PI column is filled. See §4.5.2 (SIS Issues), for more about SIS PI.

2.7 MKF Files

The `mkf` file (produced by the program `mkfilter` or `mkfilter2` at the ADF) summarizes critical housekeeping, orbit and attitude information, as well as derived parameters such as Earth elevation angle. These files have a `.mkf` extension and comprise, in a more compact form than the HK files, most of the information needed for screening data. This information is stored in a binary table extension of the `mkf` file in the form of a time-ordered list of rows. When given a screening criterion, e.g., elevation angle > 10 degrees, `XSELECT` will go through the `mkf` file to find all the good time intervals (GTI) which satisfy the criterion. We recommend that users familiarize themselves with their `mkf` files - at least the headers and the first few rows - by running `fdump` on them.

The `mkfilter` program underwent a revision between REV0 and REV1, becoming `mkfilter2`. The new version yields `mkf` files with the following important changes and enhancements:

```
-----------------------------------------------
                    mkfilter        mkfilter2
-----------------------------------------------

Used for            REV0             REV1
Input files         FRF              HK
Elevation column    ELV_MIN          ELV
Rigidity column     COR_MIN          COR
Units of Sn_PIXLm   counts/readout   counts/s
ANG_DIST present    no               yes
-----------------------------------------------
```

The meanings of these parameters are fully explained in §5 and $ 6.

2.8 Housekeeping Files

The *ASCA* housekeeping files have names that end with `HK.fits`. Note that text summaries of the GIS housekeeping files are provided in the `aux` directories in the *ASCA* archive and on PIs' data tapes. They have names like:

`ft930916_0218_1611G3HK.txt`

GIS housekeeping files include monitor counts which may be used to study time variations of bright sources. The FTOOL `ghkcurve` is used to create a FITS light curve of the L1 monitor count in a housekeeping file. The particular advantage of this is that one can make proper light curves for telemetry-saturated data from very bright sources.

Currently, SIS and 'Common' HK files, which include housekeeping information for the SIS and the satellite respectively, are not used in the *ASCA* data analysis because the critical information has been copied to the `mkf` file. An exception is the ALLGTI binary table extension which is now carried in the HK files of both SIS and GIS (see §2.5).

Chapter 3

GIS ISSUES

3.1 Introduction

This chapter describes some aspects of the GIS performance which users should be aware of when reducing and analyzing GIS data.

For the latest information about the GIS, please consult the Web pages, 'GIS News' at the URL

`http://heasarc.gsfc.nasa.gov/docs/asca/gisnews.html`

and 'Calibration Uncertainties' (§1.7)

3.2 Description of GIS Modes

Although the GIS has four modes, in practice the pulse height (PH) mode has been used for virtually all scientific observations. The multi-channel pulse count (MPC) mode was used occasionally at the beginning of the mission. The FITS keywords which pertain directly to the GIS modes are described in §3.4.

3.2.1 PH mode

In this mode, the on-board CPU calculates the event position and discards background events using a specially designed event selection algorithm. Only accepted X-ray events are sent to the ground. With the standard bit assignments, Pulse-height spectra consist of 1024 channels for each detector.

PH mode allows some flexibility in how the telemetry is allocated. There are 31 bits per event to describe the PHA value, X and Y position, rise time, spread and timing. Note that changing the bit assignments in PH mode only changes the digital resolution, i.e., the binning, of the data. For example, the standard 1024-channel PH mode spectral responses can be used for 256-channel PH mode spectra, provided the response has been rebinned (using the FTOOL `rbnrmf`) [1].

In the following table, the various alternative choices are given in parentheses, while the standard values are not:

[1] Please do not forget to rebin the background spectra as well with the FTOOL `rbnpha`, if you are going to use the data taken from blank sky fields for background.

PH:	10	(8)		
X-pos:	8	(6)	(4)	(2)
Y-pos:	8	(6)	(4)	(2)
RiseTime:	(8)	(6)	5	(0)
Spread:	0	(8)		
Timing:	31-(PH_bit)-(X-pos_bit)-(Y-bit)-(RiseTime_bit)-(Spread_bit) =0 for nominal setting.			

The standard temporal resolution (timing bit=0) is 62.5 msec (in HIGH bit rate) and 500 msec in MEDIUM bit rate: using N bits for timing makes the temporal resolution 2^N times better. It is often useful to increase the number of timing bits to achieve higher time resolution. For example, for several observations of fast X-ray pulsars, the following bit assignments were used and found effective:

8(PH)-6(X)-6(Y)-5(RT)- 6(Timing)	in high bit rate	(1.0 ms resolution)
8(PH)-6(X)-6(Y)-0(RT)-10(Timing)	in medium bit rate	(0.5 ms resolution)

The bit assignment in a PH mode events file is described by the header keyword, 'TIMEDEL'.

Telemetry capacity limits in the PH mode are 128, 16, and 4 cts/s/sensor for the HIGH, MEDIUM, and LOW telemetry rates respectively.

3.2.2 MPC mode

This mode is optimized for bright sources, trading temporal resolution and telemetry capacity for positional information: only pulse-height information is recorded – in the form of histograms, similar to proportional counter data. This is also a back-up mode against CPU failure, since the data are processed without the intervention of the CPU. Pulse-height spectra consisting of 256 channels for each time bin are produced. Alternatively, each time bin can contain a set of N spectra of 256/N channels for N equal portions of the time bin.

You can extract light curves and spectra, but not images, for MPC mode data using `XSELECT`. The lack of positional information (for the spatial gain calibration) makes analyzing MPC data problematic. Spectral response matrices do not exist for MPC mode, so accurate spectral analysis is not possible for the general user.

3.3 Imaging with the GIS

A single GIS event invokes electric pulse-heights on the 16×16 anode wires of the Imaging Photo Multiplier Tube. The GIS calculates the event position as the centroid of these 16×16 pulse-heights. As a consequence of the position determination algorithm, the GIS has a limited spatial resolution. The point spread function (PSF) of the GIS alone is a Gaussian with a FWHM of $0.5 \times (5.9/E$ [keV]) arcmin, where E is the energy in keV. Note that this is smaller than the 3-arcminute half power diameter of the XRT PSF, but at soft X-ray energies is larger than its sharp core (the FWHM of the XRT PSF is 50 arcsec). As a result, the convolved PSF of the XRT+GIS becomes much broader than that of XRT alone, and the original detailed structures in the XRT image are smeared in the GIS image. Studying small structures on a scale of an arcminute, which may be carried out with the SIS, is very difficult with the GIS.

Although the distributed GIS data contain all the events from all over the detector (50 arcmin diameter), the GIS usable Field of View (FOV) is limited by several factors. Firstly, most non-X-ray background events in the GIS occur close to the walls of the detector, i.e., at the edge of the FOV. Secondly, there is an internal calibration source which emits monochromatic X-rays and which appears at the edge of the GIS FOV. Third, not only is background high, but the gain is also less accurately known at the edge of the FOV. Indeed, because of the high background and uncertain gain, only events within the central 44 arcmin diameter of the GIS FOV are aspected (assigned RA and DEC). It is a standard practice to exclude data taken outside of a central diameter of $\sim$ 40 arcmin. For more details, see §5.5.2.

3.4 GIS Mode-Dependent Keywords

In `xselect`, once the datamode has been set, the various mode-dependent quantities, such as the number of energy channels, are set automatically. It is, however, useful to know what the corresponding keywords are in the GIS data file.

- The keyword DATAMODE can take the value PH for PH mode or MPC for MPC mode. It appears in all the headers.
- The keyword PHA_BINS gives the number of PHA bins, both for PH and MPC modes. It appears in the primary header and in the headers of the EVENTS (PH mode) and SPECTRUM (MPC mode) extensions.
- The following keywords appear only in PH mode files – in the primary header and in the header of the EVENTS extension. Together with PHA_BINS, they describe the bit assignment:

```
PHA_BINS=                 1024 / number of bins for PHA
RISEBINS=                   32 / number of bins for RISE_TIME
TIMEBINS=                    1 / number of bins for TIME
SP_BINS =                    1 / number of bins for SPREAD
RAWXBINS=                  256 / number of bins for RAWX
RAWYBINS=                  256 / number of bins for RAWY
```

  Note that the values in this example correspond to the standard bit assignment. Furthermore, when RISEBINS=1, the file contains no rise time information; consequently, background rejection based on the RTI, or invariant rise-time, using `gisclean`, cannot be performed.

- The keyword TIMEDEL gives the time resolution of both PH and MPC data. It appears in the primary header and in the headers of the EVENTS (PH mode) and SPECTRUM (MPC mode) extensions.
- The following three keywords appear in the primary headers of PH and MPC mode files. They give the status of the the high voltage:

```
HV_RED  = 'OFF     '           / HV-reduction on/off
HVH_LVL =                    3 / HV-High level (0 - 7)
HVL_LVL =                    4 / HV-Low level (0 - 7)
```

  The values given here correspond to valid data: files which have different values are garbage, and are recognized as such by `XSELECT` which does not, by default, include them in '`obscats`' (observation catalogs).

- Finally, the keyword S_DSCR indicates whether the on-board Spread Discriminator, which rejects events based on their UV light distribution, is on or off. The Spread Discriminator was first switched on in May 93: observations before then, and a small number of observations after this, were carried out with S_DSCR='OFF'. The intrinsic background is much smaller when S_DSCR='ON', which is its normal setting.

3.5 GIS Gain Determination

In the GIS calibrated event files, each event is given a PI value which is proportional to the input photon energy. In the process of calculating PI values from original PHA, instrumental gain is determined, which is a complicated function of time, detector position and temperature.

Details on the GIS gain determination method are explained at the following page:

`http://heasarc.gsfc.nasa.gov/docs/asca/gain.html`.

In the standard GIS processing, nominal accuracy of the GIS gain determination is +/- 1 which is considered to be the GIS absolute energy accuracy.

3.5.1 Recalculate GIS Gain Using the Latest Calibration

Usually users do not have to worry about the GIS gain determination in the standard processing, which keeps up with the latest calibration, except the case that the GIS gain is determined by *extrapolation*. The extrapolation is unavoidable for the most recent data, since it takes time to monitor the long-term gain change and implement the calibration results into the standard processing.

So far, it has been confirmed that the GIS gain determined by extrapolation in the standard processing is consistent with that determined by interpolation. However, if users want to apply the latest gain calibration when it is made available, follow the following procedure (see also the URL address above):

1. Obtain the latest `gis_temp2gain.fits` file from ISAS at

   `ftp://ftp.astro.isas.ac.jp/asca/calibration/gis/data/gis_temp2gain.fits`.

2. Run the `update_gis_gain.pl` script, which is available at

   `ftp://legacy.gsfc.nasa.gov/asca/scripts/reduction/update_gis_gain.pl`.

The `update_gis_gain.pl` script creates a new gain history file using `gis_temp2gain.fits` by running the `temp2gain` FTOOL, followed by `ascalin` to recalculate the PI values of the GIS event files using the new gain history file.

3.5.2 Manual Adjustment of the GIS Gain

It is possible for Guest Observers to manually adjust the gain and redetermine the PI values using `ascalin`.[2]

Here is an example to re-determine PI values that are 0.978 (=1/1.022) times the original values, for the events file `ad43001000g300370h.evt`:

```
ascalin datafile=ad43001000g300370h.evt calfile=caldb tempofile=\
ft950908_0323_0800.ghf attitude=none gainnorm=1.022
```

[2]Note that this is suggested only for experimental purposes, and ASCA GOF cannot endorse the results obtained as a result of artificial gain adjustments.

Here, `ft950908_0323_0800.ghf` is the gain history file which is in the `aux` directory of the data distribution package or the *ASCA* archives. The plausible gain normalization factor has to be determined independently by, for example, using the XSPEC gain command. Note that the new PI values will be the old PI values divided by the input `gainnorm`. This is made so that the output of the XSPEC gain command can be directly used here. Instrumental spectral features at the gold M-edge (2.2 keV) and Xenon L-edge (4.8 keV) may be used as fiducial marks for the gain adjustment.

Also, please consult the 'GIS Gain Correction' Web page at the URL

`http://heasarc.gsfc.nasa.gov/docs/asca/gain_correction.html`

for more details and examples.

3.6 Other Issues Related to GIS Data

Here are some other important points to bear in mind with the GIS.

- Events files from GIS2 and GIS3 cannot be mixed to extract images and spectra.
  The two GIS detectors have different spatial characteristics and background. It should be possible, however, to make a combined light curve from GIS2 and GIS3 data which, when analyzed, would not yield misleading timing results. It is possible to combine two energy spectra from GIS2 and GIS3[3] and to superpose GIS2 and GIS3 images taking account of the correct detector responses, after they are separately extracted from separate events files.

- Nearly all GIS data have been taken in PH mode with standard bit assignments.
  The rare exceptions are non-standard PH mode, used to increase temporal resolution, or MPC mode used for very bright sources.

- Temporal resolution depends on bit rate and bit assignment.
  Combining data with different bit rates is acceptable, provided the highest temporal resolution is not required throughout. However, if the very highest time resolution is required (e.g., for pulsar timing analysis), then only HIGH bit-rate data should be analyzed.

- Data taken in LOW bit-rate *can* be used.
  Although hot and flickering pixels completely saturate the portion of telemetry devoted to SIS data, LOW bit-rate GIS data are not affected in this way there is no reason to exclude them for *spectral work*. Note, however that the telemetry limit is low, at 4 count/s/GIS. This will be important only if accurate fluxes are required and for temporal analysis. Telemetry saturation will not affect spectral shapes and images, *but* the normalization (flux) will be reduced.

- To obtain the correct flux, a correction will be needed for the electronic deadtime.
  GIS deadtime will become important for sources with $\gg$ 10 cts/s/GIS. To carry out the deadtime correction, the FTOOLS `deadtime` (for spectra; see §8.11) and `ldeadtime` (for light curves; see 9.8) can be used.

- All GIS3 PH data acquired in PH mode between 1994 February 10 and 1994 April 8 suffered from an on-board software-related problem, resulting in a loss of digital resolution.

[3]You may use the `addascaspec` script for that. See §8.10 for detail.

The data taken with the standard bit-assignment have 128 spectral channels, as opposed to the ordinary 1024. Please consult the original announcement from the GIS team for details on this problem. This is available at

`http://heasarc.gsfc.nasa.gov/docs/asca/op_status/maxima940410.html`.

For spectral analysis of the data taken during this period, RMFs with 128 channels have to be used corresponding to the 128 channels of the PHA data. The 128 channel RMF is available in the *ASCA* calibration database at [4]

`ftp://legacy.gsfc.nasa.gov/caldb/data/asca/gis/cpf/95mar06/gis3v4_0_128ch.rmf`.

When making an ARF with `ascaarf`, the 128 channel RMF should be used so that the ARF will have 128 channels.

[4] This file was made with the FTOOL `rbnrmf` with the following command from the 1024 channel RMF: `rbnrmf infile=gis3v4_0.rmf nchan=128 cmpmode=linear outfile=gis3v4_0_128ch.rmf`

Chapter 4

SIS ISSUES

4.1 Introduction

This chapter describes the aspects of the SIS performance which users should be aware of when reducing and analyzing data. In particular, the various SIS data modes are discussed alongside the special analysis techniques they require. Also described is the issue of hot and flickering pixels. For the latest information about the SIS, please consult the Web pages 'SIS News' at the URL

`http://heasarc.gsfc.nasa.gov/docs/asca/sisnews.html`

and 'Calibration Uncertainties' (§1.7).

4.2 Description of SIS Modes

Various modes are available for observing a source with the SIS, the choice depending on source brightness, the extent of the source and the time resolution desired. For an observation, two concurrent modes are set: the clocking mode (or CCD mode), which determines how the CCDs are read out, and the data mode, which determines how the charge cloud created by a photon is described. Mode-related keywords which appear in SIS data files are described in §4.12.

4.2.1 CCD Clocking Modes

The SIS CCDs are operated in what is known as 'frame-transfer' configuration. Each CCD is divided into two areas, the imaging area, which is exposed to the X-ray optics, and the readout area, which is shielded. Each imaging-area pixel has a corresponding pixel in the readout area to which the charge is transferred (in 16 ms). Once transferred, the charge resides in the readout pixel until the pixel takes its turn to be read out. Readout is effected by applying pulses of voltage ('clock' pulses) across the CCD which move the charge packets - row by row, pixel by pixel - to the amplifier. Reading out an entire CCD in this way takes 4 seconds (the slower the readout, the lower the readout noise). Each SIS camera has four CCDs, and the time resolution is determined by the ordering of the imaging/readout cycles of the four CCDs. The various CCD clocking modes are:

- 4-CCD mode: All four CCDs are exposed at the same time. Thus, the time resolution is 16 s. Due to the increasing effects of radiation damage, 4-CCD mode became problematic during the AO-3 period.

- 2-CCD mode: Two CCDs are exposed. The field of view is half that for 4-CCD mode, and the time resolution is 8 s. For each SIS camera, any pair of chips can be used in 2-CCD mode.
- 1-CCD mode: One CCD is exposed. The field of view is a quarter of that for 4-CCD mode, and the time resolution is 4 s. For each SIS camera, any chip may be used in 1-CCD mode, although the default chips (and the best calibrated), used for almost all point sources, are SIS0-chip1 and SIS1-chip3.

In addition, a special clocking mode known as the 'parallel sum mode' is used in conjunction with FAST mode (see below).

4.2.2 CCD Data Modes

Typically, the charge cloud produced by an X-ray photon is not localized to one pixel but spread out over several pixels. There are three basic data modes, FAINT, BRIGHT and FAST, corresponding to three different schemes of analyzing and telemetering this spread to the ground.

- **FAINT mode:** SIS spectra in this mode have 4096 channels. The pixel position of the center of the event is given, along with the pulse height recorded in the nine pixels around it (central pixel plus eight surrounding pixels in a 3 x 3 sq-pixel grid).
- **BRIGHT mode:** SIS spectra in this mode have 2048 channels. This compression of channels (compared with FAINT mode) is achieved by binning up channels 1024-2047 by a factor of two and channels 2048 - 4095 by a factor of four. The pixel position of the center of the event is given, together with the *grade* describing the nature of the spread, and the total pulse height above an adjustable threshold.
- **FAST mode** (implies the use of 'parallel sum' clocking mode): One CCD is exposed and charges are continually transferred (every 15.625 ms). This mode sacrifices position information for temporal resolution. Events are time-tagged with a precision of 15.625 ms, with only 1 bit for spatial information (whether an event was 'inside' or 'outside' the selected region). There are 2048 channels in FAST mode spectra (same binning as BRIGHT mode), with a 1-dimensional version of grade.

The current generation of analysis software cannot handle FAINT mode data directly. For this reason, they are converted on the ground into BRIGHT or BRIGHT2 mode. Converted BRIGHT mode is an exact emulation of the on-board BRIGHT mode (note, therefore, that 'BRIGHT mode data' may have been processed on-board or converted from FAINT mode on the ground). BRIGHT2 mode is not a telemetry mode, but a slight variation of the BRIGHT mode which takes advantage of the ability in FAINT mode of applying two corrections, event-by-event 'echo' and 'DFE' (more about these effects later), which cannot be made in BRIGHT mode. BRIGHT2 mode spectra have 4096 channels, and cannot be combined with BRIGHT mode spectra because of the different way echo and DFE corrections are treated (see §4.6).

4.3 Summary of Issues Related to SIS Data

Before giving the properties and analysis techniques associated with each mode, here is a list of the most important issues related to SIS data:

- **SIS response is time dependent.** Due to radiation damage (in the forms of Residual Dark Distribution and non-uniform CTI), the quantum efficiency and resolution of both SIS instruments are degrading with time. It is therefore necessary to create an appropriate response matrix for each observation (see §4.8).

- **Combining SIS-0 and SIS-1 spectra leads to a loss of information.** The two SIS cameras have different responses and backgrounds, and the cross-calibration of the two is not perfect. For this reason, our software will not ordinarily allow events files from these two instruments to be combined. While images and light curves from SIS-0 and SIS-1 can be combined safely, combining spectra inevitably leads to a loss of information. We therefore recommend simultaneous fitting of SIS-0 and SIS-1 spectra (as well as GIS spectra) as the first option. For faint sources, however, where statistical error dominates over the systematics, combining spectra may prove more convenient and we therefore provide tools for this.

- **Spectra from different chips on the same SIS can be combined.** For this, PI channels *must* be used and separate response matrices for each chip must be made and combined to minimize the systematic errors. Still, imperfect calibration can lead to a degradation of energy resolution.

- **In general, data taken in different clocking modes have different responses and backgrounds.** Even if the same part of the same chip is used, data taken in different clocking modes should be analyzed separately.

- **In principle, SIS data taken in different bit rates can be analyzed together,** if that is the only difference. This is because changing the bit rate does not affect the SIS response.

- **The current generation of analysis software can analyze FAINT mode data only after they have been converted to BRIGHT or BRIGHT2 mode.** This is because FAINT mode events have nine PHA values, which have to be 'collapsed' to a single value. Note that on-board (or 'true') BRIGHT mode data and 'converted' BRIGHT mode can be analyzed together.

- **BRIGHT mode data cannot be combined with BRIGHT2 mode data.** BRIGHT2 mode data, which have an event-by-event echo correction, require a different response from BRIGHT mode, which has a mean echo correction incorporated into the response matrices. DFE and RDD may also be treated differently. See §4.6 for details.

- **FAST mode data contain almost no spatial information.** In FAST mode, all that describes the position of an event is a single bit indicating whether the event occurred inside or outside the prescribed spatial mask.

- **Data taken in LOW bit rate are invariably saturated.** Hot and flickering pixels completely saturate the portion of telemetry devoted to SIS data. Telemetry saturated SIS data may be used for spectral work but not when accurate fluxes or light curves are required. In such cases the LOW bit rated can be omitted from the analysis and/or telemetry-saturated frames screened (see §5.4.5).

4.4 Hot and Flickering Pixels

Each CCD chip in the two SIS cameras has a small number of catalogable pixels (approximately 10 out of 175,000) which have a higher than normal dark current. One of the eight chips, SIS0-chip0, has about 50 such hot pixels. Even though the number of these pixels is small as a percentage of the array total, each such pixel produces a false 'event' which is not rejected by the on-board digital processor and is telemetered.

In addition to the hot pixels, there is also a class of 'flickering pixels'. As implied by the name, they are not persistent like the hot pixels, but repeat with a variety of duty cycles on time scales typically ranging from minutes to days. For example, one may stay active for several days, during which it is 'detected' in 10% of all exposures. There are several hundred such isolated flickering pixels per CCD.

The flickering pixels are thought to be a symptom of radiation damage, although we do not know the detailed physics of how they are created. As a result, the rates of flickering pixels show a secular increase, and are causing severe problems of telemetry saturation in many modes. Recent updates can be found in the *ASCA Observation Planning Guide* at the URL

`http://heasarc.gsfc.nasa.gov/docs/asca/planning_tools/obs_guide.html`.

The rate of flickering pixels depends on the clocking mode: Since they are caused by an accumulation of dark currents, the longer the integrate time, the higher the probabilities are that a charge in a given pixel will exceed the event threshold. Thus the flickering pixel problem is most severe in 4-CCD mode, whereas in 1-CCD mode, their rate remains relatively unchanged since launch.

The spectrum of hot and flickering pixels is very soft: most of the counts being below 0.5 keV. However non-negligible effects are possible at higher energies, in some chips.

4.4.1 Removing Hot and Flickering Pixels

True X-ray photons are spread over many pixels of the CCDs, because of the vast oversampling of the XRT PSF. Therefore, for a typical observation, the total number of X-ray photons detected in each pixel remains small. In contrast, hot pixels and the more active flickering pixels are 'detected' far more often than the surrounding pixels that received a similar X-ray flux. The FTOOL `cleansis` takes advantage of this fact to remove hot and flickering pixel events from BRIGHT and BRIGHT2 mode data files.

In one version of the algorithm (method 1), a straight cut-off is used (i.e., any pixels with more than N events are removed). Although this method may be advantageous under certain circumstances, and also serves as a backup, the default is a more sophisticated method (method 2). This method uses a comparison with a Poissonian distribution to reject hot and flickering pixels iteratively. For more details, type `fhelp cleansis` at your system prompt. As with method 1, a filtered events list is extracted.

The processing script runs `cleansis` in producing the 'screened' events files; `ascascreen` also runs `cleansis` by default. It is also possible to run it from `XSELECT` (use command `sisclean`, followed by `save clean`).

The use of `cleansis` may, in principle, remove a small number of real events (either by misclassifying, or by photons landing on hot/flickering pixels). However, the fraction of hot/flickering pixels is small enough that this is not a major concern.

On the other hand, it is impossible to exclude very low duty cycle flickering pixels. Combined with the fact that the flickering pixel rate is increasing, this may lead to an imperfect subtraction of background. For example, if the PV phase blank sky field is used as background for a more recent observation (particularly of low surface brightness extended objects), it may result in a spurious low-energy 'excess'. For more details on this subject, please consult the Ueda *et al.* article in *ASCAnews #4* at the URL

`http://heasarc.gsfc.nasa.gov/docs/asca/newsletters/flickering4.html`.

Despite this, for most observations, the practical effects of hot and flickering pixels is limited to the danger of telemetry saturation.

4.4.2 Event Threshold and Level Discrimination

The flickering pixels have a predominantly soft spectrum: it is therefore possible to reduce their number in the telemetry by changing the event threshold or by applying a level discrimination.

The event threshold is a fundamental parameter of the on-board processing, and can be changed only by the consensus of the SIS team. After initial testing during the early part of the PV phase, the event threshold was set at 100 ADU for all chips until 1995 Dec 23; after this date, the event thresholds in ADU have been set to different values for different chips such that they all correspond to an energy of 0.4 keV.

Level discrimination, when activated, plays a similar role (all events whose central pixel is below the threshold are discarded during on-board processing). This can be employed in two ways.

- By a prior arrangement with the PI: throwing away photons below 0.45 keV, for example, may have little impact on the science while avoiding telemetry saturation.
- By the judgement of the scientists at the Kagoshima downlink station. This will happen if a flickering pixel was seen to be unexpectedly high in real-time data.

Note that data with and without level discrimination, or with different thresholds for level discrimination during an observation, may be mixed in a single sequence in the latter case. The processing script creates separate 'unscreened' and 'screened' files in such cases.

4.4.3 Light Leak and Address Discrimination

The CCDs that make up the SIS detector system are sensitive to optical light. Optical photons can be numerous, each creating an electron-hole pair; they can therefore have the effect of raising the dark level. We have discovered, moreover, that parts of SIS-0 Chip 2 and Chip 3 suffer from 'light leakage': when the line of sight is close to the bright Earth, these regions produce many spurious 'detections', thought to be due to light entering SIS-0 near these regions. They have effects that are similar to the flickering pixels, although the physical origins are distinct.

Since 1993 July 8, the affected areas have been masked off in observations that use these chips, whenever the line of sight is within 25 degrees of the bright Earth.

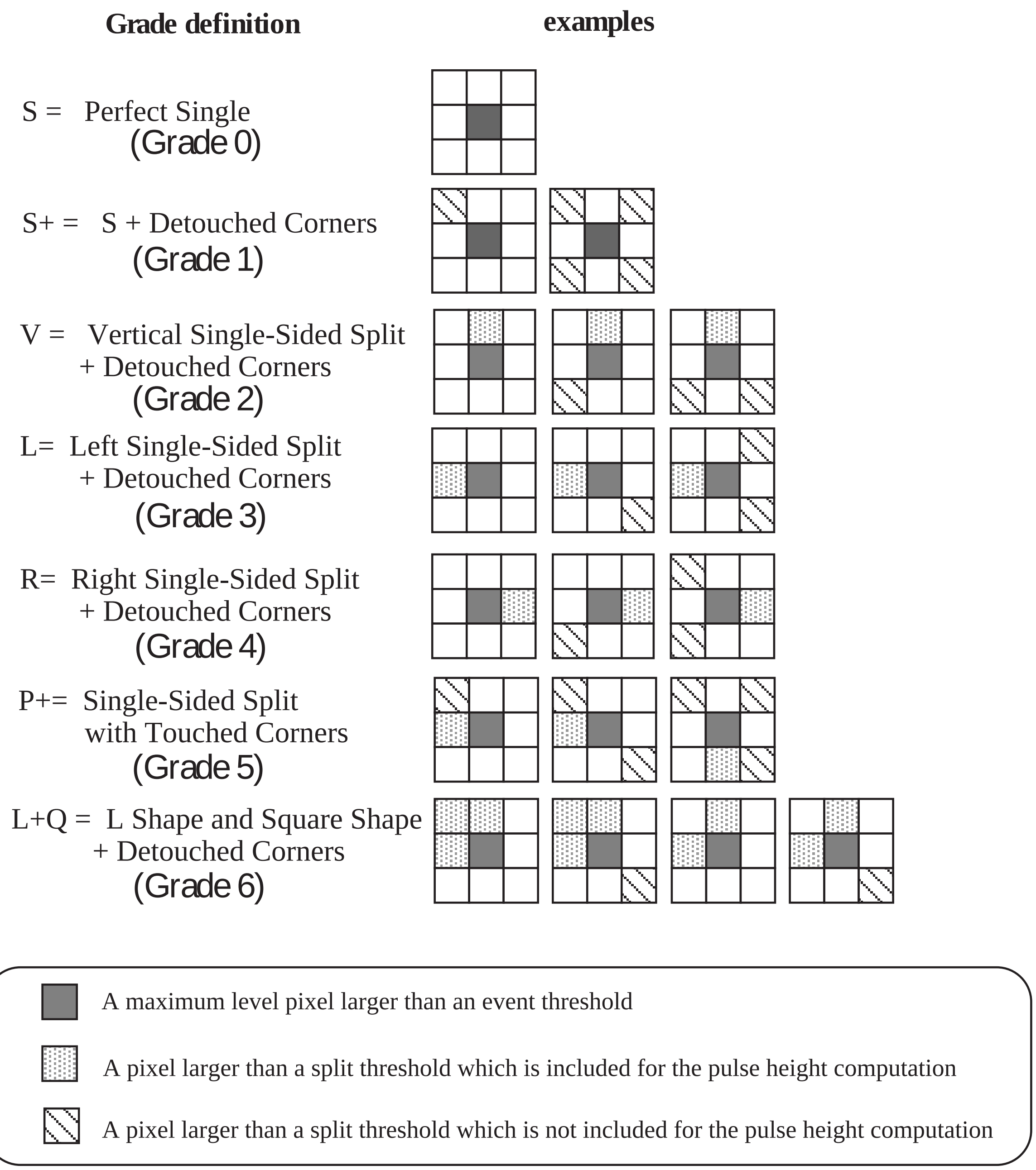
4.5 Analyzing BRIGHT Mode Data, Grade and PI

Most SIS data are reduced and analyzed in BRIGHT mode, the reason being that for observations done in a mixture of FAINT and BRIGHT modes, the largest homogeneous data set is provided by combining on-board and converted BRIGHT mode data. Moreover, many targets do not yield sufficient signal-to-noise to take advantage of the enhancements that FAINT and BRIGHT2 modes afford.

