Suzaku Project
Data Management Plan
(PDMP)

Suzaku Guest Observer Facility
NASA/GSFC, Greenbelt, MD 20771, USA,
and
Institute of Space and Astronautical Science (ISAS/JAXA)
Yoshinodai, Sagamihara, Kanagawa, 229 Japan

Version 2.0
September 27, 2007

Version History

v0.0 (September 9, 2005) — Revision from the PDMP of the Astro-E(1) project. Remove explanations about the instruments.

v0.1 (December 3, 2005) — Revision with comments from Ken Ebisawa. Update the software description. Remove documents about the XRS.

v0.2 (January 17, 2006) — Additional post-launch information included.

v1.0 (April 17, 2007) — First official version, corresponding to Version 1.X processing.

v1.1 (April 20, 2007) — Including description in the Suzaku memo. Adding comments from Yoshitaka Ishisaki.

v2.0 (September 27, 2007) — The version corresponding to Version 2.X processing. Adding comments from Ken Ebisawa, Yoshitomo Maeda, Yukikatsu Terada, Tadayuki Takahashi, Hironori Matsumoto, Masanobu Ozaki.

Contents

Chapter 1

Introduction

Suzaku, formerly Astro-E2, is the fifth Japanese X-ray astronomy satellite built by the Institute of Space and Astronautical Sciences of Japan Aerospace Exploration Agency (ISAS/JAXA). It was launched from the Uchinoura Space Center (USC) on 2005 July 10. *Suzaku* is the second ISAS X-ray astronomy satellite built in close collaboration with National Aeronautics and Space Administration's Goddard Space Flight Center (NASA/GSFC).

1.1 Scope of this Document

This document covers the following:

- An brief overview of the mission, the instruments on-board, and the *Suzaku* Guest Observer Facility (GOF).
- An overview of the end-to-end flow of data, from the satellite to the user and the archive, and the division of labor between ISAS/JAXA and NASA/GSFC, as well as that among groups within NASA/GSFC.
- The *Suzaku* data and data products.
- The support given to guest observers (GOs)

This document is *not* the original source for:

- High level agreements between ISAS/JAXA and NASA/GSFC, such as the allocation of observing time.
- Detailed technical information about the instruments, including design and calibration.
- Technical information about the telemetry.

In chapter 2, *Suzaku* operation and types of observations are briefly explained. *Suzaku* software design principles and agreements are presented in chapter 3. Further details of software are described in chapters 4, 5, and 6. Important issues regarding the calibration are given in chapter 7. Tasks regarding the Guest Observer support are shown in chapter 8, and *Suzaku* archives are explained in chapter 9.

In appendix A, acronyms used in this document are defined. Guidelines for FTOOLS developers are described in appendix B. A flow chart of the pipe-line processing is displayed in appendix C. Coordinate system of each detector is listed in appendix D.

1.2 Mission Overview

Suzaku was launched with three types of instruments on-board, covering a wide range of energies. The X-Ray Spectrometer (XRS) is the first micro-calorimeter based X-ray instrument to be launched into orbit. Although it prematurely lost all its cryogen shortly after launch and therefore stopped operation before it could obtain astronomically useful data, the XRS had an excellent energy resolution ($\Delta E \sim$ 6–7 eV) over its 0.3–12 keV bandpass.

The 4 units of X-ray Imaging Spectrometers (XISs) are CCD cameras, providing moderate spectral resolution over 0.2–12 keV ($\Delta E \sim$ 130 eV at 6 keV). There are five X-Ray Telescopes (XRTs) on-board *Suzaku*, one in front of the XRS and the other four in front of the XISs, providing high throughput and modest spatial resolution. The field of view (FOV) of XRT + XIS is $19' \times 19'$ with a spatial resolution of about $2'$ half-power diameter (HPD).

The Hard X-ray Detector (HXD) is a non-imaging, collimated instrument that covers the energy band ~10–700 keV using two types of detectors, PIN (10–60 keV) and GSO (50–700 keV). The full width at half maximum (FWHM) spectral resolution is 3 keV for the PIN detector and ~ 10 % at 600 keV for the GSO detector. The innovative design of the HXD results in low background and, hence, high sensitivity.

All instruments operate simultaneously and are co-aligned, so that a given target can be observed over 0.2–700 keV at high sensitivity and with good spectral resolution. This makes *Suzaku* a powerful observatory for a wide range of astronomical objects. In addition, the background detectors of the HXD can be used to monitor a wide area of the sky.

1.3 The *Suzaku* Guest Observer Facility

The *Suzaku* Guest Observer Facility (GOF) is located at NASA's GSFC within the Office of General Investigator Programs (OGIP). Besides the *Suzaku* GOF, OGIP contains the High Energy Astrophysical Science Archive Research Center (HEASARC) and GOFs for other major high energy missions. The HEASARC is a data center responsible for archiving data from past high energy astrophysical missions and constructing a user-friendly data analysis environment. *Suzaku* GOF carries out its tasks in collaboration with HEASARC.