BRIGHT mode is relatively straightforward, but two key issues deserve elaboration: grade, which characterizes the spatial pixel-distribution of an event, and PI (Pulse Invariance), a linearized version of PHA, which allows events from different chips to be analyzed together and secular gain drifts to be corrected. PI data are only available for BRIGHT mode and BRIGHT2 modes.

4.5.1 Classification of Events and Grade

Figure 4.1: The definition and examples of SIS grades



To eliminate events due to charged particles and to attain the expected energy resolution, X-ray events in the depletion layer from each readout are identified and classified. The first step in finding an X-ray event is to apply the criterion that the central pixel of a 3 x 3 sq-pixel block must have the highest pulse height. In FAINT Mode, if the pulse height of a pixel which satisfies this criterion is higher than the event threshold, the pulse heights of the 3 x 3 sq-pixel block will be sent to the ground.

In BRIGHT Mode, the eight pixels around the central pixel will be compared with the split event threshold which is lower than the event threshold. Based on the distribution of the pixels which have a pulse height higher than the split event threshold, the event is classified, i.e., it is assigned a grade. With this scheme, all the basic charge distributions found by experiment can be included.

The eight grades (0–7) are extensions of four basic groups: S (single), P (single-sided split; subdivided into Vertical, Left and Rights), L (L-shaped) and Q (square-shaped). The extensions arise because of the existence, in some events, of corner pixels which do not belong to the block since they touch the distributions only at the corners (so-called 'detached' corners). Usually, charge from an X-ray interaction (less than, say, 5 keV) is split into 1 or 2 pixels, i.e., S events (grades 0-1) and P events (grades 2-5). However, grade-1 events, which consist of single events with one or more detached corners, should be ignored because most are particle events (it is hard for an X-ray event to split charge diagonally). A sizeable fraction of higher energy X-rays (5-10 keV), which tend to be absorbed deeper in the CCDs, are detected as L or Q (grade-6) events, while grade 7 events are dominated by particle events. Since each pixel included in the final PHA calculation contributes its own read-out-noise, grade 0 events have the best resolution and grade 6 the worst. The SIS team has concentrated on a combination of grades 0, 2, 3 and 4; this combination is therefore the best-calibrated. In some instances, however, it may make sense to add grade 6 events (to increase signal-to-noise at high energies) or to concentrate on grade 0.

Between launch and 1993 November 30 07:30 UT, on-board BRIGHT mode telemetry included events with grades 0–4; since then, events with grades 0–6 are telemetered in BRIGHT mode. FAINT mode telemetry contain all events including grade 7; it is customary to throw out grade 7 events during the conversion to BRIGHT or BRIGHT2 data.

Note that in FAST mode, a simpler version of grade is used: FAST mode grade 0 corresponds to BRIGHT mode grades 0 and 2, i.e., to good data. FAST mode grade 1 corresponds to all other BRIGHT mode grades, i.e., to the remaining good plus the bad grades.

4.5.2 SIS PI

SIS BRIGHT and BRIGHT2 data files have a PI (Pulse Invariant) column in addition to the PHA column. The latter is used to record the amount of charge read out from the 3 x 3 sq-pixel area of the chip that contained the event. The PHA values are therefore closely related to the photon energy with the following caveats.

- The energy-to-PHA conversion is different for each chip.
- Due to CTE (Charge Transfer Efficiency), the amount of charge read out does not equal the amount of charge originally accumulated in a pixel. As a consequence, the energy-to-PHA conversion is dependent on the position on the chip (i.e., the number of transfers) and on observation epoch (accumulation of radiation damage changing the CTE).

The PI column is incorporated into the events files and is populated during processing (REV1 and later). In addition, the FTOOL `sispi` can be used to update the column if necessary. The new values will be based on PHA and other columns, as well as a calibration file, which can be obtained by FTP from

`ftp://legacy.gsfc.nasa.gov//caldb/data/asca/sis/bcf/`.

The name of this file begins with `sisph2pi_` and the remaining six digits indicate the release date in the form DDMMYY. Obviously you should obtain the latest file. As of 1997 March, the latest file is called `sisph2pi_110397.fits`. The current setting for the parameter `calfile` should be overridden with the new file name. In populating the PI column, `sispi` removes the following features of the PHA column:

1. Chip-to-chip differences in gain.
2. Secular changes in gain, i.e, the decrease in gain due to the effect of radiation damage on the CTE.
3. The differences in gain within each chip due to the positional dependence of the CTE.

Tracking of the secular changes in CTE is a continuing calibration task of the SIS team, based on the annual observations of the Cas A supernova remnant and long-term accumulation of Ni line data in the instrumental background. For the latest data, the calculation of PI values inevitably involves some extrapolation of the past trend (by up to 18 months), which can lead to some inaccuracies. Whenever a new calibration file is announced (via the `ascanews` exploder, the *ASCA* GOF homepage, and/or the *ASCA* Newsletter), the release note will include indications of which observations would benefit from re-running of `sispi`. For the most up-to-date status of the CTE calibration as of 1997 March, please consult the Dotani *et al.* article in the *ASCA* newsletter no 5.

It is also necessary to run `sispi` whenever FAINT mode data are converted to BRIGHT or BRIGHT2 mode data. This is done automatically, if the conversion is performed using `ascascreen` or `XSELECT`.

PI is currently not available for SIS FAST mode data because the PHA-to-PI conversion is position-dependent (FAST mode data do not contain positional information). See §4.10 for more information on how to analyze FAST mode data.

4.5.3 Using SIS PI

PI has been the default column for spectral extractions in `XSELECT` since the February 1995 release of FTOOLS for BRIGHT and BRIGHT2 mode data. To change the column used for spectral extractions, use the `set phaname` command. **However, it is recommended that you ALWAYS use PI channels, even for early data**.

4.6 Analyzing FAINT and BRIGHT2 Mode Data, Echo, and DFE

Each event in FAINT mode has nine PHA values, i.e., a 3 x 3 sq-pixel block, containing PHA values which exceed the event threshold and which are centered on the brightest pixel. FAINT mode data, therefore, give the user the greatest freedom to select events based on the shape of the charge cloud and hence the greatest potential to realize the maximum energy resolution of the SIS. However, since conventional X-ray analysis requires that each event has one PHA value, FAINT mode data are converted using the FTOOL `faint` which is run as part of standard processing. FAINT mode data are converted to two different data modes: (1) BRIGHT mode; and (2) BRIGHT2 mode.

By converting FAINT mode data to BRIGHT mode, users can combine 'converted' BRIGHT and 'on-board' BRIGHT mode data, thereby creating the largest homogeneous dataset for their observations (see above). However, in the conversion to BRIGHT, the opportunity is lost to make two corrections which can be important with high-signal-to-noise SIS data, namely, the event-by-event dark frame error (DFE) and echo corrections. These two corrections are applied when converting FAINT mode data to BRIGHT2 mode (this makes, however, the BRIGHT2 mode data incompatible with the on-board BRIGHT mode data; these two cannot be combined).

For REV1 and later, BRIGHT2 data files have been provided alongside the 'parent' FAINT files and the 'sister' BRIGHT files which are converted from the same FAINT files. This means that for observations done in a mixture of FAINT and BRIGHT modes, users with REV1 data will find four types of SIS data file:

1. On-board BRIGHT mode: mode code (last two digit before the bit rate code in *ASCA* file names; see *ASCA* Getting Started Guide) '02',
2. FAINT mode ('01'),
3. Converted BRIGHT mode ('02'), and
4. Converted BRIGHT2 mode ('12').

4.6.1 Echo Effect

One of the ways BRIGHT2 mode data differ from BRIGHT mode data is in how the echo effect is dealt with. This effect arises in the analog electronics on-board which misassign a small fraction (known as the echo ratio) of the charge in a pixel to the next pixel read out. If uncorrected, it results in an apparent PHA value lower than one would predict for a given photon energy, as well as a misassigned grade. The echo ratio

- differs in SIS0 and SIS1;
- but is the same from chip to chip;
- has no energy dependence (at least between 0.7-7 keV);
- shows a secular increase of unknown origin: between April 1993 and April 1994, the echo ratio increased from 1.42 to 1.84 per cent in SIS0-chip1, and from 0.84 to 1.08 per cent in SIS1-chip3.

Given the value of the echo ratio, the grade and PHA (related to energy) of each event can be easily corrected provided that the event data are in FAINT mode. With FAINT mode data, the real PHA of each pixel is estimated in the FTOOL `faint`.

For BRIGHT mode data, it is impossible to correct the echo effect event-by-event. Instead, the echo effect is accounted for by using response matrices which have the aggregate effect built in.

The echo effect is small, and usually can be neglected. To test whether it does affect your scientific results, the results of using BRIGHT (including converted FAINT data) and BRIGHT2 mode data can be compared. In many cases, the advantage of increased statistics from combining converted and on-board BRIGHT data will outweigh the more accurate echo correction that BRIGHT2 data provide.

4.6.2 Dark Frame Error

Even when no events — photons or particles — are detected, a small amount of charge flows through the CCDs. This residual level makes up the dark frame level which must be subtracted from PHA values to derive their true values. The dark frame level varies across each chip and depends on the radiation environment of the instrument. Because of these dependencies, the on-board computer calculates a coarse map of the dark frame for each chip and updates the map every read-out.

During the course of the PV phase, it was discovered that the on-board calculation of this level is not always accurate. The uncertainty, known as the dark frame error (DFE), arises because the dark frame is calculated on board by averaging pixels with PHA values between -40 and +40 ADU (1 Analog-to-Digital Unit is about 3.5 eV). When fluctuations in the dark frame occur on time scales less than the averaging period, the dark frame is not correct.

DFE can be divided into three components:

1. A slight offset for night-time data, constant across a single observation but variable from pointing to pointing. For 4-CCD mode, DFE is typically +/- 3 ADU. For 2-CCD and 1-CCD modes, which have shorter readout times, it is almost zero.

2. A different offset for day-time data, which is less stable than night-time data and often shows large excursions. Because of light leakage, DFE behaves differently during satellite day. Although the mean values are almost the same as in satellite night, the amplitude of fluctuation is typically doubled. When the angle between the SIS FOV and the bright Earth is less than 25 degrees, DFE can be a few tens of ADU. Such data should not be used because the DFE is too large for correction - nor should data with highly variable DFE.

3. Large excursions often seen at transitions between day and night and passages in and out of the South Atlantic Anomaly (SAA). As the absolute dark frame is different between satellite day and night, DFE jumps sharply at the day-night terminator. The size of the jump correlates well with the angle between the FOV and the Sun: a few ADU at angles greater than 90 degrees, to about 20 and 10 ADU at 70 degrees for SIS0 and SIS1, respectively. After a jump, DFE returns exponentially to the pre-jump level because the on-board software updates the dark frame based on the previous exposures. When the jump is large or a precise correction is needed, the data in this transition zone should be avoided. DFE levels are re-established after several read-out cycles.

   Similar jumps in DFE occur when the satellite leaves the SAA. This happens because the analog electronics of the SIS are turned off in the SAA by the Radiation Belt Monitor, keeping the dark frame at its pre-SAA level. As the particle background raises the dark frame, the dark frame does not attain its true level until several readouts have elapsed.

DFE is corrected in FAINT mode by examining the PHA distribution of the corner pixels of each 3 x 3 sq-pixel event. Only grades 0, 2, 3 and 4 are used because the corner pixels of these grades are not thought to contain charge due to X-rays or particles, i.e., they represent the true dark level. Since DFE varies with time, a 'DFE light curve' is calculated - 100 events are needed to determine the peak value of the corner pixel distribution with an accuracy of 1 ADU. The calculation of DFE is performed by the FTOOL `faintdfe` and the correction itself made by the FTOOL `faint`.

Although DFE is small, its maximum value of about 0.07 keV means that it should not be neglected in studies of spectral line features. The extent to which your scientific result can be tested, again by comparing BRIGHT and BRIGHT2 mode data.

The algorithm implemented in old versions of `faintdfe`, distributed with FTOOLS v3.4 and older, worked poorly for data which suffer from the effects of Residual Dark Distribution (see below). Newer versions (FTOOLS v3.5 and later) of `faintdfe` recognizes 3 different definitions of the zero level.

1. zerodef=0: Compatability mode with old `faintdfe`.
2. zerodef=1: The new default definition for BRIGHT2 mode.
3. zerodef=2: Best match with on-board BRIGHT mode.

Please refer to the Dotani *et al.* article in *ASCAnews #4*

`http://heasarc.gsfc.nasa.gov/docs/asca/newsletters/sis_calibration4.html`

for full details.

4.6.3 Combining FAINT and BRIGHT Modes Using FAINTDFE

Starting with FTOOLS v3.5 version, `faint` allows the use of a DFE file (the output of `faintdfe`) to convert to BRIGHT mode, but only if the DFE file is created with `zerodef=2`.

The rationale is that the day/night DFE effect can be corrected better in ground processing than on-board. Anticipating this, the SIS team has been using FAINT mode preferentially during orbital day time, and BRIGHT mode during orbital night (when the DFE is small and stable), when a mixture of the two is requested by the Principal Investigator. To take advantage of this, you must first convert the FAINT mode data to BRIGHT mode using `faintdfe` with `zerodef=2`, then:

1. Combine with all on-board BRIGHT mode data; or
2. Combine with all night-time on-board BRIGHT mode data. (In many observations, there are more BRIGHT mode data than night time data)

For the first option, no special technique is necessary: we recommend this as the default analysis method that maximizes the statistical quality of the data, while for best calibration we recommend the use of BRIGHT2 mode data only. For the on-board BRIGHT mode data, an additional `mkf` selection of NSAS<0 should be applied (see §5 and §6).

4.7 Non-uniform CTI

Radiation damage has not altered the relationship between the energy of incoming X-ray photons and the number of electron-hole pairs generated by them. Rather, it has created a number of charge traps; as the charge is transferred for read-out, each trap removes a constant fraction: this is called the Charge Transfer Inefficiency, or CTI.

The effect of CTI depends on the number of charge traps that between the pixel where the X-ray event was detected and the read-out node. There exist a sufficient number of traps that a statistical prediction can be made of the average reduction in charge, given the RAWX and RAWY positions of the event. The use of PI, rather than PHA, column restores the gain as described above.

However, the distribution of charge traps is not completely uniform, and thus the gain change may differ from one row to the next. This has the effect of spreading the PHA values measured for a mono-energetic input X-ray, i.e., a degradation of the spectral resolution.

The SIS team has derived an empirical formula for this:

$$\Delta E = 8.60 \times 10^{-3} \sqrt{\mathrm{RON}^2 + F \frac{E}{3.65 \times 10^{-3}}}$$

where RON is the read-out-noise (5 e^- RMS at launch), F is the Fano Factor, and E is the input photon energy, and ΔE is the FWHM resolution. The Fano factor was $F_0 \sim 0.12$ at launch; the effect of non-uniform CTI has been modeled by the SIS team as a linear increase in the effective Fano factor:

$$F = F_0 + F_1 \times t$$

Where t is time since launch in seconds, and F_1 is 3.3×10^{-9} for SIS-0 and 2.9×10^{-9} for SIS-1. The effective RON has become significantly (somewhat) worse than 5 e^- RMS in 4 (2) CCD mode due to RDD effects.

For the latest report on SIS spectral resolution, please read the Dotani *et al.* article in *ASCAnews #5*.

4.8 Residual Dark Distribution (RDD)

Dark frame is calculated on-board by averaging events with PHA in the range -40 to $+40$ ADU, which would give an accurate indication of the true dark level if the distribution of dark current is symmetric around 0. However, radiation damage has produced a population of pixels with higher dark currents (the extremes of which are detected as flickering pixels), thus skewing the dark frame distribution: This is known as residual dark distribution (RDD; residual after the dark frame correction, on-board or on the ground using `faintdfe`). Although this is primarily the spectral distribution of dark current values integrated over a chip, the term is often (loosely) applied to the spatial distribution of dark currents. To distinguish, we will use the term RDD map for the latter. RDD has become a major problem for 4-CCD mode, and to a lesser degree, 2-CCD mode.

RDD can lead to mis-classification of event. For example, a grade 0 event may be recognized as a higher grade event because a neighboring pixel is very active. For higher grades, this effect is worse and can even result in a true photon event being classified as grade 7, i.e., as a rejected particle event. Thus RDD causes the effective quantum efficiency of the SIS to become lower. In addition, RDD degrades the spectral resolution: this can be understood because, even in the simplest case of a grade 0 photon correctly recognized as a grade 0 event, the PHA value may be incorrect depending on the level of dark current in the central pixel. When mis-classification is involved, the error in the resultant PHA value can be even larger. Since RDD depends on readout time, it is worse in 4-CCD mode than in 2-CCD and 1-CCD modes.

The SIS response generator, `sisrmg`, includes a model of the degrading spectral resolution due to RDD. However, it does not yet have a model of the degrading quantum efficiency. Both `faintdfe` and `sisrmg` rely on an analytical model of the RDD (the spectral distribution); as of 1998 July, it appears that the RDD spectral function needs a significant revision, particularly for 4-CCD mode data.

4.8.1 RDD Correction

It appears that each pixel of each chip of SIS has a characteristic dark current level, which is stable over several months, resulting in a similar dark charge level for a given clocking mode. After some processing to remove particle events and average out fluctuations, we produce the so-called "RDD map" files [1] In the early days of *ASCA*, Frame mode data were not taken regularly. The RDD map files exists for 4-CCD mode data only in 1993 Apr, 1994 July (except chip 0 on both SIS-0 and SIS-1), 1994 Nov, and in 1995 Mar; In 1995 Apr, Frame mode data were taken in 1, 2, and 4 CCD mode in all chips that are frequently used in the respective clocking modes. Starting in late 1995, we have started taking Frame mode data regularly. The resultant RDD maps are available at

`ftp://legacy.gsfc.nasa.gov/asca/data/trend/rev2/rddmap/`.

The file names have the form `rdd9304_s0c0m4_t61_62.fits` encoding the year and the month, instrument and chip numbers, the clocking mode, and the CCD temperature range.

RDD correction can be applied to Faint mode data file, by using the FTOOLS `correctrdd`, supplying the input FAINT mode file name (from the `unscreened` directory) and the appropriate RDD map file names. However, it is necessary to apply both the RDD correction and the DFE correction (which corrects for the dark frame changes within an observation due to, for example, the light leak), and the interplay between the two can lead to errors. It appears that the order `faintdfe`, `correctrdd`, then `faint` minimizes such errors.

Files corrected using the FTOOL `correctrdd` will have a keyword `RDDCOR_V` that tells `sisrmg` not to apply the RDD-related spectral resolution degradation model.

Please note that this procedure is still experimental, and questions remain regarding the current and the ultimate effectiveness of RDD correction. Issues are:

- The Poisson noise in the dark current increases as the square root of its absolute level. It is impossible to correct for the degradation in resolution due to this statistical effect.
- The dark current has a marked dependence on CCD temperature. This is not yet taken into account, although on some occasion enough Frame mode data are taken at different temperatures so that multiple RDD maps for the same mode for the same epoch may be available.
- Although `correctrdd` will run on BRIGHT mode data, this procedure is not expected to be effective.

Information in this section (and possible updates) can also be found at:

`http://heasarc.gsfc.nasa.gov/docs/asca/rddrecipe.html`.

4.9 Event Threshold and 2-pixel Events

We have recently discovered another effect that may lead to spurious measurement of N_H in SIS data: the current version of sisrmg uses a simplified model of how 2-pixel events interact with event threshold. When the event threshold is significantly different from the default, the efficiency predicted by sisrmg for energies $< 2\times$ `event threshold` is too high for SIS events of grades 2, 3, or 4. The same observations for which RDD is significant are the ones that tend to suffer most from

[1] A better name would have been Residual Dark Level map, since RDD originally referred to the spectral distribution of Dark Levels over the entire chip, whereas these maps are the spatial distribution of Dark Levels.

this effect (since radiation damage also increases the danger of telemetry saturation in a clocking-mode dependent manner). Also, the RDD effects tend to increase the 2-pixel events and make this effect more important (in early data, the fraction of 2-pixel events is <10% below 1 keV).

The situation is much more benign for grade 0 (single pixel) events; we recommend fitting a grade 0 spectrum and a grade 234 spectrum simultaneously, whenever the event threshold is significantly greater than 0.4 keV. More details can be found at:

`http://heasarc.gsfc.nasa.gov/docs/asca/2pixel.html`.

4.10 Analyzing FAST Mode Data and Address Discrimination

FAST mode requires special treatment in `XSELECT`, and analysis techniques for light curves and spectra are different from BRIGHT and BRIGHT2 modes. Although FAST mode provides no imaging information, a crude indication of position is provided by address discrimination.

4.10.1 Address Discrimination

The high time resolution of FAST mode is achieved at the expense of positional information. Instead of giving the pixel on which an event was centered, FAST mode simply indicates when the event occurred (with a precision of 15.626 ms) and whether it occurred inside or outside the prescribed address discrimination area. In the case of a strong point source, address discrimination is used to allow the exclusion, during reduction and analysis, of the central peak of the PSF which is likely to suffer from photon pile-up. The area itself is specified by the mission operation scientists and takes the form of a horizontal strip. In the FITS science file, the keyword `Sn_STAHm` gives the starting horizontal pixel (n is 0 or 1, depending on whether the file is from SIS0 or SIS1; m is the chip number), while `Sn_ENDHm` gives the end horizontal pixel. (To get the value of a FITS keyword, you can use the FTOOL `fkeyprint`, or, if you're uncertain of the keyword name, you can use the FTOOL `fdump` which can dump the entire header). Typically, a width of 2 arcmin is used. Setting such a narrow discrimination area before an observation takes place is difficult since it is not possible to predict, with the required precision, where the source will appear on the chip in question. Instead, the source is observed first in BRIGHT mode and the area is then set on the basis of the quick-look data taken after the first pass over the ground station.

In the FAST mode file itself, the arrival time of each event occupies the vertical (V) address of the event and is assigned to the RAWY column. Whether the event is inside or outside the selected area is given in the RAWX column (0 for inside, 1 for outside).

On-board address discrimination is used not only to exclude piled-up photons but to avoid telemetry saturation. This is done by enabling the address discrimination, that is, to telemeter only those events which occur inside or outside the selected area. The keyword `Sn_ARENA` takes the value 1 if address discrimination is enabled, 0 if it is not. Note that the decision whether to enable address discrimination is made before the observation by the ISAS and GOF duty scientists in consultation with the Principal Investigator. In addition, for FAST mode data without on-board address discrimination, the `XSELECT` command `select FAST` provides a direct and transparent way of identifying FAST mode events based on whether they occurred inside or outside the selected area.

The FAST mode events are classified into two grades; FAST mode grade 1 is usually dominated by the particle background, and should not be used in timing or spectral analysis. FAST mode grade 0 roughly corresponds to BRIGHT mode grades 0 and 2.

4.10.2 How to Analyze FAST Mode Data

Before working on the FAST mode data themselves, obtain an image from GIS PH mode data or SIS BRIGHT mode data, and determine the source position in (unbinned) DETX. Note that, for the GIS PH mode data, `XSELECT` produces unbinned images by default, but for the SIS imaging mode data, it rebins the images by a factor of 4 by default. Therefore you should revert to the original SIS binning by specifying `set xybinsize 1` in `XSELECT`. The source position is necessary for time assignment; an extreme error of the length of a CCD chip (about 11 arcmin) results in an error of about 80 msec in typical cases.

Next use `ascascreen`; the DETX position, and the detector you used to determine it, are necessary inputs for using `ascascreen` for FAST mode data.

In addition to the customary questions, you will be given the opportunity of selecting events based on whether they occurred inside or outside the address discriminator. You need not do the selection at this point: such a selection can also be applied later in `XSELECT` on the output files from `ascascreen`.

WARNING: In FAST mode you're likely to be dealing with a huge number of events and a similarly large number of time bins. `XSELECT` might suffer from problems related to running out of memory/diskspace.

4.10.3 Hot and Flickering Pixels in FAST mode

The rate of hot and flickering pixels is much lower in FAST mode because the chips are read out faster: there is simply less time for a flickering pixel to accumulate enough charge to cross the event threshold. However, they do occur (there is one particular hot pixel that plagues many (but not all) sets of SIS-1 Chip-3 FAST mode data), and present a real problem since the image-based methods to remove them cannot be used. This problem is manifested as a DC offset in light curves and as a huge peak at PHA channel around 200.

4.10.4 FAST Mode Light Curves

One aspect of working with FAST mode light curves requires special attention. If the address discrimination area is narrow, then, as the satellite attitude fluctuates, so will the number of events inside the discrimination area, thereby introducing spurious variability. Users can avoid this problem by including events outside the discrimination area in their analysis.

4.10.5 Potential Problems Peculiar to FAST Mode

1. **There is no PI channel in the events files**: This is partly because we cannot accurately convert to PI without positional information (which we do not have in FAST mode), and partly because the CTI effect is not calibrated for FAST mode data (in which charges are transferred differently compared with imaging mode data). In fact, the current version of FAST mode events files do not have a PI column at all.

2. **Rectangular extraction region**: The XRT response has an azimuthal dependence; the azimuthally averaged response is calibrated much better than the full, angle-dependent response. With FAST mode data, we are forced to use rectangular extraction regions. The calibration is probably worse if 'outside the address discrimination area' is chosen.

3. **The use of a wrong chip**: Several FAST mode observations suffer from the use of a wrong chip, due to a wrong sequence of commands sent up to the satellite. Such data are generally useless.

4. **Level discrimination**: For very bright sources, level discrimination may be used to avoid telemetry saturation in MEDIUM bit rate. The current `ascascreen` does not correctly distinguish FAST mode files with or without level discrimination, so this must be done by analyzing HIGH and MEDIUM bit rate data separately.

4.11 SIS Field of View

Each SIS camera is made up of four 420 x 422 sq-pixel chips separated by gaps along the spacecraft X and Y axes of 18.5 and 4.8 pixels, respectively. Figure 4.2 makes this clear and also shows the following.

- How each chip is labelled, e.g., which is SIS0-chip1.
- How each chip is oriented, e.g., where the top is in DETX, DETY coordinates.
- Which chips are afflicted most by hot pixels.
- Which chips are afflicted most by UV/optical light leakage.
- Where the default pointing positions are for 1-CCD, 2-CCD and 4-CCD mode observations of point sources.
- The dimensions of the chips in millimeters, arcminutes and pixels.

4.12 SIS Mode-Dependent Keywords

In `XSELECT`, once the data mode has been set, the various mode-dependent quantities, such as the number of energy channels, are set automatically. It is, however, useful to know some of the corresponding keywords in the SIS data file.

- The keyword DATAMODE can take the values FAINT, BRIGHT, BRIGHT2 or FAST, depending on the data mode. It appears in all the headers.
- Three keywords describe the clocking mode. They all appear only in the primary header. For the sake of brevity, only the SIS0 keywords are given (the corresponding SIS1 keywords begin with S1 rather than S0).
  - S0CCDMOD can have the values 1, 2 or 4 and gives the number of SIS0 chips in use.
  - S0CCDPOW identifies which of the four SIS0 chips are on. For example, a value of 1100 indicates that SIS0 chips 0 and 1 are on, while chips 2 and 3 are off.
  - S0CCDLST gives the order in which the chips are read out. In 4-CCD mode, its value is always 0123, indicating that SIS0 chip0 is read before chip1 which is read before chip2 which is read before chip3. A typical value in 2-CCD mode is 1212, and in 1-CCD mode 1111.

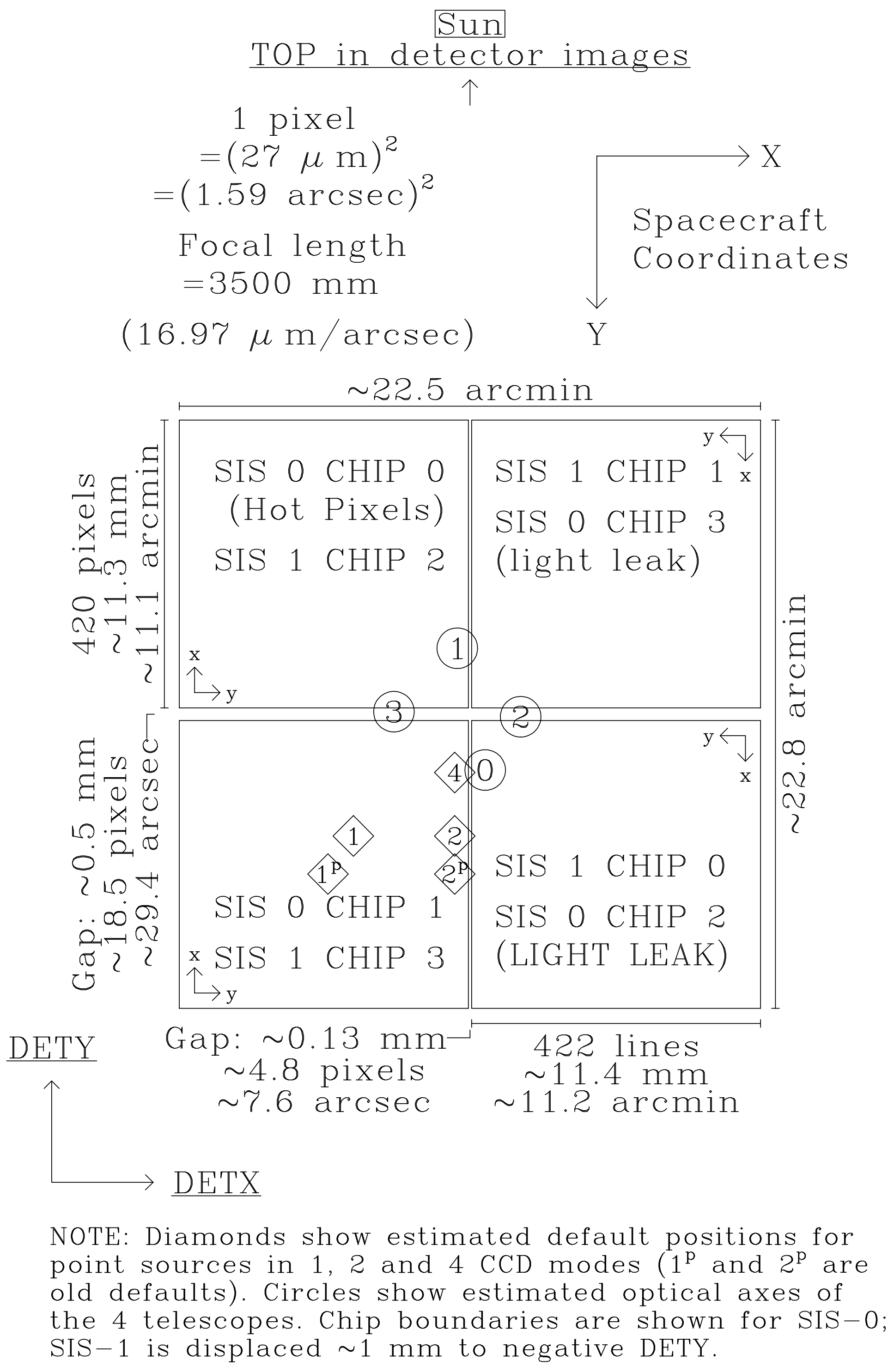


Figure 4.2: SIS FOV

Chapter 5

SCREENING CRITERIA

5.1 Introduction

The original *ASCA* data collected on-board include 'bad' data which have to be rejected in the course of data analysis. In this context, 'bad' means that such events are inappropriate for scientific analysis, for a number of different reasons which will be explained in this chapter. Standard data screening (see §5.5) is carried out during processing at GSFC, and the cleaned events lists are found in the 'screened' directory on an *ASCA* distribution data set or in the *ASCA* Archive (they have names of the form `*.evt`). The standard data screening criteria have been found by the *ASCA* GOF to provide a good balance between rejecting bad events without overly compromising signal-to-noise, and convenience (providing a manageable set of criteria).

Although one can start from these pre-screened events lists to extract images, light-curves and spectra, you may want to apply your own data screening criteria, which may be looser or tighter than the standard criteria. Unscreened data are also distributed, the files having names of the form `*.unf` and can be found in the `unscreened` directory (distributions earlier than REV1 also had 'RAW' data files in the `raw` directory).

Even if you are not going to apply your own data selection criteria, it will be helpful to understand the kind of data screening that should normally be applied to your data before extracting scientific products. Here we describe the individual criteria and how they are used to remove bad events. We also suggest how to tailor the criteria to match individual analysis priorities. Firstly, screening criteria common to both GIS and SIS are described. Then, criteria unique to the GIS and SIS are discussed separately.

There are three methods available to perform your own customized screening. These are implemented with the following programs:

- **XSELECT** Running `XSELECT` in stand-alone mode, screening can be performed by entering the appropriate Boolean expression using the `mkf` parameters and their desired ranges of values, with the command `select mkf`. For example:

  ```
  xsel:ASCA-GIS2-PH > select mkf "ACS==0 && COR>4 && ELV>5"
  > Enter the filter file directory >[.]
  ```

  The meaning of these parameters will be explained below. Screening criteria may be written in Fortran style (e.g., ELV.gt.5) or in C style (ELV>5). The `select mkf` command prompts the user to enter the directory where the `mkf` file or files is/are located.

- **ascascreen** This is a perl script which essentially creates a script which runs `XSELECT` by prompting the user for various inputs. If the default criteria are selected in `ascascreen`, the result will be a set of cleaned events lists identical to those produced by the standard GSFC processing (see §5.5).
- **tkascascreen** This is a GUI version of `ascascreen`. This provides a convenient, user-friendly method of screening.

More technical details of screening will be given in chapter 6. In this chapter we concentrate on the screening criteria themselves.

Recently, the GIS team conducted a systematic study of the characteristics of the GIS internal background. This has lead to a better understanding of screening criteria that should be used, in the sense of increasing the source signal-to-noise by avoiding the rejection of too many good events. A summary of this study and the resultant new screening criteria is given in section 5.3.1.

5.2 Screening Criteria Common to the GIS and SIS

In this section, we explain data screening criteria common to both the GIS and SIS.

5.2.1 Elevation Angle (ELV)

From the satellite, the angle between the Earth's limb and the pointing direction is known as the elevation angle. At low elevation angles the target is viewed through the Earth's outer atmosphere which absorbs and/or scatters X-rays and hence distorts the spectrum. Negative elevation angles in the `mkf` file identify Earth occultations. We have found that data quality degrades with elevation angles less than 5 degrees. At angles greater than 10 degrees, the data quality no longer depends on elevation angle. This means that users can experiment with setting the minimum acceptable elevation angle at 5 degrees (lax) or 10 degrees (strict), depending on whether they want to boost signal-to-noise at the expense of possibly compromising data quality.

Note that sensitivity to elevation angle for a given observation depends on target position. Targets close to the ecliptic poles are the most susceptible, as the elevation angle can remain modest throughout the observation.

The elevation angle is recorded in the `mkf` file in a column named ELV. (Note that for REV0 distributions ELV was known as ELV_MIN). Hence the standard elevation angle criterion you might use can be written as

$$\mathrm{ELV} > 5\ .$$

5.2.2 Stable Pointing Directions (ACS, ANG_DIST)

If the pointing of the satellite fluctuates too much, then photons from the same part of the sky are not incident on the same part of the detector. Since the response depends on detector position, this could lead to inaccurate results. To avoid this happening, only data taken during stable pointing should be used. Also, it is possible to select events based on the deviation from the mean pointing. The `mkf` parameter ACS should be zero when the satellite is in pointing mode. The `mkf` column ANG_DIST contains the root mean square deviation of the instantaneous pointing from the mean pointing. Setting ANG_DIST to be less than 0.01 degrees (0.2 times the HPD of the XRT) is a sensible default.

In such cases that there is significant deviation from the mean pointing, it is usually mostly limited to the first 1000-2000s of the observation, before the star tracker fine-tunes the pointing. Deviations after this are usually negligible. For some short observations, where the mean pointing is strongly affected by this initial segment, a larger value of the ANG_DIST threshold may be advisable. (Please note that the ANG_DIST column is not present in REV0 `mkf` files).

The ANG_DIST values should be positive by definition as long as the instantaneous attitude is correctly determined. Hence, in order to select stable pointing data, the selection criteria you might use can be written as,

$$\mathrm{ACS}{=}{=}0 \;\&\&\; \mathrm{ANG\_DIST} > 0 \;\&\&\; \mathrm{ANG\_DIST} < 0.01.$$

5.2.3 South Atlantic Anomaly (SAA)

The South Atlantic Anomaly (SAA) is a 'hole' in the geomagnetic field which allows cosmic rays to penetrate further than usual. The particle background in the SAA is extremely high. In fact, the high voltage of the GIS is usually turned off during passage through the SAA, but in the SIS the rate is not so high that the SIS is turned off. SAA passages can be explicitly excluded by selecting on the `mkf` column SAA: requiring that the value be zero excludes SAA passages. Hence, the `mkf` expression to choose data outside the SAA is written as,

$$\mathrm{SAA}{=}{=}0.$$

Note that this will have practically no effect for GIS data, since the GIS should always be turned off during SAA passages.

5.2.4 Cut-off Rigidity (COR)

Cut-off rigidity (COR) is a local measure of the ability of the geomagnetic field to repel cosmic rays. Specifically, it is the minimum momentum (in units of GeV/c) with which a cosmic-ray particle can penetrate as far as the satellite orbit. Since cosmic rays induce instrumental background, low values of COR identify those parts of the orbit which have high background. For the SIS, a value of 6 GeV/c yields plenty of good events without seriously compromising data quality. For weak sources, less than ~ 0.1 cts/s the user may want to experiment with higher values of COR to get the best compromise between signal-to-noise and low background at high energies. For the GIS, it has been found that the COR threshold can safely go down to 4 without being affected seriously by background events, IF this is combined with other appropriate selection criteria (see section 5.3.1).

Note that since background is roughly proportional to COR, the actual spectrum used for background subtraction should have the same distribution of COR as the on-source spectrum. This will automatically be the case if the background spectrum is extracted from the same screened events list as the on-source spectrum. If, on the other hand, blank-sky background is used, the COR distribution should be forced to match.

A decrease in the COR threshold from 6 to 4 GeV/c will typically result in a 20% increase in the net exposure time, while the increase in background may not be a serious problem, depending on the source intensity and the type of analysis being performed. Thus the lower threshold that is ultimately adopted is up to you, but the selection criterion may be written as

$$\mathrm{COR} > 4.$$

The cut-off rigidity is recorded in the `mkf` files in a column named COR. (Note that in REV0 `mkf` files, the corresponding column name is COR_MIN).

5.3 GIS Screening Criteria

5.3.1 Characteristics of GIS Internal Background

Before explaining screening criteria unique to the GIS, it will be helpful to become familiar with GIS internal background characteristics. The description consists of excerpts from the Web page at the URL

`http://heasarc.gsfc.nasa.gov/docs/asca/gisbgd.html`

and from the article 'Reproducibility of GIS non-X-ray background' in the *ASCANews #5*.

The GIS intrinsic (particle) background is known to vary with the orbital position of the satellite. Also, there are transitory particle events which should be excluded in data analysis. Three useful quantities which can be used to get a handle on the GIS intrinsic background and to select good time intervals with are:

1. Cut-off rigidity (COR) during the orbit,
2. Radiation Belt Monitor (RBM) counting rates, and
3. GIS monitor counting rates.

The Radiation Belt Monitor (RBM) is a small PIN diode detector attached to the bottom of GIS2. RBM is sensitive to particle background and used to automatically reduce the high-voltage of the GIS sensors on-board.

GIS monitor counts are house keeping parameters to count all the events (X-rays or particles) which hit the GIS pulse-height lower discriminator. Details can be found at the Web page with URL

`http://heasarc.gsfc.nasa.gov/docs/asca/monitor.html`.

Among the six GIS monitor count-rates for each sensor, H0 and H2 are considered to include very few X-rays and hence are good particle monitors. X-rays are included in the L1 monitor counts, so L1 must be positive as long as the observation is carried out correctly. Below, the sum of the G2_H0, G2_H2, G3_H0 and G3_H2 monitor count rates shall be referred to simply as 'H02'.

Data taken from 59 blank-field observations between June 1993 and August 1994 were studied. The distribution of the RBM and H02 counting rates during *ASCA* orbits, along with contours of COR are shown in

`http://heasarc.gsfc.nasa.gov/docs/asca/rbm.gif`

`http://heasarc.gsfc.nasa.gov/docs/asca/h02.gif`

which are also linked from the document

`http://heasarc.gsfc.nasa.gov/docs/asca/h02.gif`.

It is found that there is a good correlation between COR and H02.

Figure 5.1 shows this correlation between COR and H02 for these blank sky data. Despite the good anti-correlation, there are events having anomalously high H02 values at around COR $\sim 11 - 12$. These are transitory particle events which should be rejected in data analysis. These flare-like events turn out to have hard energy spectra, so we call them 'hard flares'. The hard-flare events, as well as the high background regions with high H02 and low COR values, can be easily rejected by throwing away data above the two following two broken lines in the diagram: H02=45.0 and H02= $0.45 \times \mathrm{COR}^2$ -13$\times$ COR +125.

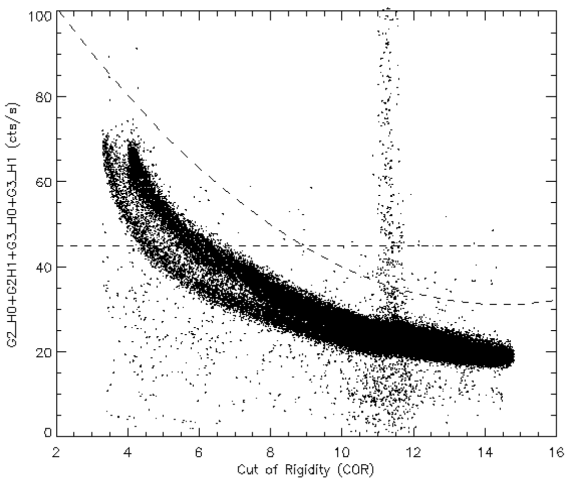


Figure 5.1: Correlation between COR and H02. The vertical branch at COR$\sim$11 corresponds to the 'hard-flare' events which should be rejected in data analysis. The two broken lines are H02=45.0 and H02= 0.45 $\times$ COR^2 -13$\times$ COR +125. Above the broken lines the data are rejected in the standard screening criteria for REV2 processing.

In figure 5.1, the bifurcate below COR=8 may be due to inaccuracies of the COR map we are using in the *ASCA* mission. On the lower branch, which corresponds to the low COR region around the east of Cuba and Florida, the H02 values are not as high as on the upper branch, in spite of the fact that COR $<$ 6.

In addition, another kind of transitory particle event is found, which we will call a 'soft flare', The soft-flares have soft energy spectra and accompany increases in the RBM count-rate, but not H02. Hence they can be rejected using RBM criteria. It is found that there are two orbital regions where the soft-flares occur preferentially (regions surrounded by broken-dot lines in the figures

`http://heasarc.gsfc.nasa.gov/docs/asca/rbm.gif` and

`http://heasarc.gsfc.nasa.gov/docs/asca/h02.gif`.

The RBM criteria should be stricter in these regions. Suggested, conservative criteria to reject 'soft-flare' events are RBM $<$ 18.75 cts/s everywhere and RBM $<$ 6.25 cts/s in these two regions.

The figures

`http://heasarc.gsfc.nasa.gov/docs/asca/rbm_clean.gif`

`http://heasarc.gsfc.nasa.gov/docs/asca/h02_clean.gif`

show the RBM and H02 count distribution after all the above three screening criteria (H02 $<$ 45 cts/s, hard-flare cut and soft-flare cut) are applied. This can be achieved with the 'strict' criterion in `ascascreen` (see §5.3.3).

5.3.2 Screening Based on Event Locations and Rise Time

Most non-X-ray background events in the GIS occur close to the walls of the detector, i.e., at the edge of the Field of View (FOV). Not only is the background high at the edge of the FOV, but the gain is also less accurately known. Indeed, because of the uncertain gain, only events within the central 44 arcmin diameter of the GIS FOV are aspected (assigned RA and DEC). Also, at the edge of the FOV in both detectors, internal Fe55 calibration sources are attached. These high-background rings and calibration sources have to be excluded when analyzing GIS data. This can be easily done by applying a spatial region filter in DETX and DETY coordinates.

Bona fide X-ray events occupy a tightly defined region in the plane formed by the gain-corrected - i.e., invariant - rise time (RTI) and the pulse height (PHA). The `XSELECT` command `gisclean` will reject events outside this region. Note that RTI is not always available. There are cases when the number of timing bits is increased to achieve high time resolution, and as a trade-off the rise-time bits are lost. In this case, `gisclean` cannot be applied, and the data will have more internal background than otherwise. **It is important to note that the standard GIS response matrices assume that the data has had the RTI filter applied**.

5.3.3 Summary

Firstly, the following screening should be applied to the GIS data. These are defaults in the GSFC REV2 processing and `ascascreen` (FTOOLS v3.7 and later). Standard REV1 screening is described in §5.5.

1. **Remove the high background ring and calibration source**.

   GSFC REV2 processing and `ascascreen` assumes the following region selections (in the case of 256×256 spatial resolution). In terms of `SAOimage` region files, these spatial regions are described below. These are modified and improved comapred to REV1 (see §5.5.2).

   For GIS2:

   ```
   CIRCLE(128.50,128.50,88.00)
   -ELLIPSE(167.50,220.00,24.66,28.95,245.298)
   ```

   For GIS3:

   ```
   CIRCLE(128.50,128.50,88.00)
   -ELLIPSE(217,95,21.56,25.92,169.216)
   ```

   In some instances you may want to modify these region selections. To do so, you can either edit the above region files manually or you can make a region file within `SAOimage`. This new region file can then be used with the `XSELECT` command `filter region` as in the following example:

   ```
   xsel:ASCA-GIS3-PH > filter region g3_cal.reg
   ```

   where `g2_cal.reg` is the name of the region file. Note that you specify the region in DETX and DETY coordinates (this is the default).

2. **Reject background based on RTI with `gisclean`.**

   This is carried out by the `XSELECT` command `gisclean` without arguments:

   ```
   xsel:ASCA-GIS2-PH > gisclean
   ```

   This is performed as long as the GIS events files have the RTI column correctly populated. For high time resolution data which do not have rise-time information, this step is skipped.

After the above screening has been done, you can specify your own further screening criteria using `mkf` parameter expressions. The version of `ascascreen` later than that distributed with FTOOLS v3.6 should have three default GIS data screening criteria: 'loose', 'standard REV2' and 'strict'. The 'standard REV2' selection is used in the REV2 processing and is different to earlier processing versions (see §5.5 for standard REV1 selection criteria). Here, we explain these three screening criteria in `ascascreen`. Users can choose one of them, or specify their own data selection criteria.

Loose Screening

Besides the screening criteria explained in section 5.2, no selection is made to reduce the GIS background. This will make almost all the GIS data available, and it is recommended that this option be used only for bright sources, for which the particle background is negligible compared to the number of source photons.

```
ACS==0&&ANG_DIST>0&&ANG_DIST<0.01&&ELV>5&&G2_L1>0&&G3_L1>0
```

GIS X-ray events are included in the monitor counts G2_L1 and G3_L1, so these quantities must be positive as long as observation is going normally.

Standard REV2 Screening

In addition to the loose screening above, the following conditions are further imposed for this option:

```
SAA==0&&COR>4 &&G2_H0+G2_H2+G3_H0+G3_H2<45 &&
G2_H0+G2_H2+G3_H0+G3_H2<0.45*COR**2-13*COR+125&&RBM_CONT<100
```

The first two items exclude regions with high particle background during the orbit. The third and fourth items reject the high background data and the hard flares respectively. The last, RBM_CONT, criterion excludes the strong soft flares. See section 5.3.1 for an explanation of the hard and soft flares.

Strict Screening

Instead of the RBM_CONT<100 criterion in the standard screening, we use stricter soft-flare rejection criteria as follows:

```
(RBM_CONT < 6.25 || (RBM_CONT <18.75 && !((SAT_LON > 200 && SAT_LAT < -16) ||
(SAT_LON > 255 && SAT_LAT < 10 && (SAT_LAT < 0.36*SAT_LON -97))||
  (SAT_LON <250 && SAT_LON > 160 && SAT_LAT > 16)||
(SAT_LAT > 8 && SAT_LON<250 && SAT_LAT > -0.53*SAT_LON+123))))
```

This means that RBM_CONT should be less than 18.75 outside of the two regions where soft flares occur preferentially and less than 6.25 inside the two regions.

5.4 SIS Screening Criteria

5.4.1 Removing Hot and Flickering Pixels

Hot and flickering pixels, which appear as false events, are a manifestation of radiation damage to the CCDs (see §4.4). Although they are unavoidably included in telemetry, they can be straightforwardly removed on the ground. The `sisclean` algorithm rejects those pixels which register an event more often than expected from Poisson statistics. Since they contain no astrophysical information and are not accounted for in the available response matrices, hot and flickering pixels should always be removed (see §4.4.1).

The number of hot and flickering pixels depends on epoch (the problem has worsened since launch) and on clocking mode (more of a problem in 4-CCD mode than in 1-CCD mode).

5.4.2 Grade Selection

Grade is a one-dimensional description of the shape of the charge cloud created by an event in a CCD. Certain grades have better spectral resolution than others (grade 0 has the best resolution) or are more likely to be bona fide X-ray events (grades 1, 5 and 7 contain mostly non X-ray events). A combination of grades 0, 2, 3 and 4 are the best-calibrated, and this combination provides a good compromise in resolution and signal-to-noise. However, there are two important cases where users might want a different selection. First, FAST mode data have different grade assignments: only grade 0 events should be selected. Second, since analyzing a light curve does not require a spectral response matrix, users can increase the signal-to-noise of SIS light curves by including grade 6 events.

In addition, please note that:

- On-board BRIGHT mode data contain only grades 0-4 (up to late November 1993) or grades 0-6 (after November 1993).
- Some Goddard-converted BRIGHT mode data contain only grades 0-4.

5.4.3 Bright Earth Angles (BR_EARTH)

As explained in section 5.2.1, ELV $> 5 - 10$ is considered an appropriate criterion to reject data contaminated as a result of being taken near the Earth rim. In the case of the SIS, which is also sensitive to optical and UV radiation, data quality is further impaired when the FOV is close to the illuminated face of the Earth, by light scattered within *ASCA* XRT. This necessitates two elevation angle criteria: one for when the Earth's limb is dark, and a second, stricter one for when the limb is bright.

The Bright Earth elevation angle is contained in a column named BR_EARTH in the `mkf` file. For the bright limb, the threshold for the parameter BR_EARTH is clocking-mode dependent. For 4-CCD mode data, the elevation angle can be set in the range 15-40 degrees for SIS0, with 20 degrees being a sensible default. For SIS1, the recommended range is 15-20 degrees. For 1 and 2-CCD mode data, lower values of the threshold (down to 10-15 deg) appears to result in no noticeable degradation of data quality. However, it is best to experiment for each observation.

5.4.4 Events Above Threshold

To avoid telemetry saturation and photon pile-up, the SIS is not used to observe very bright objects. This means that when high count rates do occur in the SIS, it is often the result of occurrences such as passing through the SAA or observing the bright limb of the Earth's atmosphere. The problems are accentuated by the existence of light leaks in the SIS. The `mkf` column `Sn_PIXLm` records the number of pixels per readout (REV0) or per second (REV1 and above) which exceed the event threshold in SIS`n`/chip`m`. By imposing an upper limit on `Sn_PIXLm`, these non X-ray peaks can be rejected. In practice, however, the same default settings are used for all eight chips and depend only on the readout time (i.e., on clocking mode). In the standard GSFC processing the threshold values used for 1, 2 and 4-CCD modes are 100, 75 and 50 respectively.

There are several effects to watch out for:

1. `Sn_PIXLm` monitors background plus source. For observations of bright sources, the threshold needs to be raised by (approximately) the source count rate.
2. In 4-CCD mode (and 2-CCD mode to a lesser degree), there is a secular increase in the `Sn_PIXLm` monitor. The default values may reject a high fraction of the observation. However, this is tied to the actual decline in the performance of the SIS in 4-CCD mode (the RDD effect), so the user must experiment.
3. When the CCDs are warm (above $\sim 60^{\circ}$C – check the `mkf` parameter `Sn_TEMP`), the `Sn_PIXLm` monitor counts are higher than normal. The threshold may have to be raised in order to obtain an acceptable exposure time, although the high values of `Sn_PIXLm` correctly indicate that the data quality is less than optimal.

5.4.5 Avoiding Telemetry-Saturated Frames

Strictly speaking, if one needs to obtain the most accurate fluxes, telemetry-saturated frames should not be used since the count-rates will be incorrect. Even if the source is relatively weak, hot and flickering pixels may still cause telemetry saturation in the SIS. If the priority is to obtain a high signal-to-noise spectrum and one is not too concerned about accurate fluxes then telemetry-saturated data can be used. In any case, it is a good idea to compare results with and without telemetry saturation.

The `mkf` files for REV1 and thereafter contain a column called `Sn_SATFm` where `n` refers to the SIS (0 or 1) and `m` is the chip number. This parameter is zero during periods of NO telemetry saturation. Therefore, unsaturated data is selected by specifying `Sn_SATFm==0`.

5.4.6 Time after passing through the South Atlantic Anomaly

To derive the true pulse-height in each pixel, the dark-frame level (see §4.6.2) is subtracted from the total pulse-height. The dark frame level varies across each chip and depends on the radiation environment of the instrument. Because of these dependencies, the on-board computer calculates a 16 x 16 map of the dark frame level for each chip and updates the map periodically. However, when the satellite clears the SAA, radioactive decays persist for a few seconds, raising the dark frame current. This elevation of the dark frame level occurs so rapidly that the dark frame map is not accurately calculated until about 4 readout times have elapsed (i.e., 16, 32 and 64 seconds for 1-CCD, 2-CCD and 4-CCD mode, respectively). The `mkf` column T_SAA gives the time in seconds after a passage through the SAA. Note that before the first SAA passage of an observation, T_SAA is negative. This means that for a 1-CCD mode observation, for example, the appropriate setting is that T_SAA be less than zero and greater than 16. Users should also be aware that `mkf` files have 32-s bins.

Since an incorrect dark-frame level affects light curves less than spectra, users extracting light curves only might want to omit the T_SAA criterion (as well as the T_DY_NT criterion below).

5.4.7 Time after passing through the Day-Night Terminator

To derive the true PHA in each pixel, the dark frame level (see §4.6.2) is subtracted from the total PHA. Dark frame varies across each chip and depends on the radiation environment of the instrument. Because of these dependencies, the on-board computer calculates a 16 x 16 map of the dark frame for each chip and updates the map periodically.

The dark-frame map described above is also inaccurate when the the satellite crosses the Day-Night boundary, again because the dark-frame level changes so rapidly. The `mkf` column T_DY_NT gives the time in seconds after a passage through the Day-Night or Night-Day transition. Note that before the first Day-Night Transition in an observation, T_DY_NT is negative. This means that for a 1-CCD mode observation, for example, the appropriate setting is that T_DY_NT be less than zero and greater than 16. Users should again be aware that mkf files have 32-s bins. As with T_SAA, light curves are less affected than spectra, if the dark-frame error is not corrected with T_DY_NT.

5.4.8 T_SAA and T_DY_NT WARNING for FTOOLS v3.6

The version of `ascascreen` in FTOOLS v3.6 does not apply the correct value of T_SAA and T_DY_NT. Instead of converting 4 readout times into the appropriate number of seconds, `ascascreen` always sets T_SAA and T_DY_NT to be greater than 4 seconds, regardless of clocking mode. This is not a serious bug because applying the T_SAA and T_DY_NT criteria, even correctly, does not screen many events. Since `ascascreen` does not prompt the user to set T_SAA or T_DY_NT, the way around the problem is to edit the `_mkf.sel` file. Specifically, you should first run `ascascreen` as usual, but type `ascascreen -q` instead of `ascascreen`. This will cause `ascascreen` to stop before running `XSELECT`. Second, type `ls` to identify two files which ascascreen has just produced: the `_mkf.sel` file, which contains the screening criteria, and the `.xco` file, which contains the `XSELECT` commands. Third, use an editor to overwrite the correct values of T_SAA and T_DY_NT in the `_mkf.sel` file (16, 32 or 64 seconds for 1-CCD, 2-CCD and 4-CCD modes, respectively). Finally, run `XSELECT`; then after choosing a session name, type `@` followed (without a space) by the name of the `.xco` file. By following these steps you are effectively running `ascascreen` as usual but with an interruption in the middle to correct the bug. The bug should be fixed in FTOOLS v3.7 and later.

5.4.9 Summary

Following is a summary of typical screening criteria to be applied to SIS data.

1. Remove hot and flickering pixels.
2. Select only grades 0,2,3 and 4.
3. Select events with a minimum elevation angle (ELV) of 5-10 degrees and with a minimum Bright Earth elevation angle (BR_EARTH) of 15-40 degrees (SIS0) or 15-20 degrees (SIS1).

4. Select events with a minimum cut-off rigidity (COR) of 4-6 GeV/c.
5. Exclude events in frames which have too many events above the event threshold (`Sn_PIXLm`).
6. Select events outside the South Atlantic Anomaly (SAA==0).
7. Select events which occur more than 4 readout cycles after the satellite passes through the South Atlantic Anomaly (T_SAA > 4 readout cycles).
8. Select events which occur more than 4 readout cycles after the satellite passes through the Day-Night transition (T_DY_NT > 4 readout cycles).
9. Exclude events collected when the pointing deviates from the mean by more than 0.01 degrees (ANG_DIST> 0.01).

5.5 Standard screening criteria used in GSFC REV1 processing

For convenience we summarize the standard screening criteria used in GSFC REV1 processing.