The GOF is responsible for the US Guest Observer support, including:

- Support of prospective GOs' proposal preparation
- Support of US peer-reviews of GO proposals.
- Receiving, validating, processing, archiving and distributing the data, in collaboration with the HEASARC.
- Providing documentations and on-online materials
- Providing expert help to GOs

Suzaku GOF WWW home page is located at

`http://suzaku.gsfc.nasa.gov/`.

1.4 Related Documents

Other important issues which cannot be covered in this document described elsewhere, including:

- The *Suzaku* Technical Description — Design of the entire satellite, instruments, and their specification. This is available at
`http://suzaku.gsfc.nasa.gov/docs/suzaku/prop_tools/suzaku_td/`

- *Suzaku* FITS File Formats — FITS formats of the *Suzaku* HK and event files, calibration files and other important files (e.g., attitude files and orbit files)
- *Suzaku* Interface Control Document (ICD) — it defines the interface between *Suzaku* processing processing systems and the HEASARC, and contains the directory structure and file name convention for files that are delivered.
- *Suzaku* Calibration — How *Suzaku* instruments and data are calibrated is explained. See 7.1 for details.
- *Suzaku* data analysis guide (also known as the ABC Guide) — Provides an overview of *Suzaku* data analysis. This document will be available at `http://suzaku.gsfc.nasa.gov/docs/suzaku/analysis/suzaku_abc/`

Chapter 2

Observations Types

In this chapter, we provide a brief description of various types of *Suzaku* observations, because different types of observations are treated differently in data distribution and archiving.

Figure 2.1 shows a flowchart illustrating various processes in the *Suzaku* observation program from GOs' proposal submission to the data reception. Important issues for individual processes outlined in this chapter are explained in more details in later chapters.

2.1 Observations Types

2.1.1 In-Orbit Checkout

The period between the launch on July 10, 2005 and the end of August, 2005 is considered the in-orbit checkout (IOC) phase. The first part of this phase was devoted to engineering activities, and no celestial X-ray sources were observed. After the XIS first light on August 12 and the HXD first light on August 15, observations of celestial X-ray sources were carried out. Telemetry data after August 12 are processed normally, although care must be taken as instrument parameters are not necessarily the same as for later observations.

2.1.2 Observatory Time

Throughout the *Suzaku* mission life, approximately ∼12 % of the time will be reserved as the Observatory Time. It will be used, for example, for instrumental calibration, maintenance of the satellite, or to compensate for unexpected observational/operational failure such as cancellation of the ground contacts due to bad weather. Target of opportunity (TOO) observations (section 2.1.6) may be also carried out using the Observatory Time.

2.1.3 Science Working Group Time

Suzaku Science Working Group (SWG) is the collective name given to the instrument teams, mission operations team, software and processing team, as well as Science Advisers who were selected to provide guidance to the *Suzaku* team.

During the period between September 2005 and March 2006, the scientific (non-Observatory Time) observations were generally selected by, and conducted by the SWG. This period is often referred to as the SWG phase of the mission. No new SWG observations were included into the observing program after April 2007, although a few SWG observations were carried out later, usually because of a problem with the original observations. All SWG observations were completed by October 2006.

2.1.4 GO Observations

Suzaku entered the guest observer (GO) phase of the mission in April 2006. During this period, all non-Observatory Time observations are selected from the world-wide astronomy community, with the exception of the delayed SWG observations (see above). Some GO observations were carried out in February and March 2006, before the nominal start of the GO period.

Targets are selected through a competitive process from observing proposals submitted by guest observers (GOs). Proposals by principal investigators (PIs) affiliated with a US institution are submitted to, and selected by, NASA, through the annual NASA Research Announcement (NRA) process.

PIs affiliated with an institution in an ESA member country submit their proposals through ESA, who conduct their own proposal review. Proposals submitted to ISAS/JAXA (principally by Japanese PIs, although PIs from non-US, non-ESA country may also apply through ISAS/JAXA) are judged by ISAS. The ESA list is folded into the Japanese list.

The final accepted target list is determined at the Japan-US merging meeting based on the Japanese (including ESA) and US target lists. In case there are identical targets on the Japanese and US target lists, the same target may be assigned to a Japanese PI and a US PI. Such targets are referred to as "merged."

The GOF serves as the principal point of contact for US PIs, including co-PIs of merged targets. This includes observation planning, notification of availability of processed data, and support in analyzing the processed data (chapter 8).

2.1.5 Calibration Observations

Suzaku team will regularly carry out calibration observations to monitor the performance of the instruments. Calibration observations are carried out using the Observatory Time.

2.1.6 Target of Opportunity Observations

Targets of Opportunity (TOOs) are observations of objects or states of objects that cannot be predicted. X-ray novae, supernovae, strong flares of known targets, and after-glows of Gamma-ray bursts (GRBs) are examples of TOO targets.