5.5.1 GIS and SIS

```
SAA==0 && ELV>10 && COR>6 && ACS==0 && ANG_DIST>0.01
```

5.5.2 GIS only

Standard RTI-rejection applied, as implemented in `gisclean`. GIS outer-background ring and calibration source removed with the following `SAOimage`-style region files:

For GIS2:

```
 CIRCLE(124,132,81.00)
-CIRCLE(166.00,221.0,24.00)
```

For GIS3:

```
CIRCLE(133.0,119.0,73.00)
-CIRCLE(205.0,99.0,8.0)
```

5.5.3 SIS only

Remove hot and flickering pixels. Apply the following further screening criteria:

```
FOV>0 && BR_EARTH>20 && Sn_SATFm==0 &&
T_SAA>16M && T_DY_NT>16M && Sn_PIXLm<T
```

where `M` is equal to 1, 2 and 4 and `T` is equal to 100, 75 and 50 for 1-, 2- and 4-CCD modes respectively.

Chapter 6

SCREENING

6.1 Introduction

The purpose of screening is to create, for each instrument, events lists that contain good data, suitable for scientific analysis.

There are three methods of applying screening criteria, and three starting points which differ in the amount of pre-screening performed by the *ASCA* Data Facility. These will all be described below.

After screening, users are ready to filter the parts of the data they wish to analyze and subsequently extract spectra, light curves, and images.

6.2 The Basics of Screening

6.2.1 Screening Using XSELECT, ASCASCREEN or TKASCASCREEN

Screening is a routine process and done by using `XSELECT` as the main workhorse to apply screening criteria to the FITS data files. Screening is made even easier with the scripts `ascascreen` and `tkascascreen` which drive `XSELECT` with convenient user-interfaces. The three methods of screening can be summarized as follows.

1. **XSELECT** Running `XSELECT` in stand-alone mode, screening can be performed by entering the appropriate Boolean expression using the `mkf` parameters and their desired ranges of values, with the command `select mkf`. example:

   ```
   xsel:ASCA-GIS2-PH > select mkf "ACS==0 && COR>4 && ELV>5"
   > Enter the filter file directory >[.]
   ```

   Screening criteria may be written in Fortran style (e.g., ELV.gt.5) or in C style (ELV>5). The `select mkf` command prompts the user to enter the directory where the `mkf` file or files is/are located. Alternatively the `mkf` directory can be specified on the command line by assigning it to the parameter `mkf_dir` (for example, `mkf_dir=../aux/`).

2. **ascascreen** This is a perl script which essentially creates a script which runs `XSELECT` by prompting the user for various inputs. By answering questions at the screen, users do not have to remember the corresponding `XSELECT` commands, the standard selection criteria, nor

their recommended values. If the default criteria are selected in `ascascreen`, the result will be a set of cleaned events lists identical to those produced by the standard GSFC processing (see §5.5). One thing to be aware of is that introducing non-standard criteria has to be done outside `ascascreen`, but this is straight-forward.

3. **tkascascreen** This is a GUI version of `ascascreen`. This provides a convenient, user-friendly method of screening.

The first stage of screening involves determining which data files correspond to the instrument, mode and bit rates you want to analyze and then applying screening criteria. For this, `ascascreen` makes using `XSELECT` easier. However, `XSELECT` must still be used for the final stage of defining and applying filters and extracting products.

6.3 Suggested Screening Strategies

As mentioned in §2.4, *ASCA* data are made available to users, on tapes and in the Archive, in three different levels of processing. These are UNSCREENED, SCREENED and RAW (but the latter are discontinued in REV1 and later revisions; see §2.4). From the point of view of screening, these levels represent three different starting points. The most common will be to read the unscreened files into `XSELECT` into `XSPEC` in order to apply screening criteria suited to the user's particular data set. On the other hand for a quick-look analysis the user can read the screened files into `XSELECT` and proceed immediately to filter and extract images, light curves and spectra.

If for some reason, the user cannot obtain the unscreened, `*.unf` files from REV1 (or later) processing, `XSELECT` and `ascascreen` will still accept RAW files.

Whether to use `XSELECT`, `ascascreen`, `tkascascreen`, unscreened files or screened files, is a matter of taste, convenience and what you want to do with your data. Here is a (non-exhaustive) list of data reduction scenarios matched to suggested screening strategies:

- **Producing a screened spectrum as fast as possible**. Since the default settings of the screening criteria applied by `ascascreen` are the same as those used in producing the screened events lists, the quickest route is to skip screening altogether. Start `XSELECT`, read in the screened events list and proceed to apply filters and to extract a spectrum.

- **Relaxing the settings of the standard criteria to increase signal-to-noise**. The most convenient way to re-apply the standard criteria with different settings is to run `ascascreen` on the unscreened data files.

- **Applying non-standard criteria**. Selection criteria can be applied to any column in the data files or `mkf` file - not just to the standard set used by `ascascreen`. If, for example, you want to select data based on the altitude of the satellite (the SAT_ALT column in the `mkf` file) then we recommend you run `ascascreen` on the raw files with the `-q` option and then edit the `*_mkf.sel` file to include the criterion. Alternatively, you can read into `XSELECT` the screened events list and apply the additional criterion with the `select mkf` or `select events` commands - whichever is appropriate.

- **Two-stage reduction**. After producing a screened events list, `ascascreen` leaves you at the `XSELECT` prompt, giving you the opportunity to continue the reduction process, i.e., filtering and extraction. If, however, you'd prefer to stop and continue later, quit the `XSELECT` session. To continue, type `XSELECT` and read in the screened events list.

6.4 ASCASCREEN

6.4.1 Before You Begin

It is generally a good idea to keep your `mkf` files, screened events lists and data products in separate directories.

6.4.2 About ASCASCREEN

The automatic screening script `ascascreen` simply carries out, with a minimum of user interaction, what the *ASCA* GOF consider to be standard screening criteria. Rather than executing the command `XSELECT` followed by a set of `XSELECT` commands, the script prompts the user for inputs which are then used by the script to produce an `XSELECT` command file (a file with a `.xco` extension) which is then run by `XSELECT`. The command file is not discarded and can be used again - edited, if you like - for a truly automatic `XSELECT` session. It can also serve as a reminder of the sequence of `XSELECT` commands if you're using `XSELECT` xselect interactively.

The `ascascreen` script comes automatically with the FTOOLS package, and can be found in the directory `$FTOOLS/bin.perl` (for example, `$FTOOLS` may be `/ftools/ALPHA/release`) which is produced by the installation process.

Please note that `ascascreen` is written in Perl and therefore requires that Perl be installed for it to run. If you do not have Perl, type `ascascreen` at your system prompt to see a set of instructions on how to obtain Perl.

Finally, it is assumed that the user has read chapter 5 and fully understood the various selection criteria that are used in analysing *ASCA* data.

6.4.3 Running ASCASCREEN

First create a directory for your screened products beneath the one containing the screened events files. Then type `ascascreen` which will cause the following series of directions and questions to appear.

1. **Enter data directory:** `ascascreen` understands relative directory names, so typing `..` is sufficient to specify the directory above (if that is indeed where your data files are). Note that `ascascreen` assumes that the `mkf` file is either in the same directory as the data files or in a directory called `aux` at the same level as the data.

2. **Which instrument do you want to process?** `ascascreen` examines the contents of your data directory and, based on what's in there, asks you to choose an instrument. Answers can be lower case, e.g., gis2. If more than one data mode is present, you'll be offered a choice.

3. **Enter product filename root [xsel]:** The names of the screened files produced by `ascascreen` will be prefixed by whatever characters you enter at this prompt. Note that `ascascreen` does not add an instrument descriptor to the name, so it's a good idea to specify prefixes like `a1060_g2`, for example.

4. **Which Bit Rates do you want to use?** It's possible to enter a combination here, such as HIGH, MEDIUM, as well as a single bit rate.

   Note that for **GIS data**:

- In GIS PH mode, temporal resolution depends on bit rate.
- There is usually very little LOW-bit rate data, but it is OK to use except for sources brighter than 4 count/s/GIS (the telemetry limit in LOW bit rate).

For **SIS data**:

- In general SIS temporal resolution does not depend on bit rate.
- There is usually very little LOW-bit rate data, which, because of hot and flickering pixels, is invariably saturated and can be excluded from analysis.

5. After looking in the data directory for the specified bit rates, `ascascreen` displays on the screen a summary of the data, like this:

```
Index NEVENTS  ONTIME     RAWXBINS RISEBINS TIMEBINS PHA_BINS POS_DET
    0  123721  66181.8      256       32        1     1024       FLF
```

for the GIS and

```
Index NEVENTS  ONTIME  S0CCDMOD S0CCDLST S0_ARENA
     0  872848  73264.8        4     0123        0
```

for the SIS. The quantities listed (apart from NEVENTS and ONTIME) correspond, for the GIS, to the PH mode bit assignments and for the SIS to various mode-dependent settings. Data for which these crucial modal parameters are different and should not in general be analyzed together. The user is thus forced to chose a data set by specifying the index (the first column). In this example only one index is present, so no choice is available.

Next, the user is prompted for actual `mkf` parameter selections.

1. **Enter Maximum allowed angular deviation [0.01 recommended]:**
This refers to the deviation from mean pointing and is measured in degrees. See §5.2.2 for more details.

2. **Enter minimum elevation angle [5-10 recommended]:**
This refers to the angle between the target and the Earth's limb and is measured in degrees. See §5.2.1 for more details.

3. **Enter angle from Bright Earth [20-40 recommended]:** (SIS ONLY)
This refers to the angle between the target and the Earth's bright limb and is measured in degrees. See §5.4.3 for more details.

4. **Enter minimum cutoff rigidity [6 recommended]:**
This identifies periods of high background based on cut-off rigidity. It is measured in GeV/c. See §5.2.4 for more details.

5. **Enter PIXL rejection threshold [50 recommended]:** (SIS ONLY) This identifies periods when the count rate per pixel exceeds a threshold due to background flares. See §5.4.4 for details.

6. **Start up SAOimage, and remain in XSELECT at the end? (y/n):**
Self-explanatory, but note that if you answer 'no', you'll need to start a new `XSELECT` session to continue the reduction process (i.e., filtering and extracting).

7. **Remove ring and calibration source? (y/n):** (GIS ONLY)
Non-X-ray events occur most often in the outer ring of the GIS FOV. It is therefore a good idea to exclude this part of the FOV, as well as the internal monochromatic calibration source which also appears at the edge of the FOV. See §5.5.2 for details.

8. **Use Rise Time window background rejection? (y/n):** (GIS ONLY)
The final question refers to using the Rise Time Invariance to reject background events. It should almost always be applied. Note that the requisite RTI column may be present but not filled. REV0 users are prompted on whether to have `ascascreen` fill it before proceeding with the screening. See §5.3.2 for details.

9. **Remove hot and flickering pixels? (y/n):** (SIS ONLY)
Unless you want to study them, hot and flickering pixels should always be removed. See §4.4.1 and §5.4.1 for more details.

10. **Select based on grade (this will keep only grades 0,2,3 and 4)?:** (SIS ONLY)
By choosing these grades, you'll be get a good combination of spectral resolution and signal-to-noise. See §5.4.2 for more details.

Note that for SIS data, `ascascreen` applies two additional criteria which, because they are usually fixed, are not prompted for. These are (1) time after passing through the SAA (`T_SAA`) and (2) the time after passing through day-night terminator (`T_DY_NT`). These selection criteria are fully described in §5.4.6 and §5.4.7 respectively. Note, however the bug in FTOOLS v3.6, described in §5.4.8.

Taking GIS data as an example, `ascascreen` produces the following files (`a1060_g2` was used as the root of the product file names in this example):

- `a1060_g2.evt`, the screened events list. If you choose not to run `SAOimage` as part of your `ascascreen` session, then this is the file you should read into `XSELECT` to continue filtering and extracting.

- `a1060_g2.xco`, the `XSELECT` command file used to drive the `XSELECT` session. If you type `@a1060_g2.xco` at the `XSELECT` prompt, you can re-run the screening.

- `a1060_g2_mkf.sel`, the file containing the `mkf`-based selection criteria. In the `XSELECT` command file, it is activated by the command `select mkf @a1060_g2_mkf.sel`.

- `a1060_g2.img`, a detector image extracted from the screened events. If you chose to run `SAOimage` as part of your `ascascreen` session, then this file is displayed on the screen. If not, you can look at it with `SAOimage:` by typing `saoimage -fits a1060_g2.img`.

- `a1060_g2_randc.reg`, the `SAOimage` region filter file corresponding to the high background ring and internal calibration source. In the `XSELECT` command file, it is activated by the command `filter region a1060_g2_randc.reg`.

- `xsel.log`, the `XSELECT` log file. If you have a problem running `ascascreen` or `XSELECT`, please send this file, with an account of the problem, to `ascahelp@athena.gsfc.nasa.gov`.

- `a1060_g2_obscat.sel`, the `obscat` selection file, contains the criteria which identify the input data files.

- `a1060_g2.cat`, a FITS file containing a catalogue of the input data files chosen.

An analogous set of files is produced with SIS data.

6.4.4 After Running ASCASCREEN

`ascascreen` stops after creating a screened events list. What you do next depends on which of the following three scenarios applies in your case.

1. If you answered 'yes' to the question about starting `SAOimage` and remaining in `XSELECT`, then you can continue the reduction process. The next steps are filtering, and extracting spectra, light curves or images, described in chapters 8, 9 and 10 respectively.

2. If you answered 'no' to the question about starting `SAOimage` and remaining in `XSELECT`, then you have to restart `XSELECT`. Type `XSELECT` at your system prompt. You'll first be prompted to specify the session name (used to identify temporary files). Next, you have to tell the program where the data (in this case, the screened events list) and the `mkf` files are. Use the commands `set mkfdir` and `set datadir`. Finally, read in the events list with the `read events` command and proceed to filter and extract.

3. If you answered 'yes' to the question about starting `SAOimage` and remaining in `XSELECT`, but then change your mind and want to exit `XSELECT`, type `exit` at the `XSELECT` prompt and follow the instructions for case 2 above.

6.4.5 The -q Option

As mentioned above, `ascascreen` creates an `XSELECT` command file which is used to drive `XSELECT`. By typing `ascascreen -q`, users can stop `ascascreen` at the point just before `XSELECT` is invoked and the command file executed, thereby returning to the system prompt. The advantage of such a procedure is that it enables the user to change the screening process without having to run `XSELECT` from scratch: users can simply modify the command file and or the `mkf` selection file and then use the modified file to run `XSELECT` automatically.

For example, if you want to create a screened events list from 4-CCD mode data which includes events from only one chip (SIS0, chip 1, say), run `ascascreen` with the `-q` option and then use a text editor to add the following line to the `XSELECT` command file produced by `ascascreen` (`sis0.xco`, say):

```
select events ccdid.eq.1
```

Then type `XSELECT` , give a session name, and then enter the command

`XSELECT>@sis0.xco`.

6.5 TKASCASCREEN

`tkascascreen` is a GUI version of `ascascreen` which does exactly the same things as `ascascreen`. It is very easy to use, but to understand the questions, please refer to the instructions for running `ascascreen`.

There is one minor difference: the session name which the user should supply on the first screen is the prefix added to the names of the output files.

6.6 XSELECT

6.6.1 Getting Acquainted

This section explains how to use `XSELECT` manually to achieve the same results as `ascascreen`. To get better acquainted with `XSELECT`, we also suggest the following.

- Re-reading the section on `ascascreen` above. It tells you what `XSELECT` will do, although not how `XSELECT` will do it.
- Looking at a `.xco` file produced by running `ascascreen`. The file contains a set of `XSELECT` commands in the order in which they should be issued.
- Typing help at the `XSELECT` prompt. `XSELECT` is equipped with extensive on-line help.
- Reading the `XSELECT` User's Guide, which can be obtained from the URL

  `http://heasarc.gsfc.nasa.gov/docs/software/ftools/xselect/xselect.html`.

6.6.2 Before You Begin

Again, it is a generally a good idea to keep your `mkf` files, events files and data products in separate directories.

6.6.3 Running XSELECT

To start up `XSELECT`, type `XSELECT` at your system prompt. In this example, we'll be reducing GIS data from the PV observation of Abell 1060. Since the data are public, you can get the same data and `mkf` files yourself via FTP from the corresponding `unscreened` and `aux` directories. After giving the session a name, the `mkf` and data directories should be set:

```
tarquin>XSELECT

                         **  XSELECT V1.3   **

>Enter session name>[xsel] A1060

 Notes: XSELECT set up for      ASCA
 Keywords for time and pha are  TIME       PI
 Units of time are              s
 Default timing binsize =   128.00
 Keywords for images are          DETX       DETY
 Keywords for the WMAP are        DETX       DETY

A1060:ASCA> set mkfdir ..
A1060:ASCA> set datadir ..

Setting data directory to /usr/day/asca/data/a1060/
A1060:ASCA>
```

Notice that `XSELECT` displays its initial default settings. The mission is *ASCA*; light curves, spectra and images will be extracted from the TIME, PI and DETX/DETY columns, respectively. At this point, we specify which instrument we want to analyze and which data mode:

```
A1060:ASCA> set instrument gis2

Setting: IMAGE binning    =    1
         WMAP binning     =    1
         Energy Column    =  PI
         Energy rebinning =    1

A1060:ASCA-GIS2> set datamode ph
```

As before, another set of default settings is displayed: extracted images will not rebinned, nor will the WMAP (§8.2.2) and spectra.

The next, crucial step is to identify which of the data files in the data directory correspond to GIS2 PH mode. This is one of the important functions of `XSELECT`. For `*.unf` files it is trivial but any users who are still using RAW data files are spared from having to 'deconstruct' the filenames. It is done by making what is called an `obscat`:

```
A1060:ASCA-GIS2> make obscat
> Default filter for the catalogue (NONE for none, DEF for default) >[DEF]
Using default selection expression:
ONTIME>100&&NEVENTS>0&&HV_RED=='OFF'&&HVH_LVL==3&&HVL_LVL==4

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

Data Directory is: /usr/day/asca/data/a1060/
HK Directory is: /usr/day/asca/data/a1060/

        OBJECT   DATAMODE BIT_RATE DATE-OBS TIME-OBS ONTIME   NEVENTS  PHA_BINS
      1 A1060    PH       MEDIUM   28/06/93 23:46:14 .146E+04     2225     1024
      2 A1060    PH       MEDIUM   29/06/93 00:20:06 .114E+04     2060     1024
      3 A1060    PH       HIGH     29/06/93 00:49:00 .136E+04     3254     1024
      .     .     .            .          .        .        .        .        .
      .     .     .            .          .        .        .        .        .
      .     .     .            .          .        .        .        .        .
     39 A1060    PH       MEDIUM   29/06/93 23:57:42 .262E+04     3458     1024
     40 A1060    PH       HIGH     30/06/93 00:41:32 .106E+04     2595     1024
     41 A1060    PH       HIGH     30/06/93 01:04:46 .392E+03      918     1024

A1060:ASCA-GIS2>
```

The 'filter for the catalogue' offers the user the opportunity to pre-select files based on certain header keywords, some of which are displayed in the `obscat` itself. The default is fine for most purposes.

Each line in the `obscat`, not all of which are shown here, corresponds to an individual data file. Specifying which ones to merge and screen is done with the `choose` command. However, before choosing, users might want to edit the `obscat` by selecting, for example, all the HIGH bit-rate files. Generally, such selections are performed with the `select` command. In this case, the first argument is `obscat` and the second argument is a selection criterion, as in the following example.

```
A1060:ASCA-GIS2 > select obscat BIT_RATE.eq.'HIGH'
```

Notice that the selection criterion is specified in Fortran style. It is also possible to use C style. The parameter selected on, BIT_RATE is a column in the `obscat` (a FITS file, incidentally). Since its values are character strings, HIGH is enclosed in quotation marks: numerical values, such those in the ONTIME column do not require quotation marks. To see the new, selected `obscat`, type `show obscat`.

We can now choose which files to work on. To choose all of them, type `choose 1-**` (** stands for the number of the last file):

```
A1060:ASCA-GIS2 > choose 1-**

   Setting datamode to PH

Got the minimum time resolution of the chosen data:  0.62500E-01,

Getting Min and Max for Energy Column...
Got min and max for PI:     0   1023

Number of files read in:   25

Files currently in use:

   1   ft930628_2345_1426G200770H.fits
   2   ft930628_2345_1426G201770H.fits
   3   ft930628_2345_1426G201970H.fits
   .                                 .
   .                                 .
   .                                 .
  23   ft930629_1426_0123G206370H.fits
  24   ft930629_1426_0123G206970H.fits
  25   ft930629_1426_0123G207170H.fits
```

As can be seen, the screen output shows the data files we've chosen.

We are now ready to apply selection criteria which are described in detail in chapter 5. For the GIS, these fall into three categories: (1) `mkf`-based criteria, (2) removing the high background ring and calibration source, and (3) applying RTI-based background rejection. Each of these uses a different `XSELECT` command.

To apply `mkf`-based selection, type `select mkf` followed by the selection criteria which can be entered separately, one per command, or strung together. The latter is better because each `select mkf` command creates a set of good-time intervals (GTI) which are combined with a logical 'AND' operation to the current set. For large files, this can be CPU-intensive:

```
A1060:ASCA-GIS2-PH> select mkf
>Boolean expression for filter file selection >[]
elv.gt.5.and.cor.gt.6.and.g2_l1.gt.0.and.saa.eq.0
```

The high background ring and calibration source are removed by applying a region filter. You can either extract an image and define the filter yourself, use a pre-existing one left over from a previous GIS2 `ascascreen` session or simply copy the following lines into an ASCII file to create an `SAOimage` file (which we'll call `ring.reg`):

```
 CIRCLE(124,132,81.00)
-CIRCLE(166.00,221.0,24.00)
```

See also §5.5.2. The filter is entered with the following command:

```
A1060:ASCA-GIS2-PH> filter region ring.reg
```

Applying RTI-based background rejection, unlike using a region filter or `mkf` file, is mission-specific. Accordingly, the procedure gets its own `XSELECT` command, `gisclean`:

```
A1060:ASCA-GIS2-PH> gisclean
Using table:/tmp_mnt/FTP/software/ascasrv/ftools/DEC/ftools/refdata/rti_gis_1024_040693.fits
Now processing /usr/day/asca/data/a1060/ft930628_2345_1426G201770H.fits
Infile # of rows    Outfile # of rows    # filtered
----------------    -----------------    ----------
        5915               5339                576
           .                  .                  .
           .                  .                  .
           .                  .                  .
Now processing /usr/day/asca/data/a1060/ft930629_1426_0123G207170H.fits
Infile # of rows    Outfile # of rows    # filtered
----------------    -----------------    ----------
         918                841                 77
```

For each data file, `XSELECT` displays the number of rows (each event occupies one row) which are accepted and rejected using RTI.

We can now create the screened events list by simply typing `extract events`. This command initiates the extractor, a program called by `XSELECT` which applies whatever GTIs and filters are in place to the current set of data files. Depending on what is extracted (events, a spectrum, image or light curve), the extractor creates a temporary file which is deleted upon exiting `XSELECT`, unless saved.

```
A1060:ASCA-GIS2-PH> extract events
 Extractor 1.0r
 XPI 2.1u
 Doing file: /usr/day/asca/data/a1060/redux/A1060_work1001.xsl
100% completed
    Total      Good    Bad: Region      Time     Phase       PHA
     5339      2623           1498      1218         0         0
 Writing events file
 .
 .
 .
```

```
 Doing file: /usr/day/asca/data/a1060/redux/A1060_work1024.xsl
100% completed
    Total      Good    Bad: Region      Time     Phase       PHA
      841       604            237         0         0         0
 Writing events file
100% completed
======================================================================
   Grand Total      Good   Bad:  Region      Time     Phase       PHA
         73565     47039          21402      5124         0         0
```

The extractor displays on the screen a summary of which events have been extracted and which discarded. There are three categories for discarded events: Region, Time, Phase and PHA which correspond to the various kinds of filter. Events screened out using the `mkf` file are tallied in the TIME column. The events list, made up of the screened events in the data files, is saved by:

```
A1060:ASCA-GIS2-PH> save events a1060_g2.evt
Wrote events list to file a1060_g2.evt
>Continue to use the filtered events list?>[yes]
Changing Data directory from:
    /usr/day/asca/data/a1060/
to the current working directory.
```

Note that `XSELECT`, by default, assumes that the user wants to work with the new, screened events list which is in the current directory rather than the data directory above it - hence the screen message about changing the working directory.

At this point you can continue the reduction process. The next steps are filtering, and extracting spectra, light curves or images - described in chapters 8, 9 and 10 respectively.

Alternatively, you can quit `XSELECT`, do something else, and then resume. Type `XSELECT` at your system prompt. You'll first be prompted to specify the session name (used to identify temporary files). Next, you have to tell the program where the data (in this case, the screened events list) and the `mkf` files are. Use the commands `set datadir` and `set mkfdir` respectively. Finally, read in the events list with the `read events` command and proceed to filter and extract.

6.6.4 Displaying mkf Parameters

It is possible to plot all the `mkf` parameters from `XSELECT` using the commands `mkfbin` and then `plot mkf`. In the following example, SIS events above threshold (`S0_PIXL1` and `S1_PIXL3`) are plotted against the Bright Earth angle (`BR_EARTH`). A full list of the `mkf` parameters can be obtained from `XSELECT` using the `show par mkf` command.

```
 xsel:ASCA-SIS1> mkfbin
 > Enter parameters in filter file >[] BR_EARTH S0_PIXL1 S1_PIXL3
 > Give print-out time interval >[20] 32
 xsel:ASCA-SIS1 > plot mkf
```

The available parameters are:

1. - TIME

2. - BR_EARTH
3. - S0_PIXL1
4. - S1_PIXL3

```
> Enter independent variable ( 0 for TIME  ) >[0] 1
> Enter dependent variable(e.g., 1-6) >[] 2-3
PLT>
```

Standard QDP commands can be used from here on.

Note that the GSFC-supplied `mkf` files have a bin size of 32s. Using a finer 'print-out time interval' than this in the `mkfbin` command will result in incorrect plots.

Plotting such `mkf` parameters as:

1. ELV, BR_EARTH, and COR
2. ANG_DIST
3. S0_PIXL1, S1_PIXL3, S0_TEMP, and S1_TEMP
4. G2_L0, G3_L0, and RBM_CONT

is highly instructive, particularly when the default screening criteria lead to a smaller than expected amount of accepted data.

Chapter 7

FILTERS

7.1 Introduction

In chapters 5 and 6 we saw how to reject 'bad' data by means of various screening processes. Filtering, the next step in data reduction, means selecting subsets of the good, screened data for particular analyses. Once the filters are set, the data are extracted through the filters to yield the desired spectra, light curves or images. The various ways `XSELECT` provides for filtering data are the subject of this chapter.

7.2 The Basics of Filtering

In `XSELECT`, filters are entered with the `filter` command followed by the type of filter, followed by the filter information itself (usually the name of a file containing that information). There are five basic types of filter available:

1. **region**
2. **time**
3. **intensity**
4. **energy**
5. **phase**

For example, `filter region bl_lac.reg` will enter the region filter contained in the file `bl_lac.reg`. All filters share the following basic features:

- The filter command by itself does not initiate any filtering. Rather, filters are applied when the extract command is next used.
- Multiple filters entered successively are applied together. For example, if you set a region filter, then a time filter, then an intensity filter, all three filters will be applied when you next extract a spectrum.
- To remove a filter, use the `clear` command. Using region filters as examples, `clear region bl_lac.reg` will remove the region filter called `bl_cal.reg`. Additionally, `clear region`

`last` will remove the most recently entered region filter, while `clear region all` will remove all region filters.

- To check what filters are in place, use the `show filters` command. This is a useful precaution to take before extracting anything.

7.3 Region Filters

In `XSELECT`, region filters are usually created by examining an extracted image using `SAOimage`. The procedure is straightforward, but there are a few points to be borne in mind when creating region filters for the GIS and SIS.

7.3.1 Using SAOimage to Create Region Filters

To create region filters in `XSELECT`, execute the following steps.

1. Decide first whether you want to work in SKY coordinates or DETECTOR coordinates. **For spectra work it is strongly advised to use detector coordinates (the default), since the spectral response depends on the location in detector rather than position on the sky**. Using SKY coordinates can give you an incorrect WMAP (§8.2.2), especially when attitude excursions are large. Errors can also arise when comparing extraction regions from other missions. To change the coordinates to SKY, use the `XSELECT` command `set image sky`. To change back to detector, use `set image detector`.

2. Extract an image from your screened events with the `extract image` command.

3. Plot the image with the `plot image` command which invokes `SAOimage`.

4. Change the appearance of the plot, if you like, using the `Scale`, `Zoom` and `Color` buttons in `SAOimage`.

5. Click on the `Cursor` button. There are two sets of cursor buttons available - toggle between them using the `region` button at the righthand end. To define the region, click on the `circle` button and then manipulate the region using the cursor. The left button changes the center of the region, the middle button changes the size of the region, and the right button changes the orientation. Once you have positioned and sized the region according to your wishes, type `s` inside the `SAOimage` window. Next, go to the region `write` button and at the prompt give the filename (e.g., `source_gis2.reg`) for the region specifier.

   To create an annular region, first position and size the outer circle and type `s`. Then, size the inner circle and type `e` which creates an exclusionary region. Finally, hit the `write` button, as before. Note that you can build up quite complicated regions by drawing multiple circles, etc., and typing `s` or `e`: all the circles will be written to the region file when you hit the write button. Hitting the `reset` button will erase the saved regions, allowing you to start again before writing the region file.

After it is created, a region filter file is applied with the `filter region` command followed by the name of the region file. To remove a region filter, use the command `clear region`

7.4 More About Region Filters

When creating a region filter, please consider the following points:

- Although the XRT PSF has considerable azimuthal structure, the azimuthal calibration in the current response matrices is limited (see also §10.6). For this reason, circular region filters will yield the most accurate spectral fitting results.
- For an unbinned 256×256 GIS image, 4 pixels $\sim$ 1 arcmin. This is the case for GIS PH mode with standard bit assignments. When an SIS image is extracted in `XSELECT`, the default is to bin the 1280×1280 image by a factor of four, i.e., `xybinsize` is set to 4. For a default-binned 320×320 SIS image, 9.5 pixels $\sim$ 1 arcmin.
- Because of the broad PSF, the jittering of the spacecraft can appear on arcminute scales. Thus, to avoid inaccurate flux determinations and spurious variability in light curves, the radius of the region filter should be no smaller than 3 arcmin (12 pixels for the GIS and 28.3 SIS pixels in a 320×320 image).
- The intrinsic PSF of the GIS depends on energy. The FWHM of the GIS PSF at 0.8 and 10 keV (the effective bounds of the GIS pass band) is 2 and 0.4 arcmin, respectively. This means that extraction regions which enclose as much of the total PSF as possible should be used for the most accurate spectral studies. In fact, the recommended region filter radius for bright sources in the GIS is 6 arcmin (24 pixels). For weak sources smaller regions could be used to reduce the background since the statistics will dominate over the systematics of the calibration.
- For most cases, the recommended region filter radius for bright sources in the SIS is 4 arcmin (38 pixels). This is smaller than the GIS because the SIS has a negligible PSF compared to the XRT.
- Since the properties of each SIS chip are different, creating a region that crosses chip boundaries should be done with caution. If a spectrum is to be extracted, then the PI column should be used. This is the currently the default in `XSELECT`. **Also, if you choose a background region which goes off the detector your background scaling factors will be wrong**!! You must explicitly exclude the off-chip area.

7.5 Time Filters

Time filters allow users to extract portions of their data based on time. `XSELECT` provides three methods for doing this.

1. Specifying parts of the light curve with the mouse cursor;
2. entering the start and stop times at the keyboard; and
3. entering a file containing the desired start and stop times.

Before reading this section, it might be a good idea to revisit the sections which describe how time is defined in GIS and SIS data files (§2.6.2).

7.5.1 Time Filtering with the Mouse Cursor

In brief, cursor-based time filtering involves first extracting and plotting a light curve and then using the cursor to mark out portions of the light curve for extraction. In more detail, the various steps are:

1. Before extracting a light curve, users might want to set other filters, such as a region filter or an energy filter. The time bin size can be selected by using the `set binsize` command. For example, `set binsize 64` causes the light curve to be extracted in 64-s bins. Integral multiples of the original GIS and SIS bin sizes are recommended (see §9.12).

2. Extract the light curve with the `extract curve` command.

3. Initiate the cursor-based time filtering with the command `filter time cursor`. After specifying the PGPLOT device (e.g., `/xw` for `XWindows`), a plot of the light curve will appear on the screen. The X-axis displays the time, in seconds, from the start of the observation which appears in MJD and Spacecraft time at the top of the plot. The Y-axis gives the count rate. Meanwhile, in the `XSELECT` window, a command summary appears, followed by the `PLT>` prompt.

4. There are two modes of interacting with the display: 'plotting' mode and 'selection' mode. Plotting mode - the initial state - allows the user to alter the appearance of the plot by entering commands at the `PLT>` prompt. For example, `rescale x 20000 40000` will replot the light curve with the X axis covering the time range 20,000-40,000 s. Typing `?` at the prompt will give a list of `PLT` commands.

5. Once the plot appears to your satisfaction, type `quit` at the `PLT>` prompt to enter selection mode (which will cause the cursor to change shape). At this point, you can use the cursor to mark out either the portions of the light curve you want to extract, or the portions you want to exclude from extraction.

   Inclusion of time intervals of is done by positioning the cursor at the beginning of the portion you want, clicking, and then moving the cursor to the end of the portion and clicking again. A horizontal line will then appear on the screen to indicate the part you selected.

   Exculsion of time intervals is done in a similar way, but with the difference that you type `e` instead of clicking. As before, the horizontal line which appears on the screen indicates the portion you selected, so an excluded part appears as a gap.

   It is possible to mix included and excluded portions, and to return to plotting mode to specify another set of portions. When you have finished selecting parts of the light curve, type `x` in selection mode or, if you are in plotting mode, type `quit` followed by `x`.

Leaving cursor selection creates a temporary file containing your time selections, in the form of a series of good time intervals (GTIs). By default, it will be used in the next extraction and can be removed with the `clear time cursor` command.

Also by default, the temporary file will be deleted on exiting `XSELECT` unless saved. To save the file, use the command `save time cursor` and name the file (but without an extension - `XSELECT` will append `.curs_gti` to the name). The file created is in FITS GTI format and may be reapplied with the `filter time file` command.

7.5.2 Time Filtering with the Keyboard

Perhaps the simplest method of creating a time filter is to enter pairs of start and stop times at the keyboard. There are three ways of specifying the times:

1. **Universal Time**, in which case the command is `filter time ut` and the format for the time is, e.g., 20/09/95 14:12:00.00.
2. `Space Craft Clock Time`, in which case the command is `filter time scc` and the format for the time is, e.g., 1.372975399487495E+07 or 13729753.99487495.
3. **Modified Julian Day**, in which case the command is `filter time mjd` and the format for the time is, e.g., 49250.75223900.

Keyboard time filters, regardless of type, are removed with the `clear time keyboard` command.

If you have extracted a light curve before creating the keyboard time filter, then typing, say, `filter time scc` will cause the light curve to be plotted and a set of instructions to appear on the screen. The instructions are very similar to those for creating time filters with the mouse cursor:

1. At first, the user has the opportunity to alter the appearance of the plot by entering commands at the PLT> prompt, e.g., `rescale y 0 4` to change the range of the Y-axis range to 0-4 count/s. Typing `?` provides a list of the various PLT commands.
2. Once the plot is satisfactory, type `quit` at the PLT> prompt to start making selections.
3. The on-screen instructions are straightforward: when filtering in Space Craft Clock time, typing, for example, `i 13730000, 13750000` will cause events between 13,730,000 and 13,750,000 seconds to be included. This interval will appear as a horizontal line on the plot. Note that start and stop times should be separated with a comma.
4. Further intervals can be specified, and the plot can be altered again by typing `p` to return to the PLT> prompt. When all the intervals have been specified, type `x` (or `quit` then `x` if at the PLT> prompt).

Leaving keyboard selection creates a temporary file containing your time selections. By default, it will be used in the next extraction and can be removed with the `clear time keyboard` command.

Also by default, the temporary file will be deleted on exiting `XSELECT` unless saved. To save the file, use the command `save time keyboard` and name the file (but without an extension - `XSELECT` will append `.hnd_gti` to the name). The file created is in FITS GTI format and may be reapplied with the `filter time file` command.

The procedure for creating keyboard time filters in the absence of a light curve is essentially the same, but without the opportunity to view the selected portions of the light curve.

7.5.3 Time Filtering with Files

Files containing sets of start and stop times can be used as time filters with the `filter time file` command. Three formats, which `XSELECT` distinguishes automatically, are possible:

1. ASCII,

2. FITS GTI and
3. XRONOS window.

ASCII time filter files are the simplest of the three: they contain pairs, one per line, of the start and stop times you wish to include, as in this example:

```
1.372975399487495E+07   1.374917324292182E+07
1.376167806128120E+07   1.378212711987495E+07
```

Please note that ASCII time filter files

- can be created with a text editor;
- are entered with the command `filter time file`;
- contain times in Space Craft clock time, which is what the TIME columns in GIS and SIS data files actually contain;
- are removed with the command `clear time ascii`;
- cannot be used with GIS MPC mode data.

The time filters produced with the `save time cursor` and `save time keyboard` commands are examples of FITS GTI filter files. Like their ASCII counterparts, they are entered with the `filter time file` command, but are removed with the command `clear time fits` instead.

XRONOS windows are described in the XRONOS manual (see §11.2).

7.5.4 How Time Filter Files Are Combined

Time filter files are combined in the following way:

- The intervals within each file are subjected to a logical OR operation, i.e., an event has to fall within one of the GTIs listed in a file to be accepted as a good event.
- When files are combined, a logical AND operation is performed on them. An event has to fall within *every* GTI in each time filter file to be accepted as a good event.

7.6 Energy Filters

Strictly speaking, it is not possible to filter by energy since events in the events lists are assigned a channel number rather than an energy: only in the spectral response matrix is the energy-to-channel conversion applied. However, XSELECT does allow users to filter by PHA or PI channel. All that is needed to filter by energy, therefore, are the energy-to-channel conversions for the various GIS and SIS data modes.

To enter a PI or PHA filter, type `filter pha_cut` followed by the lower and upper channel boundaries. To remove a PHA filter, `clear pha_cut`. In addition, please note the following.

- Filter commands work on the events lists. This means that the channels correspond to those of the original events list and depend on the GIS or SIS data mode. For example, GIS PH mode data have 1024 channels, and these are the channels which should be referred to when filtering by PI - even though `XSELECT`, by default, will group the channels by a factor of four when a spectrum is extracted.
- Energy-to-channel conversion formulae for the various modes can be found in §7.9.
- By default, `XSELECT` treats `filter pha` as an abbreviation of the `filter phase` command (see §7.8) rather than filter `pha_cut`.

7.7 Intensity Filters

Filtering by intensity is useful for variable sources - especially for spectral studies of high- and low-flux states. A light curve must be extracted first, as the filter settings refer to the count rate of the light curve. The steps are as follows:

1. Before extracting a light curve, users might want to set other filters, such as a region filter or an energy filter. Select the bin size first with `set binsize`. Extract the light curve with the `extract curve` command.
2. Plot the light curve with the `plot curve` command, and examine the plot to determine the intensity bands you wish to extract.
3. Create the intensity filter with the `filter intensity` command. The arguments are the upper and lower bounds of the intensity band to be included. For example, `filter intensity 0.8-2.1` will cause only those events to be extracted which lie in the parts of the light curve having count rates between 0.8 and 2.1 counts per second. Multiple bands can be specified by separating them with commas.

After setting the intensity filter, a temporary file containing the corresponding GTIs is created. By default, it will be used in the next extraction and can be removed with the `clear intensity` command.

Also by default, the temporary file will be deleted on exiting `XSELECT` unless saved. To save the file, use the command `save intensity` and name the file (but without an extension - `XSELECT` will append `.int` to the name). The file created is in FITS GTI format and may be reapplied with the `filter time file` command.

Please note: unless they are cleared beforehand, any filters used to create the light curve will be applied in conjunction with the intensity filter the next time anything is extracted. If, for example, you created an intensity filter based on a soft light curve, you should clear the corresponding energy filter before extracting a spectrum.

7.8 Phase Filters

The simplest way to describe phase filters is by example. The command

```
filter phase 49396 0.00782407 0.0-0.2
```

will cause events to be extracted between the phases of 0 and 0.2, where the full range in phase is 0-1. The first argument is the epoch of phase zero in MJD. The second argument is the period in days (676 seconds, in this case).

More than one phase range can be entered by separating the ranges with commas and enclosing them in a pair of quotation marks. The command `clear phase` removes a phase filter.

In general, any set of `XSELECT` commands can be written into an ASCII command file and implemented with the `@` command followed by the name of the command filename. Phase filters are particularly suited for this treatment as they usually form a set of very similar commands. The following file, called `phases.xco`, is used for extracting a set of five phase-resolved GIS spectra:

```
filter phase 49396 0.00782407 0.0-0.2
extract spectrum
save spectrum pul1

clear phase
filter phase 49396 0.00782407 0.2-0.4
extract spectrum
save spectrum pul2

clear phase
filter phase 49396 0.00782407 0.4-0.6
extract spectrum
save spectrum pul3

clear phase
filter phase 49396 0.00782407 0.6-0.8
extract spectrum
save spectrum pul4

clear phase
filter phase 49396 0.00782407 0.8-1.0
extract spectrum
save spectrum pul5

clear phase
```

Please note the following.

- Time and region filters are not included: they were set beforehand in this example and apply to all the spectral extractions.
- As well as the name of the output file, the `save spectrum` command requires an answer to the question of whether to apply the default binning and grouping: a carriage return enters the default - hence the blank line after each `save spectrum` command.
- `XSELECT` cannot determine periods. In this example, the period was derived using `XRONOS`

7.9 Energy-to-Channel Conversion

7.9.1 GIS PH Mode

The energy-to-channel conversion is approximately linear for GIS PH mode events extracted from the PI column (the default). It is the same for GIS2 and GIS3 and can be expressed by the following *approximate* formula:

```
N = 84.9*E
```

where N is the PI channel number and E is the energy in keV. Note that the formula applies for GIS PH mode with standard bit assignments. When 8 bits, rather than the standard 10, are used for PH, there are 256 channels in the events list. In this case, N should first be calculated using the formula above and then divided by 4.

7.9.2 SIS FAINT and BRIGHT2 Modes

For SIS PHA bins, each chip has a different gain. The gain also has a spatial and temporal dependence. Therefore we strongly advise using PI channels, *even for early observations* in the PV and AO-1 phases.

In converting 4096 SIS PHA bins to PI, the channels are linearized so that each channel is 3.65 eV wide. However, this is not strictly the case over the whole pass band: some non-linearities remain. Even so, the following simple relationship is a good approximation for all eight chips:

```
N = 274*E   for E < 10.7
```

where N is the PI channel number and E is the energy in keV.

7.9.3 SIS BRIGHT and FAST Modes

The 2048 channels of BRIGHT and FAST mode events lists are related to those of FAINT and BRIGHT2 mode as follows. The first 1024 channels are unbinned; channels 1025-2048 are binned by a factor of 2; the remaining channels 2049-4096 are binned by a factor of 4. This means that the energy-to-channel relationship is a bit more complicated. In PI, for all eight chips, we have

```
N = 274*E - 1            for        E < 3.74

N = 1023+137*(E-3.74)    for 3.74 < E < 7.47

N = 1535+68.5*(E-7.47)   for 7.47 < E
```

where N is the PI channel number and E is the energy in keV. The same caveats apply as for FAINT and BRIGHT2 modes: there are some small non-linearities in the energy-channel relationship, while above 10.7 keV the relationship changes.

7.10 Using Region Filters From Other Missions

7.10.1 SAOimage Region Files

The region files created by `SAOimage` are very simple: they contain only a description of the shape of the region, its position and its size - as in this example:

```
# gis2.img
# Wed Sep 13 11:49:47 1995
# shape x, y, [x dimension, y dimension], [angle]
 CIRCLE(109,115,32.08)
```

This corresponds to a circular region centered at the X-Y pixel position of (109,116) with a radius of 32.08 pixels. The lines beginning with # are headers and are ignored by `SAOimage`.

With such a simple scheme, it is not surprising that an `SAOimage` region file derived from, say, an Einstein IPC image, cannot be directly used as a filter for *ASCA* data. However, it is straightforward to convert the coordinates of one region file into the coordinates on the other, thanks to the use of standard OGIP FITS keywords in the headers of image files.

7.10.2 Converting Coordinates In Region Files

The steps involved in converting coordinates in region files from one mission to another comprise the following.

1. For the first mission, extract an image in SKY coordinates and create a region filter.
2. For the second mission, extract an image in SKY coordinates.
3. Obtain the values of the following keywords from the headers of both image files (the FTOOLS `fdump` or `fkeyprint` can be used for this):
   - `CRPIX1` and `CRPIX2`, which give the reference pixels for X (RA) and Y (DEC), respectively.
   - `CDELT1` and `CDELT2` , which give the size, in degrees, of the reference pixels for X and Y, respectively.
   - `CRVAL1` and `CRVAL2`, which give the SKY coordinates, in degrees, of the reference pixels for X and Y, respectively.
4. Convert the values in the region filter from the first mission using the algorithm given below. Here, the values of the keywords for the first and second missions are denoted by the suffixes `_in` and `_out`, respectively. The coordinates and lengths in the region files follow the same convention. Thus, `x_in`, `y_in` and `r_in` are the coordinates and length(s) in the first region file, and `x_out`, `y_out` and `r_out` - the quantities we need to derive - are the coordinates and length(s) in the second region file.

```
x_out = (x_in-crpix1_in)*[cdelt1_in/cdelt1_out]*
[cos(crval2_out)/cos(crval2_in)] +
        cos(crval2_out)*(crval1_in-crval1_out)/cdelt1_out + crpix1_out
```

```
y_out = (y_in - crpix2_in)*[cdelt2_in/cdelt2_out] +
        (crval2_in-crval2_out)/cdelt2_out + crpix2_out

r_out = r_in * cdelt_out/cdelt_in

where cdelt = (abs(cdelt1)+abs(cdelt2))*0.5
```

The last expression is strictly NOT valid if CDELT1 and CDELT2 differ for the input and output image, in which case, e.g., a circular region would have to be mapped to an ellipse.

5. With a text editor, create a region filter for the second mission containing the converted values.

7.10.3 Example: Using a ROSAT PSPC Region for the *ASCA* GIS

This example uses the *ROSAT* `PSPC` image of the cluster Abell 496, as obtained from the ROSPUBLIC database via HEASARC's W3Browse facility.

After extracting the image from the database, the first step is to display it using `SAOimage` and create the filter. In this example we have created a large circular region encompassing all the cluster emission. The corresponding region filter is:

```
# rp800024_im1.fits
# Thu Sep 14 10:36:29 1995
# shape x, y, [x dimension, y dimension], [angle]
 CIRCLE(256,257,36.06)
```

Next, I run fdump to display the values of the keywords we need:

```
tarquin> fdump rp800024_im1.fits
Name of optional output file[STDOUT]
Names of columns[-]
Lists of rows[-]
SIMPLE  =                    T  /  FITS STANDARD
BITPIX  =                   16  /  Binary Data
NAXIS   =                    2  /  Number of image axes
NAXIS1  =                  512  /  Dimension of axis 1
NAXIS2  =                  512  /  Dimension of axis 2
BSCALE  =          1.000000E0  /  Real = tape*BSCALE + BZERO
BZERO   =          0.000000E0  /  Real = tape*BSCALE + BZERO
DATE    = '27/09/91'  /  FITS creation date
IRAFNAME= './rp800024_im1.imh'  /  Output IRAF image name
TELESCOP= 'ROSAT   '  /  telescope (mission) name
INSTRUME= 'PSPC    '  /  instrument (detector) name
RADECSYS= 'FK5     '  /  WCS for this file (e.g. Fk4)
EQUINOX =          2.000000E3  /  equinox (epoch) for WCS
CTYPE1  = 'RA---TAN'  /  axis type for dim. 1 (e.g. RA---TAN)
CTYPE2  = 'DEC--TAN'  /  axis type for dim. 2 (e.g. DEC--TAN)
CRVAL1 =        6.841000E1 / sky coord of 1st axis (deg.)
CRVAL2 =       -1.326000E1 / sky coord of 2nd axis (deg.)
```

```
CDELT1 =        -4.166667E-3 / x degrees per pixel
CDELT2 =         4.166667E-3 / y degrees per pixel
CRPIX1 =         2.560000E2 / x pixel of tangent plane direction
CRPIX2 =         2.560000E2 / y pixel of tangent plane direction
CROTA2  =           0.000000E0  /  rotation angle (degrees)
MJD-OBS =           4.832162E4  /  MJD of start of obs.
More?[Yes] no
```

After obtaining the keyword values for the `ROSAT PSPC` image, I get the corresponding values for the *ASCA* GIS image by extracting a sky image from the A496 data and running `fdump` again. Here are the keywords:

```
CRPIX1  =  1.28500000000000000000E+02 / X axis reference pixel
CRPIX2  =  1.28500000000000000000E+02 / Y axis reference pixel
CRVAL1  =  6.84831770000000000000E+01 / Sky coord of X ref pixel (degrees)
CRVAL2  = -1.32060000000000000000E+01 / Sky coord of Y ref pixel (degrees)
CDELT1  = -4.09300000000000000000E-03 / X axis increment (degrees)
CDELT2  =  4.09300000000000000000E-03 / Y axis increment (degrees)
```

With the PSPC and GIS keyword values in hand, I use the formulae above to convert the X, Y and radius values from the `ROSAT PSPC` region file into their equivalents for the *ASCA* GIS region file:

```
x_out = (256-256)*-0.004166667/-0.004093*
        cos(-13.206)/cos(-13.26) +
        cos(-13.206)*(68.41-68.483177)/-0.004093 + 128.5
      = 145.91

y_out = (257 - 256)*0.004166667/0.004093 +
        (-13.26+13.206)/0.004093 + 128.5
      = 115.07

r_out = 36.06*0.004093/0.004166667
      = 35.42
```

The final stage is to use a text editor to create the GIS region file which contains the converted coordinates:

```
CIRCLE(145.91,115.07,35.42)
```

Please note that the above procedure is limited by the pointing accuracy of *ASCA*. Details are given in the 'Calibration Uncertainties' Web page (§1.7).

Chapter 8

SPECTRAL ANALYSIS

8.1 Extracting Spectra

Once the data have been screened and the desired filters set, to extract a spectrum simply type `extract spectrum` at the `XSELECT` prompt. This command initiates the extractor, an FTOOL run by `XSELECT`, which extracts from the events list photons satisfying the GTI and filter constraints and bins them up as a spectrum. The extractor places the spectrum in a temporary file which can be saved using `save spectrum`. Although this procedure is as straightforward as it sounds, please note the following.

- Before running the extractor, it is a good idea to check what filters are in place with the `show filter` command.
- The extractor displays on the screen a summary of which events have been extracted and which discarded. There are three categories for discarded events: Region, Time, Phase and PHA which correspond to the various kinds of filter. Events screened out using the `mkf` file are tallied in the Time column.
- After issuing the `save spectrum` command, the user is asked whether the default binning and/or grouping should be applied. The distinction between binning and grouping is important (§8.3). `XSELECT` *groups* the GIS spectra and *bins* the SIS spectra.
  - GIS PH mode spectra are grouped by a factor of four (1024 to 256).
  - SIS BRIGHT mode spectra are linearized and binned by a factor of four (2048 to 512) and the first 13 rebinned channels are flagged as bad.
  - SIS BRIGHT2 mode spectra are binned by a factor of four (4096 to 1024) and the first 25 rebinned channels are flagged as bad.

  For all except GIS background spectra, the answer in `XSELECT` to the binning/grouping question should usually be in the affirmative.
- Since background and spectral response depend on instrument, you might find it helpful to include a reference to the instrument in the file name, as in `burst_g2.pha` and `halo_s0c1.pi`, for example.

8.2 Spectral Files

It is not necessary to know all about *ASCA* spectral files in order to use them. However, it is a good idea to be familiar with their basic structure and contents.

The general principles behind the design and structure of the FITS spectral files (also known as PHA or PI files) from *ASCA* are described in Arnaud *et al.* 1992, *Legacy #2, 65* and

`http://heasarc.gsfc.nasa.gov/docs/heasarc/ofwg/docs/spectra/ogip_92_007/ogip_92_007.html`.

This article also lists all the keywords, extension names and column names. The key components of an *ASCA* spectral file are described below.

8.2.1 Primary Header

Below is a short list of some of the important keywords in the primary header.

EXPOSURE	Integration time (in secs) of PHA data.
BACKSCAL	Scaling factor used in background subtraction.
BACKFILE	Background file name (blank unless filled by user).
RESPFILE	RMF file name (blank unless filled by user).
ANCRFILE	ARF file name (blank unless filled by user).
POISSERR	Whether Poisson errors should be applied.
CHANTYPE	Whether channels are PHA or PI.
TLMIN1	Channel number of first channel.
NCHAN	Number of detector channels in the data set.
QUALITY	Whether quality flags are attached to the data.
GROUPING	Whether data are grouped.

Note that the background scaling factor, with keyword **BACKSCAL**, is defined as the ratio of the area of the region used to extract the spectrum to the total detector pixel area. Thus multiplying **BACKSCAL** by 256^2 or 1280^2 gives the area of the spectral extraction region (in unbinned pixels) for the GIS or SIS respectively.

8.2.2 The Weighted Map (WMAP)

The weighted map, or WMAP, is an image of the count distribution in the region used to extract the spectrum. The WMAP is an image array which resides in the primary extension of the FITS spectral file. This information is used to generate the XRT ancillary response file (ARF; see §8.7) which requires the spatial information of the counts on the detector plane. Since it is a FITS image, the WMAP can actually be displayed using an image display package such as `SAOimage` (e.g., `saoimage -fits burst_g2.pha`). In `XSELECT` the default binning for WMAP is unity for the GIS and a factor 8 for the SIS.

8.2.3 Spectrum, Quality and Grouping Flags

The SPECTRUM extension contains columns corresponding to channel number and the counts in each channel. The SPECTRUM extension can also contain additional columns for errors (if non-Poissonian), as well as quality and grouping flags.

The *quality flag*, following the OGIP standard, can have the following values.

0	good
1	defined bad by software
2	defined dubious by software
5	defined bad by user
-1	reason for bad flag unknown

`XSPEC` will automatically ignore channels with a quality flag of 1, and on the command `ignore bad` will ignore channels with a quality flag of 5. Quality flags can be set or reset with the FTOOL `grppha`.

The *grouping flag* works as follows. `XSPEC` combines the counts in a channel with a grouping flag of 1 with all successive channels with grouping flags of -1. Grouping flags can be set or reset with the FTOOL `grppha`.

8.2.4 Spectrum GTI

The GTI extension contains the individual time intervals (start and stop times) used to make the spectral file.

8.3 Binning and Grouping

A key concept when dealing with spectral files is the difference between binning and grouping, both of which relate to the combining of spectral channels. An important difference, for our purposes, is that grouping is *reversible* but binning is *not*. Otherwise, the two processes are equivalent.

8.3.1 Binning

Binning refers to the recasting of counts from the original set of channels into a new, smaller set of binned channels. In general, a spectrum must be used with a background file and response file with matching channel arrays, i.e., all three files must share the same number of channels and channel boundaries. This means that when a spectrum is binned in a certain way, so must the background and response. To rebin spectral files, you can use the FTOOL `rbnpha`, and to rebin a response matrix, `rbnrmf`.

In the course of normal *ASCA* data reduction and analysis, the binning of the spectral files matches that of the response by default. However, there are three cases when changing the binning is an issue:

1. Saving 1024–channel BRIGHT mode spectral files. By default, when BRIGHT mode spectral files are saved in `XSELECT`, `rbnpha` is applied to linearize the binning and to rebin the channels by a factor of four (i.e., 2048 to 512 channels). If you want a BRIGHT mode spectral file with 1024 channels, then you should not apply the default binning, and, instead, run `rbnpha` outside `XSELECT`. In this case, the appropriate 'compression mode' required by `rbnpha` is `bright2linear`.

2. Rebinning the GIS RMF for non-standard bit assignments. In GIS PH mode, if 8 bits rather than the standard 10 are assigned to the PHA, then the spectral files will have 256 channels rather than the standard 1024. If this is the case, the GIS RMF should be rebinned with `rbnrmf`. Here, the appropriate compression mode is `linear`.

3. Reducing the size of the response and spectral files. To reduce the amount of computer memory required to perform spectral fitting, it is sometimes a good idea to rebin response and spectral files in addition to – or instead of – grouping the spectral files. This is especially useful when fitting more than one spectral file simultaneously. For this, use `rbnpha` and `rbnrmf` on the spectral files and response, respectively, with an identical number of resulting channels and compression mode.

8.3.2 Grouping

Grouping is performed by the FTOOL `grppha`. For more details about this program refer to `fhelp grppha` and §8.13.

Grouping refers to the setting of flags for combining spectral channels. The flags are used internally by `XSPEC`. Neither `XSPEC` nor the grouping program (`grppha`) physically alters the channels or their contents in the spectral file – unlike binning. When a spectral file is read into `XSPEC`, the program consults the grouping column in the file and applies the grouping information it contains to the spectral file, its associated background file and to its response. The effect of grouping the spectral file, therefore, is the same as binning the spectral file, background file and response. However, since it requires only one step and is reversible, changing the grouping is often more convenient than changing the binning. Note that background files should not be grouped since `XSPEC` will automatically group the background to match the source data. By default, GIS PH mode spectral files are regrouped by a factor of four when saved in `XSELECT`.

An instance where one *must* use binning and not grouping is if a response matrix and spectrum have a different number of intrinsic channels. In this case, grouping will not work. Either the spectrum or response matrix must be rebinned.

8.4 Spectral Responses

The instrument response can be split up into two parts. A 'redistribution' matrix, which specifies the channel probability distribution for a photon of given energy, and an effective area curve, which specifies the telescope area and window absorption. We refer to the redistribution matrix as the RMF (Redistribution Matrix File) and the effective area curve as the ARF (Ancillary Response File). The combined response is the product of the ARF and RMF and is conventionally termed the RSP (response) file.

Users obtain GIS RMFs from the HEASARC calibration database and generate SIS RMFs using the FTOOL `sisrmg`. Users generate ARFs appropriate to their spectra using the FTOOL `ascaarf`.

In `XSPEC`, RMFs are entered using the `response` command, while ARFs are entered using the `arf` command. Alternatively, the RMF and ARF file names can be written into the header of the spectral file using `grppha`.

8.5 Obtaining GIS RMFs from the Calibration Database

GIS RMFs are straightforward. Only one kind, for PH mode, is available. The latest matrices can be found at

```
ftp://legacy.gsfc.nasa.gov/caldb/data/asca/gis/cpf/95mar06/gis2v4_0.rmf
```

`ftp://legacy.gsfc.nasa.gov/caldb/data/asca/gis/cpf/95mar06/gis3v4_0.rmf`.

The above directory, and the *ASCA GOF* Web page, should be checked regularly for any later releases.

8.6 Generating SIS RMFs

SIS RMFs are more complicated. Each SIS camera comprises four CCD chips, each of which requires its own RMF. A different RMF is also required for different event grades, split event thresholds, echo and CTI corrections. Moreover, the SIS resolution is degrading with time due to the cumulative effect of radiation damage. Therefore it is now recommended to generate the RMF file for each observation, in PI channels.

The FTOOL `sisrmg` (v1.0 or later, included in FTOOLS v3.5 or later) should be used to generate the RMF file, appropriate for your data. `sisrmg` will read the necessary information from the spectral file. Currently, the spectral files do not contain the grade selection information in a easily machine-readable way, therefore that information needs to be supplied on the command line.

```
tarquin> sisrmg grades=0234
Name of PHA input file [NONE] s0b.pha
Name of ARF input file [NONE]
Name of RM output file [NONE] s0b.rmf
```

Note that `sisrmg` requires the PHA to PI conversion calibration file. You must check that you are accessing the latest file as a new file is often released to keep up with the changing CTI (see §4.5.2). You must force `sisrmg` to use the latest file either by changing the parameter file or specifying the parameter `calfile` on the command line.

The ARF input file can be ignored in most cases, unless an RMF file that exactly matches an existing ARF file in terms of the energy grid is required.

8.7 Generating ARFs with ASCAARF

The Ancillary Response File (or ARF) contains all the information about

1. the XRT effective area for the given extraction region taking into account the point spread function (PSF), assuming a particular source distribution relative to the optical axis,
2. the transmission of the detector window, and
3. optionally, detector efficiency.

All these effects have been built into a convenient FTOOL called `ascaarf` which will generate the appropriate ARF for a given spectral file by using information in the spectral file itself - specifically, the WMAP which contains a map of where in the extraction region the counts in the spectrum came from.

`ascaarf` needs XRT response functions to calculate ARFs, as well as the source distribution. In the standard method, the precalculated XRT response files (effective area and point spread function) are used, and users should specify the type of source distribution. In the Ray-tracing method, which is a new feature since `ascaarf` v3.00, users should specify a set of ray-raced images for a particular source distribution.

8.7.1 Standard Method – Using Standard XRT Calibration Files

The energies at which the ARF is calculated are obtained from the corresponding RMF file, hence the arguments of the program are as follows (the XRT calibration files[1] are usually specified as hidden parameters):

1. Input spectral file.
2. Input RMF file.
3. Output ARF file.

The user also needs to tell the program whether the source is point-like, and, if so, whether it is in the center of the WMAP; if the source is not centered in the WMAP, then the user is prompted for the unbinned DETX and DETY coordinates of the source. For the case of a point source, `ascaarf` calculates the effective area at the source position and multiplies this by the (energy-dependent) fraction of events expected to fall within the selected region. For an extended source, `ascaarf` calculates a weighted-average effective area with the weighting factor being the number of events at each pixel position. In this case no attempt is made to correct for the spatial response and in particular no correction is made for events being scattered out of the selected region. For extended sources, creating ARFs through ray-tracing will be more precise (see below; see also §10.6).

Two important hidden parameters for `ascaarf`, and their default values, are `fudge = yes` and `arffil = yes`. The `fudge` parameter applies a Gaussian at 2.2 keV for the SIS and 1.9 keV for the GIS in order to account empirically for sharp residual features in the XRT response. The `arffil` parameter applies corrections (of order less than 5%) based on the fitting residuals to Crab GIS data. The average for GIS2 and GIS3 are used in the case of the SIS. At the time of going to press (March 1997), a calibration effort is underway to understand the physical origin of both these features and it is expected that `ascaarf` and the SIS and GIS response matrices will be modified and updated. Therefore the user should regularly check the 'Calibration Uncertainties' Web page (§1.7) for recent developments.

Below are listed some more general points about `ascaarf`.

1. The azimuthal dependence of the XRT response is less certain than the azimuthally averaged response so that more accurate results will obtained for circular extraction regions (see also §10.6).
2. If, after generating an ARF, you rebin the spectral file and RMF, you do not need to generate a new, rebinned ARF.
3. For the GIS, `ascaarf` has to convolve the XRT response with the GIS PSF. This calculation is rather CPU-intensive and can result in the program taking tens of minutes to create an ARF.
4. `ascaarf` does not work well for point sources extracted in SKY coordinates or for any observation whose pointing position changes.
5. Dead time correction is not included in `ascaarf`. It can, however, be corrected for the GIS spectral file using the FTOOL `deadtime` (see §8.11).

[1] As of January 2000, `xrt_ea_v2_0.fits` (effective area) and `xrt_psf_v2_0.fits` (point spread function) are the latest.

6. When GIS RTI information is not available due to non-standard bit-assignment (§2.6.4), `ascaarf` creates a corresponding ARF automatically, taking account of the effect of not applying the RTI screening [2].

8.7.2 Ray-tracing Method

In this method, first, you have to create a set of ray-traced images using the `ascaray` ftool. You should run ray-tracing for each of the energy bins which should cover the entire RMF energy range with minute enough resolution. The `make_ascaray_images` script will run `ascaray` sequentially to create a set of ray-traced images to be used with `ascaarf`.

For the usage of `make_ascaray_images` and how to create ARFs for extended sources using `ascaarf`, please find

`http://heasarc.gsfc.nasa.gov/docs/asca/make_ascaray_images/`.

In principle, the ray-tracing method can be used for any types of source distribution (including point-sources), and create precise ARFs as long as there are no spectral variations within the distribution[3]. However, this method is most effective when the source distribution is known to be completely *flat* over the detector field of view, in which case we can create accurate ARFs and carry out precise spectral analysis. See the URL address above for an examples of the Cosmic X-ray Background analysis.

We have created sets of ray-traced images using `make_ascaray_images` for uniformly extended sources with the radius of 1 degree, 2 degrees, and 3 degrees. These images are found at

`ftp://legacy.gsfc.nasa.gov/asca/make_ascaray_images/`.

Users may use these ready-made ray-tracing results with `ascaarf` to create ARFs for uniformly extended sources with 1, 2 or 3 degree radius, or run `make_ascaray_images` by themselves for different source distributions.

8.8 Background Subtraction

At present, for spectra, there are two background subtraction techniques. These are (1) subtract suitable portions of the blank-sky observations that the GOF has made available, or (2) subtract a source-free part of the same observation. As the mission matures, it is likely that other, perhaps better, techniques will emerge, possibly involving fully prescriptive background models.

For more information about the GIS background and how to subtract it, please consult the articles by Kubo *et al* (*ASCANews #2, 14*) and Ikebe *et al.* (*ASCANews #3, 13*). The internal background of the SIS is described by Keith Gendreau in *ASCANews #2, 5.*

Whatever method is used, the relative normalization between the on-source and background spectra is taken care of by the **EXPOSURE** and **BACKSCAL** keywords. The value of the latter keyword is set in every spectral file when it is created (whether from a source or background region) to be proportional to the geometrical detector area of the extraction region (see §8.2.1 for precise definition).

[2] This is possible since bit-assignment is written in the GIS spectral file keywords (copied from the event file header; see §3.4) which `ascaarf` checks.

[3] If there are significant spectral variation within the region of interest, spectral analysis based on the concept of ARF is no long valid. See also §10.7.

8.8.1 Blank-Sky Observations

SIS Blank Sky Files

The blank-sky events lists for background subtraction are available at

`ftp://legacy.gsfc.nasa.gov/caldb/data/asca/sis/bcf/bgd/94nov/`

for the SIS.

These background files have been created from several superposed PV phase observations and are sorted by cut-off rigidity. They should only be used to create products in detector coordinates. The files themselves are described in detail in the README files that accompany them. As FITS events files, they can be read into `XSELECT` with the `read events` command.

An important point to remember for the SIS is that these early blank-sky observations were made with the SIS in 4-CCD mode but the vast majority of point-source Guest Observer observations are made in 1- or 2-CCD mode. Since the SIS internal background depends on clocking-mode, this could lead to problems, especially at high energies (see §8.8.3). Also, the SIS sensitivity is declining with time in a manner which depends on the clocking-mode (primarily due to RDD effects - see §4.8) so the blank-sky background may not work well for the more recent observations.

GIS Blank Sky Files

Blank-sky events for accurate background subtractions are now available for the GIS. These files have been generated using high latitude observations taken between June 1993 and December 1995. The total exposure time is approximately 2.1 Msec (the previous blank-sky dataset had 0.35 Msec; see below). These observations have also had all point-like sources brighter than 2×10^{-13} erg/s/cm^2 in the 2-10 keV range removed. The files are located at

`ftp://legacy.gsfc.nasa.gov/caldb/data/asca/gis/bcf/bgd/no_sources`.

Standard data screening including the RTI filtering (§5.3.2) is already carried out in these event files.

Because of the masking of the point sources, you *must* compute the effective exposure time for each pixel using the `mkgisbgd` FTOOL, otherwise you will get wrong results. Please read

`http://asca.gsfc.nasa.gov/docs/asca/mkgisbgd/mkgisbgd.html`

for more information on how to use these files.

The previous version of GIS blank sky dataset, which is collected during the PV phase and includes dim point sources, is still available at

`ftp://legacy.gsfc.nasa.gov/caldb/data/asca/gis/bcf/bgd/94may/`.

This old dataset may be still useful, since you can read them directly in `XSELECT` to extract spectra. Please note that the old dataset has not been subjected to RTI-based background rejection (see §5.3.2), This means that, if your source spectrum has RTI-based background rejection, then you should use the `XSELECT` command `gisclean` on the file before extracting a background spectrum.

8.8.2 GIS Night Earth Observations

In addition to the blank-sky observations, the *ASCA* GOF has also made available GIS events files corresponding to observations of the night Earth. Since the night Earth is X-ray dark, the files represent, to a good approximation, the purely instrumental background of the GIS.

There is a new release of Night-Earth observations, covering the period from 1993 June to 1999 August (total $\sim$ 13 Msec exposure and $\sim$ 1.6 million events per sensor):

`ftp://legacy.gsfc.nasa.gov/caldb/data/asca/gis/bcf/bgd/night_earth_1999/`.

The files have been processed using the identical screening that applied to the standard processed data. If needed, and depending on the analysis, it is possible to apply additional cuts on these files.

As FITS events files, they can be read into `XSELECT` with the `read events` command. Please access

`http://heasarc.gsfc.nasa.gov/docs/asca/gis_night_earth/gis_night_earth.html`

for more information on these Night Earth Observations. In particular, please note that there is a long term increase of the Night Earth event counting rates (= GIS intrinsic background), which you may have to take into account for background sensitive observations.

8.8.3 How to Subtract Background

The best background subtraction depends on matching as closely as possible the background in your source region. There are four main aspects to this which, to some extent, vary in relative importance depending on the nature of your observation.

1. Extraction region.
2. Screening criteria.
3. Instrument mode.
4. Galactic position.

Note that the first two are actually mutually exclusive: you can only extract background from the same region as the source by using a different, blank-sky observation; and you can only use an identical set of screening criteria by using the same observation for background and source.

Background: Extraction Region

Largely because of the vignetting of the XRT, the responses of the GIS and SIS depend on position in the field of view. For this reason, background events should technically be extracted from the same part of the field of view as the source events. In `XSELECT` this is easy:

1. Read in the appropriate blank-sky background file with the command `read events`.
2. For GIS files, issue the command `gisclean` to subject the events to RTI-based background subtraction.

3. For SIS files, make sure that the background spectrum will be extracted from the same energy column as the source spectrum, i.e., PHA or PI. If necessary, to change the extraction column, type `set phaname` followed by `pha` or `pi`. In any case, you should now always be using PI.

4. Then, extract a background spectrum with the same region filter file used for the source spectrum, making sure that the spatial binning and coordinate system are the same (use the command `show status` to check).

5. Finally, save the background file with the command `save spectrum`. If GIS, do not apply the default grouping (`XSPEC` will get the grouping from the source file instead).

WARNING! If you background region goes outside the chips of the SIS, or outside the GIS detector area, your spectral files will contain the wrong values of BACKSCAL, the background scaling factor, and therefore your background subtraction will be wrong. You must explicitly exclude the off-detector regions.

Background: Screening Criteria

It is very important that the screening criteria used for the source and the background should be as similar as possible. The first release of background files is not accompanied by the `mkf` files, so the full range of selection criteria cannot be applied. Since the background files have been screened in a standard way and are sorted by cut-off rigidity, they should be acceptable for most cases. However, if you have a point source, we recommend that, as well as using the background files, you also extract background events from a source-free part of your source field. In the case of the SIS, this should be from the same chip; for the GIS, from a region at the same distance from the optical axis (within 14 arcmin from the optical axis, the GIS background does not vary much).

To find a source-free region, it is a good idea to make soft and hard images in case a contaminating source is not obvious in the image extracted from the full pass band. Of course, this background subtraction method contravenes the previous recommendation, *but usually closely matching screening criteria are much more important for good background subtraction.* Please use both methods and compare the results.

Background: Instrument Mode

As mentioned in chapter 4 and §8.8.1, the internal background of the SIS depends on clocking mode, i.e., whether 1-CCD, 2-CCD 4-CCD or parallel sum (FAST) mode was used. Since the total background is dominated by the cosmic background, this effect is small - except at energies above 7 keV. The rate of hot and flickering pixels also depends on mode, and it is possible that if, for example, the 4-CCD background files are used with a 1-CCD mode source file, then spurious effects could appear. Also, as already mentioned, the effect of RDD (§4.8) is reducing the SIS sensitivity with time in a manner which depends on clocking mode so the blank-sky background may not work so well for more recent observations. Better results will often come from using background from a source-free region of the same chip from the current or even from a different observation.

Background: Galactic Position

The fields used to make the blank sky background files all have high Galactic latitudes. For observations which are within 3 or 4 degrees of the Galactic plane, the Galactic X-ray background can become important. It may be necessary, in those cases to use a background spectrum extracted from a source-free region of the field of view and compare with the results obtained with the high-galactic background. Within 10 arcmin radius, the GIS background is relatively flat and its two main components (Cosmic X-ray background and Non-X-ray background) can be considered together.Beyond this limit, this assumption is no longer true (the CXB and NXB behave in fact very differently as a function of radius) and results are to be considered with extreme caution (see §10 and section on extended sources).

8.8.4 Using Blank-Sky Data for BRIGHT2 Mode Spectra

The blank-sky data for the SIS are in BRIGHT mode. They may also be used for BRIGHT2 mode source spectra. In this case, do not group or rebin when saving the spectra in `XSELECT`. Instead, run `rbnpha` on the saved spectra, using the BRIGHT2LINEAR option.

8.9 Analyzing SIS Spectra from Two or More Chips

When analyzing SIS spectra, if the photons from the source are spread over two or more chips and if you chose an extraction region over these chips, you have to consider that the chips have different responses (RMFs).

1. Create a set of region files. One is for the entire source region (typically circular), excluding the inter-chip gap using the 'box' shaping and hitting `e` in `SAOimage`. The other regions are sub-sets of the above, each lying entirely within a single chip (combine the same circle and a box, using `s` for both). There may be 2 or 4 such sub-regions.
2. Extract spectra for each of the sub-regions. Run `sisrmg` on each. Also get the total number of counts in each spectrum (using e.g. the TOTCTS keyword).
3. Use `addrmf` to combine the RMF files, weighting each file by the total number of counts in the corresponding spectrum.
4. Extract the spectrum from the entire source region. Use this and the combined RMF to generate the ARF. Now you are ready for spectral fitting.

Note that this method is not mathematically exact, but considered a fairly good approximation. The exact way is to make an ARF for each chip (though this may not be so simple), multiply the ARF and RMF for each chip, and average RSPs of different chips with equal weights. Since ARF for each chip can be approximated with the total ARF times (number of counts on that chip)/(total number of counts), the above method should work for most cases.

If you want to follow the exact way by creating ARFs for each chip, you may use the `addascaspec` script to combine spectral files and responses for different chips (§8.10).

8.10 Combining Spectral Files

It may be helpful to add together spectral files from the two GIS or from the two SIS, rather than fit the spectral files with the same model simultaneously. The advantage is that, with the better signal-to-noise, it is easier to see spectral features in the combined spectrum than in the individual spectra. By the same reason, you may want to combine two or more spectral files taken with the same detector at different time periods. The `addascaspec` script may be used for this purpose.

This script, written in Perl, runs several ftools such as `mathpha`, `addarf`, `addrmf` and `marfrmf` sequentially to perform the task.

8.10.1 For GIS

1. Extract source and background spectra for GIS2 and GIS3. Let's assume here that the source spectra are `gis2.spec` and `gis3.spec`, and the background spectra are `gis2_bgd.spec` and `gis3_bgd.spec`.[4]

2. Make ARFs for the GIS2 and GIS3 source spectral files using `ascaarf` with an RMF. Let's assume the RMF is `gis2v4_0.rmf`, and the ARFs are `gis2.arf` and `gis3.arf` respectively.

3. Make a "listfile" for an `addascaspec` input. This file should have the following entries:

   ```
   gis2.spec gis3.spec
   gis2_bgd.spec gis3_bgd.spec
   gis2.arf gis3.arf
   ```

   Note that GIS2 and GIS3 RMFs, though having different names, are identical. Hence, the same RMF can be used for the GIS2 and GIS3 combined spectra, and only the ARFs have to be averaged.

4. Run addascaspec.

   ```
   addascaspec listfile gis23.spec gis23.arf gis23_bgd.spec
   ```

   This command creates the GIS2 and 3 combined spectral file (`gis23.spec`), background file (`gis23_bgd.spec`), and ARF (`gis23.arf`).

5. Use these files with `gis2v4_0.rmf` in `XSPEC`. `XSPEC` may give warning messages, such that instruments are not consistent for spectral files and response files. This does not do any harm, but you may want to change the INSTRUME header keywords in these files with the `grppha chkey` command, or the FTOOL `fparkey`.

Follow the same procedure to combine two or more GIS spectral files taken at different periods.

8.10.2 For SIS

In the case of 1-CCD mode:

1. Extract SIS0 and SIS1 spectra (e.g., `sis0.spec` and `sis1.spec`), and corresponding background spectra (`sis0_bgd.spec` and `sis1_bgd.spec`).

2. Create the SIS0 and SIS1 RMFs using `sisrmg` (`sis0.rmf` and `sis1.rmf`).

3. Create SIS0 and SIS1 ARF using `ascaarf` (`sis0.arf` and `sis1.arf`).

4. Make a "listfile" for an `addascaspec` input. This file should have the following entries:

[4]Note that the background spectra do not have to have the same detector region or exposure time as the source spectra, as `addascaspec` automatically normalized the exposure time and detector region (§8.10.3).

```
sis0.spec sis1.spec
sis0_bgd.spec sis1_bgd.spec
sis0.arf sis0.arf
sis0.rmf sis0.rmf
```

5. Run addascaspec.

```
addascaspec listfile sis01.spec sis01.rsp sis01_bgd.spec
```

   This command creates the SIS0 and 1 combined spectral file (`sis01.spec`), background file (`sis01_bgd.spec`), and RSP (= RMF and ARF combined) (`sis01.rsp`).

6. Use these files in `XSPEC`.

In the case of 2-CCD or 4-CCD modes, first combine the chips by calculating the spectral files, ARFs and RMFs for SIS0 and SIS1 each (§8.9). Then follow the procedure above for 1-CCD mode to combine sensors.

Alternatively, you may create spectral files, RMFs and ARFs for individual chips, then combine them at once with `addascaspec` (§8.9).

8.10.3 Computing the Correct Background Normalization for Combined Spectra

If the background and the source spectra are made from different detector regions, the BACKSCAL keywords of the background spectra have to be calculated to specify the correct background normalization. Due account must be taken of the correct weights for the region sizes and exposure times, but this is automatically taken into account by `addascaspec`. If you are interested, full details of how to calculate the BACKSCAL value when combining two or more energy spectra are given in the document 'Background Normalization' at

`http://heasarc.gsfc.nasa.gov/docs/asca/abc_backscal.html`.

8.11 GIS Deadtime Correction

GIS PH mode has a typical deadtime of about 8 msec per event. For bright sources, GIS deadtime will be significant and deadtime correction is necessary to obtain the correct incident flux through spectral analysis.

GIS deadtime can be calculated using the GIS monitor count rates. The `mkf` files created in the standard processing have two columns, G2_DEADT and G3_DEADT, in which the deadtime fraction values thus calculated are stored.

Using these deadtime fraction values, with the FTOOL `deadtime`, the deadtime correction can be done as follows. In this example the GIS spectrum is called `g2.spec`. As is usual for an *ASCA* spectral file, the first extension contains the energy spectrum and the second extension contains the GTIs. At the system prompt type

```
deadtime g2.spec ft941222_1327_0210.mkf exposure=EXPOSURE deadcol=G2_DEADT
```

The EXPOSURE keyword in the spectral extension is overwritten with the correct exposure time taking deadtime into account. It is a good idea, when using `deadtime`, to verify that the value of EXPOSURE decreases due to the deadtime correction. (The FTOOLS `grppha` or `fkeyprint` can conveniently display the value of the EXPOSURE keyword).

8.12 How to Cope with SIS Pile-up Problem

For bright enough point sources ($\gg$ 10 cts/s/sensor), SIS spectra are likely to be affected by the photon pile-up, that is, two or more photons are detected on the same pixel or adjacent pixels within a single read-out, and taken as a single SIS event (see also §4.10.1). Pile-up will alter the spectral shape, and in principle this is an irreversible process. However, when and where pile-up is not extremely significant, the intrinsic spectrum prior to being affected by the pile-up may be *guessed* from the observed piled-up spectrum itself. `corpileup` ftools is written for that purpose.

`corpileup` reads a cleaned SIS event file, determines the point source center and the radius within which pile-up is too significant to be corrected, and creates a spectral file with the pile-up correction from the region outside.

The `corpileup` output spectral file is ready to be used in `XSPEC`, but responses have to be created independently. Therefore, the following procedure should be taken to carry out SIS spectral analysis with pile-up correction:

1. Create a screened SIS 1CCD Bright or Bright2 mode event file. `corpileup` can handle only 1CCD mode data. If necessary, the event file may have been applied the region selection (such that to select only within some radius).

2. Run `corpileup` to create a pile-up corrected spectrum, which should be used in `XSPEC`. Also, `corpileup` outputs several intermediate files, among which "img1" will tell you the region in the RAW coordinates from which the spectral file is created (PSF core where counting rates exceed 0.023 cnt/pixel/exposure is discarded).

3. Extract a spectral file using `xselect` for the same region as "img1". Using this spectral file[5], which is affected by the pile-up, create RMF with `sisrmg` and ARF with `ascaarf`.

For more details, as well as the algorithm of pile-up correction, please refer to the `corpileup` help file.

8.13 Getting Started with XSPEC

`XSPEC` is a powerful and versatile spectral-fitting program. It is fully documented, with an extensive manual and on-line help which can be obtained at the URL

`http://heasarc.gsfc.nasa.gov/docs/xanadu/xspec/manual/manual.html`.

The following, which covers `XSPEC` basics, is a very brief guide to get you started.

[5] Cross-check that this spectrum is almost identical to the "pha0" spectrum `corpileup` outputs.

8.13.1 Entering Data into XSPEC

Having typed `XSPEC` to start the program, there are two ways of entering data: with `XSPEC` commands, or with the header keywords in the spectral file. A third method, using a command file, is really a more convenient version of the first.

To illustrate these methods, we assume we have produced and obtained the following files for our SIS0-chip1 data:

mkn841_s0c1.pi	source spectral file
back_s0c1.pi	background file
mkn841_s0c1.arf	ARF
s0c1g0234p40e1_512v0_8i.rmf	RMF

Each of these files has a different `XSPEC` command which enters it into the program. These are:

```
XSPEC>data  mkn841_s0c1.pi
XSPEC>backgrnd  back_s0c1.pi
XSPEC>arf  mkn841_s0c1.arf
XSPEC>response  s0c1g0234p40e1_512v0_8i.rmf
```

These lines can be copied with a text editor into an ASCII command file `data_s0c1.xcm`, say, and run with the `XSPEC` command `@data_s0c1`.

Alternatively, you can write the names of the background file, ARF and RMF into the header of the spectral file with the FTOOL `grppha`. Keyword values are changed with the `grppha` command `chkey`. In our example, the following `grppha` commands would be used:

```
chkey BACKFILE  back_s0c1.pi
chkey ANCRFILE  mkn841_s0c1.arf
chkey RESPFILE  s0c1g0234p40e1_512v0_8i.rmf
```

Note that `grppha` will overwrite an existing file (rather than create a new one) only if an exclamation mark is put before the input file name, as in:

```
tarquin> grppha mkn841_s0c1.pi
Please enter output filename[]!mkn841_s0c1.pi
```

More than one data file can be entered into `XSPEC`. For more information about the data command, consult the `XSPEC` manual or type `help commands data` at the `XSPEC>` prompt.

8.13.2 Ignoring Channels and Energy Ranges

It is nearly always good policy to exclude from a fit channels at the lower and upper ends of the pass band, where the instrument efficiency is low, the background predominant and the calibration less certain. The `XSPEC` command `ignore` causes channels to be excluded: `ignore 1-40`, for example, excludes channels 1-40, while `ignore bad` will exclude channels with a quality flag of 5. Note that the `ignore` command operates on regrouped channels, not on the original channels. Its inverse is the `notice` command.

Users can set quality flags themselves with `grppha`. Typing `help quality` at the `GRPPHA>` prompt explains how to do so.

Versions of `XSPEC` later than 9.0 allow the user to ignore or notice channels by specifying energy ranges directly. Thus

```
ignore 1-4:0.0-0.7
```

will ignore all channels in files 1–4 between 0.0 and 0.7 keV.

8.13.3 Defining Models

In `XSPEC`, models are built up from a suite of model components which are either 'additive' (supplying model photons) or 'multiplicative' (modifying the flux of model photons). To see a list of the models available in `XSPEC`, type `model ?`.

Models are defined with the `model` command. For example, the spectrum of a high-redshift quasar with both Galactic and intrinsic absorption might be defined by the command `model wabs * zwabs (zpowerl)`. For help on the `model` command, type `help commands model` and for an explanation of an individual component, type, e.g., `help model zwabs`. Once the `model` command is entered, the user is prompted for the initial values of the corresponding parameters (a carriage return enters the default).

Parameters are fixed with the `freeze` command and unfixed with the `thaw` command. To change a parameter value, use the `newpar` command.

For more information about `XSPEC` models, please consult the `XSPEC` manual and on-line help. In particular note that major changes to model syntax were introduced in `XSPEC` v10.0.

8.13.4 Fitting Models

After defining a model and assigning initial parameter values, fitting is initiated by typing the command `fit`. If a minimum is not found after 10 iterations, the user is given the option of continuing or stopping - perhaps to reset parameters or to try a different model. When the fit converges, a summary is displayed on the screen giving the best-fitting parameter values and chi-squared.

The fit command has several options which you learn about by typing `help commands fit` at the `XSPEC`> prompt.

8.13.5 Deriving Errors

Although some errors are displayed at the culmination of a successful fit, these errors are approximate and should not be quoted in scientific papers. Instead, you should use the `error` command which initiates a further search of chi-squared space to find the width of the minimum in terms of parameter confidence ranges. For example, `error 3` will find the 90 per cent confidence range for the third parameter, i.e., the values which cause chi-squared to depart from its minimum by an increment of 2.7. For more options, type `help commands error`.

8.13.6 Plotting Results

Plotting the results of a fit in `XSPEC` is a three-stage process:

1. Choose the plot device with the `cpd` command. The choices can be seen by typing `cpd ?`. For most workstations, the device is `/xw`.

2. Set the X-axis to be energy, wavelength or channels. Type either **setplot energy**, **setplot wave** or **setplot channels**.

3. Plot the fit, residuals etc. There are two plot commands, **plot**, which simply displays the plot with the plot device, and **iplot**, which displays the plot as well as allowing the user to modify it. Several things may be plotted. For example, **plot data residuals** causes the data (with fit) to be plotted in a large upper panel, with the residuals in a smaller, lower panel. To view the options, type **plot ?**.

To make a PostScript file of your plot, use **iplot** rather than **plot** and type, for example, **hard two_temp_fit.ps/ps** at the PLT> prompt to create the PostScript file **two_temp_fit.ps**.

Chapter 9

TEMPORAL ANALYSIS

9.1 Introduction

This chapter concerns extracting light curves after the data have been screened and/or filtered to prepare the data for temporal analysis. There are three formats for light curves - two FITS and one ASCII. Also covered in this chapter are dead time, barycentric and geocentric corrections and getting started with the timing analysis program `XRONOS`. The User's Guide can be obtained at the URL

`http://heasarc.gsfc.nasa.gov/docs/xanadu/xronos/xronos.html`.

For users who want to produce light curves for figures rather than for `XRONOS`-style temporal analysis, we show how to use `XSELECT` for creating light curve figures.

The latest information about the accuracy of *ASCA* timing analysis can be found in the 'Calibration Uncertainties' Web page (§1.7).

9.2 Three Formats of Light Curve and How to Extract Them

Light curves are produced in `XSELECT` either for creating time filters, i.e., for extracting events based on time, or for temporal analysis outside `XSELECT`. For this latter purpose, the main subject of this chapter, `XSELECT` can create light curves in three formats, each of which has its advantages and disadvantages:

1. Events lists (FITS),
2. Rate files (FITS) and
3. QDP files (ASCII).

Although their arrival times are quantized with the precision appropriate to their data mode and bit rate, the events in an events list should be regarded as unbinned. On the other hand, a light curve is *ipso facto* always binned. To derive the correct count rate in each light curve bin, exposure information is required so that the absence of counts can be attributed correctly either to the non-detection of a photon or to the instrument not being on. When extracting light curves from *ASCA* events lists, this means making sure that when the start or end of a GTI falls within a bin, the counts in that bin are reduced in the same proportion as the bin is shortened. This issue is dealt with differently depending on the light curve format.

With light curves, the most common filter used is an energy filter which allows light curves to be extracted in various energy bands.

Errors for the FITS rate and QDP files that are not background-subtracted are calculated in the same way, by taking the square root of the number of counts in the bin and dividing by the binsize.

9.3 Event Lists as Light Curves

The timing analysis program `XRONOS` can read in the screened GIS and SIS events lists. When the program bins up the data, it consults the GTI extension to calculate the correct exposure. With the original events list (or a region-selected subset of the events list), users always obtain the highest (i.e., the original) temporal resolution. However, the events list contains a lot of information (such as PHA and position) that `XRONOS` does not need, so the input file is rather large.

In `XSELECT`, to produce an events list from the region of interest, use the command `extract events` followed by `save events`, after applying the desired filters.

The structure and contents of events lists, i.e,.the basic FITS data files, is covered in §2.

9.4 FITS Rate Files

FITS rate files contain the light curve in the first extension (called RATE), and the good time intervals in the second extension (called GTI). They differ from events lists in two important respects: they are binned and they contain only rate data (i.e., no columns for position, grade, RTI, PHA, etc.). This results in a considerable saving. For example, an events list containing SIS 1-CCD BRIGHT mode data from GX301-2 occupies 6.6 times more disk space than the corresponding rate file binned at the minimum 4s resolution of the data.

`XRONOS` can read this file and calculates the exposure correctly by applying the GTIs to the binned counts.

In `XSELECT`, to produce a FITS rate file from the region of interest, first choose the binning with the `set binsize` command. Then use the `extract curve` and `save curve` commands to extract, save and name the file. NOTE: If the screened events list from which you extract the light curve contains data with different temporal resolutions (e.g., GIS PH mode with MEDIUM and HIGH bit rates), then make sure that the binsize you choose is no smaller than the largest in the data.

9.5 QDP (ASCII) Rate Files

Many users simply want a binned light curve - with errors and in ASCII - which they can read into their own timing analysis or plotting programs. The QDP rate file satisfies this need. Apart from an ASCII header, the file comprises columns containing time, count rate and count rate error. It can be read directly into the QDP plotting program, as well as into `XRONOS`. The exposure information that `XRONOS` needs is taken from an accompanying file (prefixed with B) that `XSELECT` produces when the QDP rate file is saved. The procedure for producing and saving the QDP rate file is the same as for the FITS rate file except that the commands are augmented with the appropriate qualifiers - like this (for a light curve called `3c273_lc_sis0.qdp` with 32 s bins):

```
xsel> set binsize 32
```

```
xsel> extract curve use_qdp = yes
xsel> save curve save_qdp = yes 3c273_lc_sis0.qdp
```

9.6 Creating Light Curve Figures with XSELECT

Users not interested in full-blown temporal analysis might still want to produce a light curve for a figure. Fortunately, `XSELECT` has an interface to the PGPLOT graphics package which can be used to produce plots without having to quit `XSELECT` and run another program. The same interface is used when creating time and intensity filters.

To make a light curve figure from screened and filtered data execute the following scheme. An alternative is to edit and insert the commands directly into the `.qdp` or `.pco` file.

1. Set the size of the light curve bins with the `set binsize` command. The binsize in seconds is the argument.
2. Extract a light curve with the `extract curve` command.
3. Plot the light curve with the `plot curve` command. If you have not already set a plot device, then you will be prompted for one: `/xw`, for `XWindows`, is a good choice for most workstations.
4. A plot will now appear on the screen with the default appearance. To tailor the plot to your requirements, enter commands at the `PLT>` prompt. Here are some of the basic ones. To see a full list, type `?` at the `PLT>` prompt. Note that some commands, like `rescale`, automatically re-plot, while others, like `label`, require an additional plot command to see the results of a change.
   - Rescaling the X and Y axes is done with the `rescale X` and `rescale Y` commands, respectively. Both commands take the upper and lower limits as arguments. For example, `rescale y 0 1.4` will redraw the plot with the Y-axis running between 0 and 1.4. You can also rescale X and Y in one go by specifying `rescale Xmin Xmax Ymin Ymax`.
   - Labelling is done with the `label` command. At its simplest, the command takes two arguments: a string to indicate the location of the label and the text of the label itself. For example, `label X Time (sec)` will put the label 'Time (sec)' on the X-axis. Other locations are:

     ```
     OX - under the x-axis label
     Y - y axis
     OY - left of the y-axis label
     FILE - where the filename is written by default
     TOP - above the plot window
     OTOP - above the top label
     ```

     The time tag at the bottom right of the plot can be removed with the `time off` command.
   - Changing the size of the plot window is done with the `viewport` command. For the purposes of defining windows, the full screen has a length and height of unity, with the lower left-hand corner being at (0,0) and the upper right-hand corner at (1,1). The default window has vertices at (0.1,0.1) and (0.9,0.9). To change, for example, to a smaller, more letter-box-like window, type `viewport 0.2 0.3 0.8 0.7`.

- Changing the size of the characters is done with the `csize` command. For example, `csize 1.25` will increase the size of the numbers on the axes and the letters in the labels by 25 per cent.
- Changing the font of the characters is done with the font command. For example, `font roman` will change the font to roman from the default, sans-serif font. Other fonts are italic and script.
- Rotating the numbers on the Y-axis is done with the `label rotate` command.
- Changing the thickness of lines is done with the `lwidth` command. This is useful for enhancing the appearance of hardcopy plots for viewgraphs or papers. The default, the thinnest, is a line width of 1. Alternatives are 2, 3, 4, etc.
- All commands can be abbreviated with the shortest unambiguous string

5. The final step is creating a hardcopy which is done with the hardcopy command. For example, to create the PostScript file, `eclipse.ps`, type `hardcopy eclipse.ps/ps` at the `PLT>` prompt.

To do more sophisticated manipulation consult the QDP/PLT manual and/or the on-line help.

9.7 Background Subtraction for Light Curves

There is no general program for subtracting background from *ASCA* light curves. However it can be done with a combination of FTOOLS or your own software. There are two basic methods. Both methods require making a light curve from a background region from the same observation, with the same selection criteria and preferably the same GTI.

1. If the binsize is large enough that you have enough background in each bin, subtract the background from each corresponding on-source light curve bin directly.
2. Since the *ASCA* background will be fairly constant during an observation, especially after screening, you can fit the background light curve with a simple function such as a polynomial (and in most cases, simply a straight line) and subtract this from the on-source light curve.

The IDL program `makeqdp` uses the latter method (simply subtracting the mean background level) and is available at the URL

`http://lheawww.gsfc.nasa.gov/ yaqoob/ascaidlsys.html`.

9.8 GIS Light Curve Deadtime Correction

GIS PH mode data has a typical deadtime of about 8 msec per event, and the deadtime has to be corrected for bright sources in order to obtain the intrinsic X-ray flux and its time variation. GIS deadtime can be calculated using the GIS monitor count rates, and the `mkf` files created in the standard processing (REV1 and later) have two columns, G2_DEADT and G3_DEADT, in which the deadtime fraction values thus calculated are stored.

The FTOOL `ldeadtime` uses these deadtime fraction and the deadtime correction can be done as follows. In this example of the use of `ldeadtime` the GIS light curve is called `g2.curve` which has a corresponding `mkf` file `ft941123_0821_2301.mkf`:

```
ldeadtime g2.curve ft941123_0821_2301.mkf
```

The RATE and ERROR columns of the light curve file are overwritten, now corrected for the deadtime. The FRACEXP column will have the livetime fraction for each time bin, and can be used to get obtain the original counting rates before the correction.

9.9 Telemetry Saturation Effects for SIS Data

Since the SIS is not a true photon-counting detector, there is no hardware deadtime as such: a pixel into which an X-ray photon enters remains responsive to further X-ray photons throughout the exposure cycle. This does, however, lead to the problem of 'photon pile-up' for the spectroscopy of very bright sources.

In time-series analysis, the most important SIS 'dead time' effect is telemetry saturation. When the total count rate of the source, X-ray and non X-ray background exceeds the telemetry limit of the SIS mode/bit rate combination, events are lost in a manner that makes dead-time correction difficult. For `mkf` files originating in REV1 or later processing, a series of telemetry saturation flags (`Sn_SATFm`, where `n` is the SIS number and `m` is the chip number) are included. By selecting, say, `S0_SATF1 = 0`, you can select time intervals when events in SIS-0 Chip 1 did not saturate the telemetry.

Telemetry saturation limits, in counts per second per chip, are summarized in the following table.

	FAINT mode			BRIGHT mode			FAST mode
CCD mode	1	2	4	1	2	4	PS
High	64	32	16	256	128	64	512
Medium	8	4	2	32	16	8	64

The rate of hot/flickering pixels has to be included when assessing the net count-rates as well as the source and the X-ray background count-rates.

9.10 Barycentric and Geocentric Corrections

The FTOOL `timeconv` converts photon arrival times (represented by satellite time by default) to geocentric or barycentric time. It was written by Yutaro Sekimoto and Masaharu Hirayama (University of Tokyo), and converted to an FTOOL at GSFC.

The program `timeconv` runs on the screened events list rather than on the FITS rate files or QDP rate files. Note that since it alters the times in the `mkf` file, timeconv should be run after all selections have been performed. Two files are needed.

- `frf.orbit` The satellite orbit file which can be found in the `aux` directory on PIs' datatapes and in the same place for each sequence in the *ASCA* Archive.
- `earth.dat` Earth orbital parameter file, which is available via anonymous FTP at `ftp://legacy.gsfc.nasa.gov/software/ftools/ALPHA/ftools/refdata/`.

The program `timeconv` is run as follows:

> `timeconv data.evt m ra dec earth.dat frf.orbit`

where `data.evt` is the screened events list; `m` is set to

- 1 for geocentric correction,
- 2 for barycentric, and
- 3 for barycentric-ascatime (see below).

RA and DEC are self-explanatory (and must be given in J2000).

Since the time systems used in geocentric time and barycentric time are different, care must be taken when using `timeconv`. The following is a brief description of several different time systems:

- **TAI**: International Atomic Time. It is defined by atomic clocks. TAI is continuous.
- **UTC**: Coordinated Universal Time. UTC differs from TAI by an integral number of seconds. UTC sometimes includes a jump, called a leap second. UTC is artificially adjusted to set the difference from UT1, which is basically defined by the spin period of the Earth, within a certain value. As the Earth's spin period has increased since the mid 19th century, when the mean solar day equaled 86400.000 SI seconds, a leap second is occasionally inserted. On 1993 Jan 1st, It differed from TAI by 27 sec. Between the launch of ASCA and 1999 May, a leap second had been inserted on 1993 July 1st, 1994 July 1st, 1996 Jan 1st, 1997 July 1st, and 1999 Jan 1st. See `ftp://maia.usno.navy.mil/ser7/tai-utc.dat` for the latest and historical leap second record.
- **TDB**: Barycentric Dynamical Time. The concept of time that is used as the variable in gravitational equations of motion. It is based on the SI (System International) second and measured by atomic clocks. It commenced in 1977, when the relationship between TDT (Terrestrial Dynamical Time) and TAI was defined to be: TDT = TAI + 32.184 seconds. TDB is intended for use in the equations of motion of planetary bodies with reference to the barycenter of the solar system. It is not uniquely defined but depends on the theory of gravitation that is adopted. However, it is stipulated that it differs from TDT by only periodic discrepancies. Please see the American Astronomical Almanac for more details.
- **ASCATIME**: TAI-27.0 seconds (definition). ASCATIME was the same as UTC before 1993 July 1, when the first leap second was inserted after the launch of ASCA.

The three options in `timeconv` work as follows:

1. **Geocentric**: Correct the light travel time between the satellite and the center of the Earth.
2. **Barycentric**: Correct the light travel time between the satellite and the barycenter of the solar system, and then convert the photon arrival time, which is represented by ASCATIME, to TDB. Note that TDB differs from ASCATIME by 32.184+27.0 sec. Timing results from different missions are conventionally compared by using TDB.
3. **Barycentric-ascatime**:Useful to see the time difference between the satellite and the barycenter.

9.11 GIS Light Curves Using Monitor Counts

There are GIS house-keeping parameters which are called 'monitor counts' and can be used to study time variations of X-ray sources. Among several different kinds of monitor counts, the 'L1' monitor counts are considered mostly X-rays, and suitable for astrophysical study. Although the L1 monitor counts do not have energy nor spatial resolution, its small deadtime (25 micro-sec/event), large telemetry limit (2048 cts/s/sensor) and moderate time resolution (0.125 sec) make it effective for timing studies of bright X-ray sources for which standard PH mode data might be hardly usable because of the significant deadtime and the telemetry saturation.

Here is an example of making a FITS format L1 light curve, `g3_L1.curve`, from the HK file, `ft950420_1006_2240G3HK.fits`, using the FTOOL `ghkcurve`:

```
ghkcurve ft950420_1006_2240G3HK.fits g3_L1.curve bit_high.gti High
```

`bit_high.gti` is the GTI file. The last option is either HIGH or MEDIUM, corresponding to whether the GTI file includes HIGH bit rate (with a time resolution of 0.125 sec) or MEDIUM bit rate (with a time resolution of 1.0 sec) respectively. The light curve file thus made can be read by `XRONOS` in the standard manner.

9.12 Temporal Resolution

The temporal resolution of *ASCA* data depends on instrument, mode, and - in the case of the GIS only - bit rate.

The keyword TIMEDEL contains the temporal resolution of an events list, i.e., the smallest data accumulation time. It appears in the primary header and in the header of the EVENTS extension (but SPECTRUM extension for MPC mode). But beware: when events lists of differing temporal resolution are combined (e.g., when combining GIS HIGH and MEDIUM bit rate data), TIMEDEL has the value of the first set of events, regardless of whether it applies throughout the file.

9.12.1 GIS PH Mode

For standard bit assignments, the temporal resolution is 62.5 msec in HIGH bit rate and 500 msec in MEDIUM bit rate.

For non-standard bit assignments, when N bits are used for timing, the temporal resolution is 2**N times better.

9.12.2 GIS MPC Mode

The temporal resolution in MPC mode depends on bit rate, as well as on how many bits are assigned to timing versus PHA, as shown in the table below.

```
---------------------------------------------------
                        Timing bits

BIT RATE         0         2         4         8
---------------------------------------------------
HIGH           0.5s    0.125s   31.25ms   1.95ms
```

```
MEDIUM           4s      1.s    0.25s   15.60ms
---------------------------------------------------
```

9.12.3 SIS FAINT, BRIGHT and BRIGHT2 Modes

For the three SIS imaging modes, FAINT, BRIGHT and BRIGHT2, the temporal resolution depends on the clocking mode, i.e., how many CCD chips are exposed. It does not depend on bit rate:

```
-------------------------------------------------
CLOCKING MODE  4-CCD     2-CCD     1-CCD
-------------------------------------------------
                 16s        8s        4s
-------------------------------------------------
```

9.12.4 SIS FAST Mode

In FAST mode events lists, the values in the TIME column are the photon arrival times with a precision of 4 s. The RAWY column contains a correction to this value which, when applied by `XSELECT` (via the FTOOL `fasttime`), increases the precision to 15.625 ms.

Chapter 10

Spatial Analysis

10.1 Introduction

In this chapter we describe in more detail image extraction and the structure of the image files. We will also address some issues relating to attitude reconstruction, image deconvolution, exposure maps, and extended source analysis. In this chapter we also show you how to get started using the image display and analysis program `XIMAGE`.

10.2 Extracting Images

Once the data have been screened and the desired filters set, simply type `extract image` at the `XSELECT` prompt. This command initiates the extractor, which applies whatever GTIs and filters are in place to the current events list. The extractor creates a temporary file which is deleted on exiting `XSELECT` unless saved. Use the `save image` command, giving the name of the image file as the argument. Although this procedure is as straightforward as it sounds, please note the following.

- Before running the extractor, it is a good idea to check what filters are in place with the `show status` command. The same command also shows which X and Y coordinate systems are in use and how the image will be binned upon extraction.
- By default, images are extracted in detector coordinates. To change to SKY coordinates, type `set image sky`. A SKY image, as well as being in astronomical units, also has the attitude solution applied to the events. Thus the image is more accurate as the astrometery has been applied.
- With images, the most common filter used is an energy filter which allows images to be extracted in various energy bands.
- The extractor displays on the screen a summary of which events have been extracted and which discarded. There are three categories of discarded events: Region, Time, Phase and PHA/PI which correspond to the various kinds of filter. Events screened out using the `mkf` file are tallied in the Time column.
- You might find it helpful to include a reference to the instrument in the file name, as in `a1736_g2.img` and `kepler_soft_s0c1.img`, for example.

For the detector-specific properties of GIS and SIS images, please consult chapters 3 and 4 respectively.

10.3 Image Files

It is not necessary to know all about *ASCA* image files in order to use them. However, it is a good idea to be familiar with their basic structure and contents.

Compared with *ASCA* spectral files, image files are much simpler. They comprise only the primary header (containing keywords, some of which are used by `SAOimage` and `XIMAGE`) and the primary image array (containing the actual image data). Some of the important keywords in the primary header of both detector and SKY image files are:

```
NAXIS1 - Length of data axis 1 (number of X or DETX pixels)
NAXIS2 - Length of data axis 2 (number of Y or DETY pixels)
IMGBIN - Image binning factor
EXPOSURE - Exposure in seconds (sum of GTIs used for extraction)
RA_NOM - Right Ascension (decimal degree) of target from Observation Plan
DEC_NOM - Declination (decimal degree) of target from Observation Plan
DROLLANG - Mean roll angle (decimal degree)
CRPIX1 - X axis reference pixel
DRPIX1 - DETX axis reference pixel
CRPIX2 - Y axis reference pixel
DRPIX2 - DETY axis reference pixel
CRVAL1 - Sky coord of X reference pixel (degree)
CRVAL2 - Sky coord of Y reference pixel (degree)
CDELT1 - X axis increment (degree)
CDELT2 - Y axis increment (degree)
DRDELT1 - DETX axis increment (degree)
DRDELT2 - DETY axis increment (degree)
CROTA2 - Roll angle (degree)
```

Unlike SKY image files, detector image files have non-zero values of CROTA2 which gives the rotation of the Spacecraft Y axis from the detector to the SKY coordinate system. In addition, detector image files have an extra pair of keywords:

```
OPTIC1 - DETX pixel of the telescope optical axis.
OPTIC2 - DETY pixel of the telescope optical axis.
```

The primary header of a FITS image file can be displayed on the screen using the FTOOL `fdump`. The image data themselves can be converted to ASCII and displayed on the screen with the FTOOL `fimgdmp`.

To convert pixel coordinates from one mission to another, please follow the instructions for multi-mission region filters in §7.10.

10.4 Attitude Reconstruction

Here, attitude reconstruction means the conversion of detector coordinates to SKY coordinates. For *ASCA*, this conversion is done as part of the standard processing by the *ASCA* Data Facility: data delivered to PIs and in the *ASCA* archive therefore carry SKY coordinates - except for the non-imaging GIS MPC and SIS FAST modes.

The accuracy of the reconstruction depends on two things, the pointing stability of the spacecraft and the accuracy of the reconstruction algorithm itself.

10.4.1 Pointing Stability

The *ASCA* spacecraft can rotate about all three of its axes at a maximum rate of 0.15 degrees per second. At the end of a maneuver, when the target has been acquired, the spacecraft settles into a stable attitude. The Attitude Control System (ACS) has been performing as follows:

```
Pointing stability:
  Z-axis, 3-sigma                                          5 arcsec
  Around Z-axis, 3-sigma                                  20 arcsec

Post-maneuver settling time:                         15-20 minutes
```

10.4.2 Reconstruction Algorithm

The attitude reconstruction algorithm is embodied in an FTOOL called `ascalin` which, as mentioned above, is normally run by the ADF rather than by the user. It takes as input the attitude file, the data file (events list), gain history file and telescope definition file.

The typical error circle for *ASCA* is ~ 40 arcsec. A more thorough explanation is given in the article 'The *ASCA* Source Position Uncertainties', *ASCANews, #4*.

10.5 Exposure Maps

An exposure map gives the net exposure time per SKY pixel for a given observation. It is used to normalize the associated sky count map to derive counts per seconds per pixel. This is useful for generating exposure corrected surface brightness sky maps.

The FTOOL `ascaexpo` is a powerful tool used to generate exposure maps for both SIS and GIS observations. `ascaexpo` uses the header information in an events file, the telescope definition file, and the attitude file to produce an exposure map in SKY coordinates. This takes into account the attitude reconstruction, and includes, for the GIS, the detector geometry, and for the SIS, the chip arrangement, area discrimination, and hot/flickering pixel (for files run through the program CLEANSIS). Note that removal of SIS telemetry-saturated events is dealt with in §5.4.5.

Warning! If `none` (the default) is given as an input to the question: `Input ASCA instrument map filename (or NONE) []` `ascaexpo` assumes a uniform detector efficiency and adds attitude jitter to it. In order to generate an exposure map, a detector efficiency map has to be used as an input. The FTOOL `ascaeffmap` generates such map. This method takes into account the observed spectral distribution, the mirror response, and the instrument efficiency to estimate a flat-field. There are several potential pitfalls while using `ascaeffmap`. First it is essential to check the range of PHA given as input. In particular, one should exclude all channels below 0.7 keV (for the GIS) and make sure that the upper limit is not above 10 keV. Because `ascaeffmap` uses the grouped channels, it can be useful to check the screen output while the program is running. This is because the GIS has no effective area below 0.7 keV but there are events with PHA/PI corresponding to lower energies than that due to the low energy tail of the response. If those value are included while running `ascaeffmap`, the program strongly biases the efficiency map. To avoid being dominated by the low energy contribution from the background, the PHA file used as an input to the program should be extracted from a region covering all the source, but not all the detector. If the PHA is dominated by the background, `ascaeffmap` will not produce an accurate result. If XRT effective area is included in the computation, the output of `ascaeffmap` is in cm^2.

When the output of `ascaeffmap` is given as a input to `ascaexpo`, the hidden parameter `imath` **has** to be set to `mul` on the command line (look at the help page of `ascaexpo`).

To generate an appropriate flat-fielded image, a detector efficiency map can be used as an input to `ascaexpo`. The FTOOL `ascaeffmap` is available to estimate the detector/mirror efficiency based on user parameters germane to a particular analysis. This method takes into account the observed spectral distribution, the mirror response, and the instrument efficiency to estimate a flat-field. The output map from `ascaeffmap` can be given as input to `ascaexpo`.

Below is a typical session using `ascaexpo`, complete with running annotations. Symbols at the beginning of each line denote the following.

```
(>) inputs to ASCAEXPO
(<) outputs from ASCAEXPO
(o) running comments
```

Use `fhelp ascaexpo` for additional details, features, and limitations.

10.5.1 Example ASCAEXPO Session

```
ascaexpo_V0.9a


    o First we input the various files and options:

> Input ASCA science file filename[] ad42000000s000202h.evt


    o A single modally merged events file.

> Input ASCA telescope definition filename (or CALDB)[] s0_teldef_070294.fits


    o If you have the CALDB installed, you may enter 'caldb' to
      automatically read in the correct telescope definition file,
      otherwise use the `tel_def' file which came with your data (in the
      `aux' directory).

> Input ASCA attitude filename (or DEFAULT/NONE)[] fa940529_2031.2020

    o If `none' is entered, a fixed aspect will be performed (using
      the FTOOL FIXEDASP; see help file for details).

> Input ASCA rate filename (or NONE)[] none

    o Only option available thus far.


> Input ASCA instrument map filename (or NONE)[] none

    o Entering `none' creates an internal instrument map based on the
      events file observing mode.

    o Or, input the output file from ascaeffmap.

> Output exposure map filename (or DEFAULT)[] default

    o Output exposure map, `default' will append `.expo' to events filename.

> Output instrument map filename (or DEFAULT/NONE)[] default

    o Output instrument map, `default' will append `.inst' to events filename.

    o If it is not necessary to output this map, use the `none' option.

> Output sky image filename (or DEFAULT/NONE)[] default

    o Output sky image map, `default' will append `.sky' to events filename.
```

```
    o If it is not necessary to output this map, use the 'none' option.

    o This SKY image map will be a perfect match to the exposure map!

> Maximum attitude deviation (arcsecs)[4] 1

    o This option allows you to trade off speed for accuracy. The attitude
      file typically contains records every 2 seconds (but depends on the
      bit rate).

    o For each step though the attitude file, ASCAEXPO generates a temporary
      exposure map for that interval and attitude. This map is then added to
      the summed exposure map.

    o It is very slow to build up an exposure map for every step in
      the attitude file. ASCAEXPO allows three methods to speed up the
      processes.

      1) Enter -N to skip N attitude file records between exposure map updates.

      2) Enter X to skip records until the attitude deviated by more than
         X arcmin from the last exposure map update.

      3) Use a smaller image size with the 'rebin' option below.

    o To use the full accuracy available in the attitude file, i.e.
      to build up the exposure map for each step in the attitude file,
      select -1.

> Integer image rebin factor (-1 for default)[] -1

    o You may wish to rebin the output image. Choosing -1 will
      rebin SIS maps by a factor of 4, and by unity for the GIS.

> Pixel convention offset for CRPIX of output images[] 0.5

    o This option allows for none-standard image CRPIX pixel conventions.
    o Enter a number between 0.0 and 1.0; normally 0.5.

<   reading data file: ad42000000s000202h.evt
<   reading   gti ext: STDGTI
<   reading    hp ext: HOT_PIXELS
<   reading  cal file: s0_teldef_070294.fits

    o Now ASCAEXPO displays each steps as it goes...

    o For the SIS, the events file header info, GTI and HOT_PIXELS extension
      data are read in.
```

```
    o Then the Telescope Definition File is read.

<   making an inst map...

    o If appropriate, creates the instrument map.

< SIS AREA DISC ENABL          ON

<             CHIP:            0           1           2           3

< CCD POWER  ON/OFF:          OFF          ON         OFF         OFF
< AREA DISC  IN/OUT:          OUT          IN          IN          IN
< AREA DISC H START:            6         226           6         316
< AREA DISC H  STOP:          425         300         200         425
< AREA DISC V START:            2         220           2           2
< AREA DISC V  STOP:          422         294         150         112

   o Display the SIS AREA DISCRIMINATION state and values.

<    writing inst file: ad42000000s000202h.evt.imap

   o If appropriate, writes out the instrument map.


<    reading att  file: fa940529_2031.2020

   o Just read in the attitude file.

<    making a sky image...
<    writing sky image: ad42000000s000202h.evt.sky

   o If appropriate, creates and writes out the sky image.

<    making an exposure map...

< Aspect RA/DEC/ROLL :      308.1400      41.0414     297.8467
< Mean   RA/DEC/ROLL :      308.1349      41.0176     297.8467
< Pnt    RA/DEC/ROLL :      308.1489      41.0613     297.8467

   o Analysed the coordinates system.

< Image rebin factor :             4
< Attitude Records   :         75032
< Hot Pixels         :            19
< GTI intervals      :            65
< Total GTI (secs)   :      7228.517

   o Display file information.

< Max attitude excursion (arcsecs) :         1.000
```

```
   o Display attitude excursion option.

<   0 Percent Complete: Total/live time:       0.0000000      0.0000000
<  10 Percent Complete: Total/live time:     812.0728760    812.0728760
<  20 Percent Complete: Total/live time:    1552.5705566   1552.5705566
<  30 Percent Complete: Total/live time:    2255.6794434   2255.6794434
<  40 Percent Complete: Total/live time:    3344.9746094   3344.9746094
<  50 Percent Complete: Total/live time:    3754.4421387   3754.4421387
<  60 Percent Complete: Total/live time:    4429.9404297   4429.9404297
<  70 Percent Complete: Total/live time:    5138.4086914   5138.4086914
<  80 Percent Complete: Total/live time:    5855.1186523   5855.1186523
<  90 Percent Complete: Total/live time:    6583.0859375   6583.0859375
< 100 Percent Complete: Total/live time:    7228.5229492   7228.5229492

   o ASCAEXPO is now computing the exposure map. For convenience the
     percentage completed is displayed.

< Number of attitude steps  used:          496
< Number of attitude steps avail:        18685
< Mean RA/DEC pixel offset:      -67.1511     -90.6348

   o ASCAEXPO has completed the exposure map. It used 496 attitude steps
     out of 18685 available in the file. That is because (a) the events file
     contains a subset of the time in the attitude file, and (b) we skipped
     over records in the file by choosing the 'max attitude excursion'
     option.

   o The Mean RA/DEC pixel offset is the average deviation of the attitude
     from the pointing direction of this file.

<    writing expo file: ad42000000s000202h.evt.expo

   o Write out the final exposure map

<    closing attitude file...
<    closing data file...

   o Close up shop....
```

10.5.2 HINTS on running ASCAEXPO and using its products

- Run `ascaexpo` on modally merged files.
- Read the collection of files into `XIMAGE`, `IRAF`, or other image analysis package.
- For the most accurate results use an attitude deviation value of -1
- For single sequences, all the events files are aspected to the same point in the sky (FITS header keywords RA_NOM and DEC_NOM) so you can add the files from each instrument pixel-by-pixel.

- To make an exposure corrected image for a given *ASCA* sequence using FTOOLS:

  1. Add the collection of image and exposure maps using the FTOOL `farith`.
  2. Smooth the images using the FTOOL `fadapt`.
  3. Divide the image by the exposure map using `farith`.

- For multiple observations - add the images with an offset using `fimgmerge` (Use SKY2XY/XY2SKY to determine offsets).

- Run the FTOOL `ldeadtime` on the events file to determine livetime.

10.6 The ASCA PSF

In order to understand how to do spatial and extended source analysis with *ASCA* data, it is necessary to understand the properties of the Point Spread Function (PSF) and how it was calibrated both on the ground and inflight. The PSF describes, for photons of a given energy, E, the two-dimensional spatial distribution of count rates due to a point source.

The PSF of the *ASCA* X-ray telescopes (XRT) has a relatively sharp core (FWHM of $\sim$ 50 arcsec) but broad wings (half-power diameter of 3 arcmin). In general the XRT PSF is a function of energy, the angle from the optical axis and also the azimuthal angle about the source position. The energy dependence is such that core of the PSF is sharper at lower energies. In addition, the GIS has its own PSF which is comparable in width to that of the XRT but with a different shape (a Gaussian with σ 30 arcsec at 6 keV and a $1/\sqrt(E)$ dependence). The intrinsic spatial broadening of the SIS is negligible compared to that of the XRT.

In the early part of the *ASCA* mission the XRT PSF that was used was based on ray-tracing results. The PSF was then fine-tuned using observations of Cyg X-1 placed at different points in the focal plane. The current XRT PSF files can be obtained by anonymous FTP from `ftp://legacy.gsfc.nasa.gov/` in the directory

`/caldb/data/asca/xrt/bcf`.

At the time of going to press the PSF file in use is `xrt_psf_v2_0.fits` and the associated XRT effective area file is `xrt_ea_v2_0.fits`. The calibration images of Cyg X-1 can be obtained from the same place in the directory

`/caldb/data/asca/xrt/bcf/psf`

Check the 'README' for details.

A problem with the Cyg X-1 PSF calibration is that the source is thought to be extended below $\sim$ 2 keV and this may introduce errors of the order of $\sim$ 10%. More details can be found in Kunieda *et al.*, *ASCANews, #3* in which the *azimuthal* calibration of the PSF is discussed. The azimuthal properties of the *ASCA* PSF are not as well understood as the azimuthally-averaged properties so that circular data-extraction regions currently give the most accurate results.

Further PSF calibration observations are planned, this time of Her X-1 which is thought to be a point source even at soft energies. Consult the Web page 'Calibration Uncertainties' for the latest information (§1.7).

10.7 Extended Sources and Spatio-Spectral Analysis

From the above, it should be clear that the analysis of extended source using *ASCA* data is non-trivial. For extended sources, the astrophysical implications of the broad PSF are complicated and not easy to deal with. If you are analyzing an extended source, then please note the following effects which, if not taken into account, could lead to spurious scientific results. It is important to realize that these effects are not calibration uncertainties or instrumental defects, but features intrinsic to the design of the XRT which emphasizes effective area as much as angular resolution.

1. When `ascaarf` is used to make an ARF for a point source, XRT effective area and PSF calibration files are used to generate the ancillary response file. If the 'extended source' option is utilized, the count distribution in the WMAP of the spectral file is used as the template for the spatial counts distribution (thus, the 'extended source' computation is actually faster than the point-source option). The extended-source option is inherently an approximation. A more accurate method is to generate an ARF using a ray-tracing code to simulate the real data. This requires either finding the true, intrinsic spatial distribution of the source by trial and error or using a ROSAT image as a surface-brightness template for ray-tracing. However, an important point to bear in mind is that ROSAT covers a much soft X-ray energy band than *ASCA* so the spatial structure in the ROSAT band may be very different to that in the *ASCA* band.

2. The XRT PSF has a sharp core and broad wings. If your extended source has a brightness distribution which is peaked on the same scale as the PSF, then the outer parts of the image will contain a significant proportion of counts from the core. For example, the moderate redshift cluster A2218 has a core radius of about 1 arcmin. If the image is divided into annulli (3 arcmin wide centered on the core) then the second annulus (between 3 and 6 arcmin) will contain more emission from the cluster core than from those parts of the cluster which actually lie in the central 3 arcmin circle.

3. The effect described above will be compounded by telescope vignetting if the core of your object is close to the optical axis of the XRT.

4. The XRT scatters high-energy X-rays more than low-energy X-rays. In other words, the PSF broadens with increasing energy. One consequence of this effect is to introduce spurious (outwardly increasing) temperature gradients in isothermal distributions. If there is a negative temperature gradient present, that gradient will appear to be reduced. The GIS has its own intrinsic energy-dependent PSF, although the energy dependence is in the opposite sense to that of the XRT.

10.7.1 Spatio-Spectral Analysis

In view of the above, it should be clear by now that any combined spatial and spectral analysis on extended source is highly non-trivial. There are many cases where it is nevertheless necessary: the determination of X-ray temperature maps of clusters of galaxies, for example, or the detection of a non-thermal contribution to the spectrum of a supernova remnant.

The two most accurate methods which have been developed so far, are described in an article *ASCANews, # 3*, by Takahashi *et al.* It is beyond the scope of this document to describe these in detail but essentially the two methods can be summarized as follows.

1. Simulate the real data, either with trial, theoretical temperature and brightness distributions, and/or using ROSAT data (again, bear in mind that the ROSAT energy band is sufficiently different from that of *ASCA* that the spatial distribution in the two bandpasses may be different). The photons produced can be analyzed in exactly the same manners as the real data (e.g., using `xselect`, etc.). The input model is then modified to reproduce the data. It is necessary to simulate 5 to 10 times more photons than the real data so to minimize the statistical fluctuations of the simulated data. This method has been applied to the Centaurus and Fornax clusters by Ikebe (1995, PhD thesis, University of Tokyo) and to A1795 and 3A0336+09 by Ohashi (1995, Proceedings of the 17th Texas Symposium on Relativistic Astrophysics).

2. Another way is to modify the spectral fitting procedure to include the mirror scattering. This method transforms the telescope response transform into a matrix which includes all the information about the source geometry and integration regions, vignetting and PSF scattering. When there is no PSF scattering, the matrix is diagonal and all is reduced to the standard scheme. Errors are estimated with Monte-Carlo simulations. The reader is urged to read Markevitch (1996, ApJ, 465, L1) in which temperature maps were made for four clusters using *ASCA* data.

10.8 Merging Observations

In the case of several observations of a large extended source, it is possible to merge the data to map the totality of the source. A program called `fmosaic` is available to do just so. The `fmosaic` program is a fortran program inspired by an existing program written by E. Churazov, M. Gilfanov, and A. Finoguenov. `fmosaic` creates a mosaic of several observations and take correctly into account, both the energy and the spatial binning of the data files. The user specifies the center of the image to be created, the image size (in arcmin) and the energy range of photons to be included in the final image. A mosaic of the background and exposure map, using the same image definition, can be generated as an option.

To create an image mosaic of the observations and nothing else, the input file must consist of 2 columns containing the name of the event files and of the RMF file associated respectively (to allow for energy range selection). **WARNING!** if the rmf file and the event file are not binned the same way, `fmosaic` will stop).

Options: There are two ways to generate a mosaic background map. One is to generate blank files for each observation and fill the third column of the input file with the name of this background file. These files can be generated using `mkgisbgd` and the newest files in the CALDB directory or they can be "private" background maps generated with some user-defined routine. This is the prefered mode.

The other option is to use the default option and access the old CALDB background files. For the moment the files accessed through CALDB options are still the ones under the `/94may/` directory and not the newest ones (see Chapter 8). In this case, the input file's third column should contain the name of the MKF file associated with each observation. The MKF file is used in the case of the ASCA to derive the rigidity histogram and then assigning the same weight to the background files found in CALDB.

The exposure maps associated with each observation are computed with the program (`ascaexpo`) and combined later. Their name is given either in the third or the fourth column, depending if a mosaic of the background is generated or not. `fmosaic` code is available at: `ftp://legacy.gsfc.nasa.gov/asca/software/fmosaic_v1.00.tar.gz`. Please note that it is still the first version of the code and that it was only compiled on Solaris machine. If you have any problems running the code, please contact the *ASCA* GOF at asca-help@olegacy.gsfc.nasa.gov.

10.9 Image Deconvolution

The deconvolution of images is also non-trivial. Application of the 'Lucy-Richardson' method to *ASCA* data, as well as a description of the XRT performance can be found in *Jalota, L., Gotthelf, E.V., and Zoonematkermani, S. 1993, SPIE 1945, 453.* The method is able to resolve two point sources of equal intensity, $\sim$ 30 arcsec apart. An example of the method applied to actual *ASCA* data of Cas A can be found in *Holt, S. S., Gotthelf E. V., Tsunemi, H., Negoro, H., 1994, PASJ, 46, L151.*

There is also a deconvolution routine available in `IDL` called `max_entropy`. Given the similarity of the XRT PSF with the original, uncorrected PSF of the Hubble Space Telescope, users might also want to check out some of the early HST imaging papers.

10.10 Getting Started with XIMAGE

`XIMAGE` is a powerful and versatile image display and analysis program. It is fully documented, with an extensive manual and on-line help. The User's Guide can be obtained by consulting the URL

`http://heasarc.gsfc.nasa.gov/docs/xanadu/ximage/ximage.html`.

Note that while spectral work is more accurate with image manipulation in detector coordinates, image analysis is more accurate in SKY coordinates. The following, which covers `XIMAGE` basics, is a very brief guide to get you started. Note that many `XIMAGE` commands have several qualifiers to extend their function: please use the on-line help to find out about them.

- **Entering data into XIMAGE**. *ASCA* image files, whether in detector coordinates or SKY coordinates, are in FITS format. Accordingly, they are read into `XIMAGE` with the `read/fits` command.
- **Setting the plotting device**. This is done with the `cpd` command. For most workstations, `cpd /xw`, which changes the plot device to `XWindows`, is appropriate.
- **Displaying images**. The command `display` plots the current image on the plotting device with the default colour table. Other display options are:
  1. Rebinning the image with the `rebin` command.
  2. Smoothing the image with the `smooth` command.
  3. Creating and displaying a contour map with the `contour` command.
  4. Overlaying a coordinate grid with the `grid` command.
- **Measuring background**. The command `background/box_size=32` will, for example, divide the image into 32 x 32 sq-pixel boxes and analyze the uniformity of the image, i.e., quantify its flatness.
- **Deriving source statistics**. The `sosta` command counts the number of events within a specified box, corrects those counts for vignetting, exposure and the PSF to give the source intensity and the statistical significance of its detection. This is a sophisticated command: please read the on-line help before using it - i.e., type `help sosta` at the `XIMAGE>` prompt.
- **Detecting sources**. The `detect` command locates point sources using a sliding cell method. Like `sosta`, it is a sophisticated command: type `help detect` before using it.

Chapter 11

APPENDICES

11.1 Acronyms

AO .... Announcement of Opportunity
ADF ...... Astrophysical Data Facility
ASCA ..... Advanced Satellite for Cosmology and Astrophysics
ARF ...... Ancillary Response File
CCD ...... Charged Coupled Device
COR ...... Cut-Off Rigidity
CPU ...... Central Processing Unit
CTE ...... Charge Transfer Efficiency
CTI ...... Charge Transfer Inefficiency
DFE ...... Dark Frame Error
FITS ..... Flexible Image Transport System
FOV ...... Field of View
FWHM ..... Full Width at Half Maximum
FRF ...... First Reduction File
FTP ...... File Transfer Protocol
GIS ...... Gas Imaging Spectrometer
GOF ...... Guest Observer Facility
GTI ...... Good Time Interval
HEASARC .. High Energy Astrophysics Science Archive Research Center
HK .... Housekeeping
HTML ..... Hyper-Text Mark-up language
HTTP ..... Hyper-Text Transfer Protocol
ISAS ..... Institute of Space and Astronautical Science
LHEA ..... Laboratory for High Energy Astrophysics
mkf ...... mkfilter file
MPC ...... Multi Pulse Count
OGIP ..... Office of Guest Investigator Programs
PHA ...... Pulse Height Analyzer
PI .... Pulse Invariant
PSF ...... Point Spread Function
PV .... Performance Verification
QDP ...... Quick and Dandy Plotter (previously Quick and Dirty Plotter)
RDD ...... Residual Dark Distribution

```
RMF ...... Redistribution Matrix File
RTI ...... Rise Time Invariance
SAA ...... South Atlantic Anomaly
SCC ...... Space Craft Clock
SIS ...... Solid-state Imaging Spectrometer
TAI ...... International Atomic Time
TDB ...... Barycentric Dynamical Time
URL ...... Uniform Resource Locator
UT ....... Universal Time
UTC ...... Coordinated Universal Time
WWW ...... World Wide Web
XRT ...... X-ray Telescope
```

11.2 Software Packages

The following are major software packages commonly used to analyse data once it has been reduced.

- **XRONOS** Pronounced *Crow-noz*, this is a powerful tool for timing analysis. Please consult the URL

  `http://heasarc.gsfc.nasa.gov/docs/xanadu/xronos/xronos.html`

  to obtain the User's Guide.

- **XIMAGE** As the name implies this package is used for image analysis and the User's Guide can be obtained by consulting the URL

  `http://heasarc.gsfc.nasa.gov/docs/xanadu/ximage/ximage.html`.

- **XSPEC** This package is used to perform spectral analysis, specifically by folding theoretical models into the instrument response, comparing with the data, and finding the best-fitting model parameters and their allowed ranges for a given confidence level. The User's Guide may be obtained by consulting the URL

  `http://heasarc.gsfc.nasa.gov/docs/xanadu/xspec/manual/manual.html`.

Note the a User's Guide for `XSELECT`, the package used to reduce the data, can be obtained by consulting the URL

`http://heasarc.gsfc.nasa.gov/docs/software/ftools/xselect/xselect.html`.

11.3 XSELECT Command Sequences

Chapters 5 to 7 on screening and filtering contain extensively annotated `ascascreen` and `XSELECT` sessions. Here, however, only sets of command sequences are given, the aim being to provide compact reference points and *aides de memoire*. In subsequent sections, the following command sequences will be described.

1. Read several events files into `XSELECT` directly.
2. Screen and extract GIS PH mode events data.
3. Screen and extract SIS BRIGHT and BRIGHT2 mode events data.

4. Select regions for source and background and extract spectra.
5. Obtain GIS response matrices.
6. Obtain or Create SIS response matrices.
7. Generate the Ancillary Response File (ARF).
8. Extract an events list to use as a light curve for `XRONOS`.
9. Extract FITS rate file to use as a light curve for `XRONOS`.
10. Extract soft and hard SKY images.

In the following examples, it is assumed that the events files reside in the directory above the working directory and that the `mkf` file is in same directory. Since *ASCA* is the default mission, the `set mission asca` command has been omitted. The screening criteria used in the examples are not unique and the user should use criteria appropriate for each case and should therefore consult chapters 5 and 6 for more details. We omit SIS FAST mode here, as it is somewhat specialized and does not constitute mainstream *ASCA* analysis (but full details are given in §4.10).

11.3.1 Read Several Events Files Directly

All the subsequent examples read in data into `XSELECT` by means of the so-called `obscat`. However, it is possible to read in several events files directly and in such a case the appropriate commands in the examples should be replaced as described here.

First make an ascii list of all the events files you want to read into `XSELECT`. For example

```
ls -1 *s0*.unf > s0.list
```

At this stage be VERY CAREFUL that you keep SIS FAINT, BRIGHT and BRIGHT2 files in separate places, or else edit them out of the list file. You may duplicate the data. You may also need to select the file list on bit rate.

Then read the files within `XSELECT` by

```
read events "@s0.list"
```

11.3.2 Screen and Extract GIS PH Mode Events Data

This example is based on GIS2.

```
set datadir ..
set instrument gis2
set datamode ph
make obscat
show obscat
choose 1-**
select mkf
  SAA==0&&ELV>5&&COR>6&&ANG_DIST>0.0&&ANG_DIST<0.01&&G2_L1>0.0
filter region a1060_g2_randc.reg
```

```
gisclean
extract events
save events a1060_g2.evt
```

Please note that, by not selecting on bit rate, all bit rates are included. To use, say, HIGH bit rate data only, insert the command `select obscat bit_rate.eq.'HIGH'` after making the `obscat`. The file `a1060_g2_randc.reg` contains the lines:

```
 CIRCLE(124,132,81.00)
-CIRCLE(166.00,221.0,24.00)
```

and corresponds to the high background ring and calibration source in GIS2 (see §5.5.2 for GIS3).

11.3.3 Screen and Extract SIS BRIGHT or BRIGHT2 Mode Events Data

This example assumes SIS0 4-CCD mode BRIGHT mode data. The `Sn_PIXLm` criteria depend on CCD mode (see chapters 5 and 6). Analysis of BRIGHT2 mode data is identical except for the `set datamode` command.

```
set instru sis0
set datadir ..
set datamode bright
make obscat
select obscat bit_rate.ne.'LOW'
show obscat
choose 1-**
select mkf
  SAA==0&&BR_EARTH>20
  &&ELV>10
  &&COR>6
  &&ANG_DIST>0.0&&ANG_DIST<0.01
  && s0_pixl0 > 0 &&s0_pixl0 < 50
  && s0_pixl1 > 0 &&s0_pixl1 < 50
  && s0_pixl2 > 0 &&s0_pixl2 < 50
  && s0_pixl3 > 0 &&s0_pixl3 < 50
  &&(T_DY_NT<0||T_DY_NT>4)&&(T_SAA<0||T_SAA>4)
sisclean
select events grade.ne.1.and.grade.lt.5
extract events
save events a1060_s0.evt
```

Please note that default settings are used with the `sisclean` command and are entered with a carriage return.

11.3.4 Select Extraction Regions for Source and Background and Extract Spectrum

Here, the assumed starting point is a single, already-screened events list (`a1060_g2.evt`, in this example). Note that the instrument and data mode do not have to be set because `XSELECT` reads them from the header of the events list. An image is extracted first to enable a region filter (`cf_g2.reg`, in this example) to be defined. For more details see §7.3 and §7.5.

```
set mkfdir ..
set datadir .
read events a1060_g2.evt
extract image
plot image
```

In `SAOimage`, use the `Scale, Pan and Color` buttons to adjust the appearance of the plot. Then hit the `Cursor` button. Choose a circular region (a circular region is recommended for greatest accuracy). Move the circle so that its center coincides with the source centroid with the left mouse button, and adjust its size with the middle button. Type `s` at the keyboard to save the region. Hit the `region` button and then the `write` button. Name the file (`cf_g2.reg`, in this example) and hit return. After hitting the `reset` button we repeat this procedure to define a background region file (`back_g2.reg` here). The background region does not have to be circular, and is likely not to be for the SIS. Finally, hit the `etc` button and then `quit`. Note that *'exclusion'* regions can be created in `SAOimage` by typing `e` instead of `s`.

Continuing the `XSELECT` commands:

```
filter region cf_g2.reg
extract spectrum
save spectrum cf_g2.pi
yes
clear region
filter region back_g2.reg
extract spectrum
save spectrum back_g2.pi
no
```

The `yes` and `no` which appear in the command sequence are answers to the the question 'Group or rebin the spectra before outputting?' The GIS spectra will be *grouped* but the SIS spectra will be *rebinned*. In the case of GIS source spectra, the answer should be `yes`; for GIS background, `no`. For the SIS the answers for both source and background spectra will be `yes` in most cases. See §8.1 and §8.3 for more details.

11.3.5 Obtain GIS Response Matrices

For the GIS the latest response matrices, or RMF files, are obtained from the CALDB (e.g. by anonymous FTP to `legacy.gsfc.nasa.gov`). Look in the directory `/caldb/data/asca/gis/cpf/` for a sub-directory with a name corresponding to the latest date. As of March 1997, the latest matrices are obtained from

`/caldb/data/asca/gis/cpf/95mar06`

and are called (`gis2v4_0.rmf`) and (`gis3v4_0.rmf`) for GIS2 and GIS3 respectively.

11.3.6 Obtain or Create SIS Response Matrices

For *ASCA* data taken in the PV phase or early AO-1, ready-made SIS response matrices can be obtained by anonymous FTP to `legacy.gsfc.nasa.gov` from the directory

`/caldb/data/asca/sis/cpf/94nov9/`.

There are many `rmf` files in this directory but deciphering the name of just one of them is sufficient to understand what all the rest correspond to. One of the SIS0, chip 1 files is called

`s0c1g0234p40e1_512v0_8i.rmf`.

The '`s0c1`' clearly means SIS0, chip 1; `g0234` means that the *ASCA* data must have SIS grades 0,2,3,4 selected; `p40` means the so-called 'split-threshold' is 40 ADU (this is the case for almost all observations); `512` means that the RMF file has 512 output energy bins; `v0.8` means that the matrix was created with program `sisrmg`, version 0.8, and finally the `i` means that the spectral files must have PI bins (matrices with `h` instead of `i` are appropriate for PHA spectra).

Late into the AO-1 phase, the time-dependence of various aspects of the SIS instrument responses became too large to neglect. In general, the safest option is to generate your own response matrices for *all* your data, using the FTOOL `sisrmg`. The 'standard' matrices can still be used 'Quick-Look Analyses'. If the spectral files were created by `XSELECT`, `sisrmg` can obtain almost all of its inputs directly from the spectral files.

11.3.7 Generate the Ancillary Response File (ARF)

To generate the ARF, run the FTOOL `ascaarf`, giving as input the names of the spectral file and the RMF. The program `ascaarf` asks for the name of the RMF file for the sole purpose of setting the energy-bin array, although this is optional. The program `sisrmg` also asks for the name of the ARF file. The way to get around this apparent contradiction (apart from ignoring the question) is to run `ascaarf` with one of the 'standard' SIS response matrices (see §11.3.6 above). See §8.7, 10.6 and 10.7.1 for more details on `ascaarf`.

11.3.8 Extract Events List to Use as a Light Curve for XRONOS

As described in §9.4, `XRONOS` can read in events lists and use them as light curves. In this example, we assume that the starting point is an already-screened GIS PH-mode events list (`gx301_g2.evt`) which the user wants to filter by region and energy.

```
set mkfdir ..
set datadir .
read events gx301_g2.evt
extract image
```

Now make a source-extraction region file as described in §11.3.4, and then

```
filter region source_g2.reg
filter pha_cut 68 170
extract events
save events source_g2_soft.evt
```

The channel range 68-170 corresponds, in GIS PH mode, to $\sim 0.8 - 2.0$ keV. See §7.9 for channel-to-energy conversion formulae.

11.3.9 Extract FITS Rate File to Use as a Light Curve for XRONOS

FITS rate files, described in §9.4, can be read into `XRONOS`. The required steps are identical to those in §11.3.2 or §11.3.3 except for the following.

1. A temporal binsize must be set (or the default used) with the `set binsize` command, just before the `filter region` command.
2. The commands `extract events` and `save events` are replaced with `extract curve` and `save curve` respectively.

11.3.10 Extract Soft and Hard Sky Images

In this example, the starting point is an already-screened events list. Apart from setting the energy filters, the only 'extra' command is `set image sky`, which changes the columns for which the image is extracted from DETX/DETY (detector coordinates - the default) to X/Y (RA and DEC).

```
set mkfdir ..
set datadir .
read events kepler_g2.evt
set image sky
filter pha_cut 68 170
extract image
save image kepler_g2_soft.img
clear pha_cut
filter pha_cut 509 849
extract image
save image kepler_g2_hard.img
```

The channel ranges 68-170 and 509-849 correspond, in GIS PH mode, to 0.8-2 keV and 6-10 keV, respectively.

11.4 MKF Parameter Summary

Here we list, for reference, all the parameters in the `mkf` files.

11.4.1 Time-Related Columns

```
TIME            Seconds from Jan. 1, 1993
START           Start time of record (e.g., 961005222917177)
BN_WIDTH        Data Bin Width
ETI             Extended TI counter
```

11.4.2 Attitude, Pointing, and Bit Rate

```
BIT_RATE        DP Bit Rate 0:H, 1:M, 2:L
ACS             ACS Status 0:fine mode, 1:corse mode
NSAS            NSAS cone angle (sun angle) (deg) (<0 during satellite night)
```

Z_ALPHA	R.A.(2000) of Z-Axis (deg)
Z_DELTA	Dec.(2000) of Z-Axis (deg)
EULER_3	3rd Euler Angle (Z-Y-Z)
SAT_ALT	Satellite altitude (km)
SAT_LON	Satellite longitude (deg)
SAT_LAT	Satellite lattitude (deg)
ELV	Target elevation from the Earth egde (deg)
COR	Cut Off Rigidity (GeV/c)
FOV	Field of Veiw 0:Sky/1:Night Earth/2:Day Earth
BR_EARTH	Angular distance from Bright Earth (deg)
SAA	In South Athrantic Anormaly? 1:yes/0:no
T_SAA	Time after SAA passage (s)
SUNSHINE	1:satellite is in daytime/ 0:night
T_DY_NT	Time after day/night transition (s)
ANG_DIST	Angular Distance of FOV from specified direction (deg)

11.4.3 SIS Status/ Monitors

Note `n`=0, 1 for SIS0 and SIS1 respectively, and `m` is the chip identification number.

Sn_MODE	SIS_n observation mode 0:Fnt/1:Brt/2:Fst/3:Frm
Sn_ID	SIS_n CCD ID LIST (e.g., 1111)
Sn_DSCR	SIS_n Discriminator status
SIS_ADRS	SIS Address Dscri 0:in 1:out for each chip
Sn_GRADE	SIS_n grade discriminate value (e.g., 127)
Sn_EVTRm	SIS_n Chip_m Event Threshold
Sn_SPTRm	SIS_n Chip_m Split Threshold
Sn_AE	SIS_n AE Status 0:normal/1:A-off/2:Power off
Sn_TEMP	SIS_n CCD temperature (deg C)
Sn_EVNTm	SIS_n chip_m HK Event number (counts/s)
Sn_PIXLm	SIS_n chip_m HK Pixel number over the threshold (couts/s)
Sn_TELMm	SIS_n chip_m telemely event number (couts/s)
Sn_SATFm	SIS_n chip_m saturation flag 0:no/ 1:yes
Sn_DFEm	SIS_n chip_m dark frame error (ADU)

11.4.4 GIS Status/ Monitors

Note `n`=2,3 means GIS2 and GIS3 respectively.

GIS_MODE	GIS observation mode, 0:PH/ 1:MPC/ 2:PCAL
GHVn_L	GIS HVLn status 16:off/ 8:reduction/ 0-7:level
GHVn_H	GIS HVHn status 16:off/ 8:reduction/ 0-7:level
Gn_LDHIT	GIS_n Lower Discri Hit counting rate (counts/s)
Gn_H0	GIS_n HK monitor H0 (counts/s)
Gn_H1	GIS_n HK monitor H1 (counts/s)
Gn_H2	GIS_n HK monitor H2 (counts/s)
Gn_L0	GIS_n HK monitor L0 (counts/s)
Gn_L1	GIS_n HK monitor L1 (counts/s)
Gn_L2	GIS_n HK monitor L2 (counts/s)

```
Gn_CPU_I       GIS_n HK monitor CPU_IN (counts/s)
Gn_CPU_O       GIS_n HK monitor CPU_OUT (counts/s)
Gn_TELM        GIS_n telemely event number (counts/s)
Gn_CPU_S       GIS_n CPU status, run +4, stop +2, error +1
GIS_HAMM       GIS Hamming Error 0:off/1:on
Gn_TEMP        GIS_n temperature (deg C)
Gn_HVHMN       GISn HV-H monitor (V)
Gn_HVLMN       GISn HV-L monitor (V)
Gn_HVHCM       GISn HV-H current monitor (uA)
Gn_DEADT       GIS_n Dead time correction factor (0-1)
```

11.4.5 Radiation Belt Monitor

```
RBM_TEMP       RBM temperature (deg C)
GIS_RBMF       RBM flag status of GIS 0:off/1:on
SIS_RBMF       RBM flag status of SIS 0:off/1:on
RBM_CONT       RBM counting rate (counts/s)
```

11.5 Important URLs

Here we list some important URLs mentioned in this document. They are listed in the alphabetical order of their 'alias' names.

11.5.1 ASCA Getting Started Guide

http://adfwww.gsfc.nasa.gov/asca/processing_doc/GS/getting_started.html

11.5.2 ASCA GOF

http://heasarc.gsfc.nasa.gov/docs/asca/ascagof.html

11.5.3 ASCA GOF: Processing and Data Analysis

http://heasarc.gsfc.nasa.gov/docs/asca/ahp_proc_analysis.html

11.5.4 ASCA GOF: What's New

http://heasarc.gsfc.nasa.gov/docs/asca/whatsnew.html

11.5.5 ASCANews

http://heasarc.gsfc.nasa.gov/docs/asca/newsletters.html

11.5.6 ASCA Observation Planning Guide

http://heasarc.gsfc.nasa.gov/docs/asca/planning_tools/obs_guide.html

11.5.7 ASCA Science Data Processing

http://adfwww.gsfc.nasa.gov/asca/processing_doc/proc/processing.html

11.5.8 Background Normalization for Co-added Spectra

http://heasarc.gsfc.nasa.gov/docs/asca/abc_backscal.html

11.5.9 Calibration Uncertainties

http://heasarc.gsfc.nasa.gov/docs/asca/cal_probs.html.

11.5.10 FTOOLS

http://heasarc.gsfc.nasa.gov/docs/software/ftools/ftools_menu.html

11.5.11 GIS Background

http://heasarc.gsfc.nasa.gov/docs/asca/gisbgd.html

11.5.12 GIS3 CPU Trouble

http://heasarc.gsfc.nasa.gov/docs/asca/op_status/maxima940410.html

11.5.13 GIS Gain Correction

http://heasarc.gsfc.nasa.gov/docs/asca/gain_correction.html

11.5.14 GIS News

http://heasarc.gsfc.nasa.gov/docs/asca/gisnews.html

11.5.15 SIS News

http://heasarc.gsfc.nasa.gov/docs/asca/sisnews.html

11.5.16 XANADU

http://heasarc.gsfc.nasa.gov/docs/xanadu/xanadu.html

11.5.17 XIMAGE User's Guide

http://heasarc.gsfc.nasa.gov/docs/xanadu/ximage/ximage.html

11.5.18 XRONOS User's Guide

http://heasarc.gsfc.nasa.gov/docs/xanadu/xronos/xronos.html

11.5.19 XSELECT User's Guide

`http://heasarc.gsfc.nasa.gov/docs/software/ftools/xselect/xselect.html`

11.5.20 XSPEC User's Guide

`http://heasarc.gsfc.nasa.gov/docs/xanadu/xspec/manual/manual.html`