TOO observations may enter the *Suzaku* observing program in one of two possible ways. Pre-approved TOOs are part of the GO observations, and are limited to unpredictable phenomena on specific, known objects. In addition, genuinely unpredictable objects or events can be observed as part of the Observatory Time.

2.1.7 HXD WAM Observations

The anti-coincidence detectors of the HXD can be used to detect GRBs and to monitor the flux levels of bright hard X-ray/γ-ray sources. This aspect of the HXD is known as the Wide-band All-sky Monitor (WAM). Even during the GO phase, the WAM data do not belong exclusively to the PI.

2.2 Proprietary Period

The SWG data are proprietary to the SWG until May 27, 2007, or 1 year after the date of observation, whichever is later. In general, GO observation has a proprietary period of 1 year after the delivery of the processed data. The project may extend the proprietary period of GO data in cases where a lack of analysis software or calibration data seriously impacted the usefulness of the data. In such cases, the proprietary period will extend 1 year after the availability of the software/calibration data, as judged by the project. Calibration observations and TOO observations taken using the Observatory Time during the GO phase have no proprietary time.

Proprietary data are available for download in encrypted form. The decryption keys are supplied to the PIs, who may share them with their co-investigators. After the proprietary period is over, the decrypted data are placed in the *Suzaku* archives (section 2.4.4; chapter 9), and open to all interested researchers.

2.3 Satellite and Instrument Monitoring

Duty scientists will monitor the health and safety of the satellite and the instruments, both at the downlink station at the Uchinoura Space Center (USC) and at ISAS. They may not carry out scientific analysis of the data. Any scientific insights incidentally gained by the duty scientists are considered confidential.

Certain aspects of the data are considered non-proprietary. In addition to the HXD/WAM data, they include any data during which the instruments are pointed at the Earth, and XIS data from the area of the CCD chips dominated by the on-board calibration source. Such data can be placed in the trend archive in unencrypted form, even during the proprietary period for that observation.

In addition, the instrumental teams may access proprietary data for the purpose of monitoring the performance of the instruments. They must refrain from performing any scientific analysis of the data, and keep any knowledge incidentally gained while performing their duties confidential.

2.4 Data Flow

2.4.1 Data Retrieval and Raw Data Archives

The data are retrieved from the satellite only at USC. *Suzaku* has the data recorder with the 6 Gbits data capacity and can downlink the data to USC by up to $\sim$10 Gbits daily in 5 contact passes. Raw data are sent from USC to ISAS through a dedicated network, and saved in the raw database named SIRIUS. The SIRIUS database at ISAS stores the raw telemetry data of all the current and past ISAS missions.

2.4.2 Data Processing at ISAS and GSFC

The *Suzaku data processing* means conversion from the raw telemetry data to the high-level calibrated data deliverable to the *Suzaku* Observers. Details of the data processing are explained at section 6.1, and only an outline is given here (figure 2.1).

At ISAS, telemetry files in the SIRIUS database are wrapped into portable *Raw Packet Telemetry* (RPT) FITS files, with a minimum set of FITS keywords. Routinely, ISAS will process RPT files to produce *First FITS Files*, which conform to high level FITS standards.

Attitude of the satellite and the clock correction is calculated at ISAS, and the satellite orbit is determined[1]. The First FITS Files, attitude files, orbit files and timing correction files constitute a complete data package for each observational sequence. These packages are archived at ISAS, and the identical copies are delivered to GSFC regularly. The RPT files are also delivered to GSFC for archival and back-up purposes, so that the First FITS Files may be produced at GSFC if necessary.

The same *Pipe-line Processing* runs on the First FITS Files at ISAS and GSFC, to apply the calibration information and to produce the high-level processing products (section 6.6).

2.4.3 Data Delivery to *Suzaku* Observers

The processing products are delivered to the Guest Observer or the SWG members, as appropriate. US *Suzaku* Observers will receive data from GSFC, and Japanese Observers will receive from ISAS. The proprietary data are placed in on the *Suzaku* archives with a secure data protection method such as the PGP encryption.

Suzaku Observers will be able to conduct scientific analysis immediately from the processing products. The analysis software and user support are provided by the *Suzaku* GOF (see chapter 3, 4 and 8).

2.4.4 *Suzaku* Archives

All the *Suzaku* data will be delivered to and archived at the HEASARC at NASA/GSFC and to the PLAIN Center at ISAS/JAXA. After the proprietary period is over, the data are made public (i.e., decrypted

[1]In fact, the satellite orbit is monitored at ground stations of JAXA/TKSC. JAXA/TKSC determines the *Suzaku* orbit, and delivers the orbit files to ISAS regularly.

version will be made available), so that archive users are able to obtain exactly the same datasets as the original Guest Observers have received. From time to time, contents of the archives ma be updated, after being reprocessed with updated software and calibration files. Details of the *Suzaku* archives are explained in chapter 9.

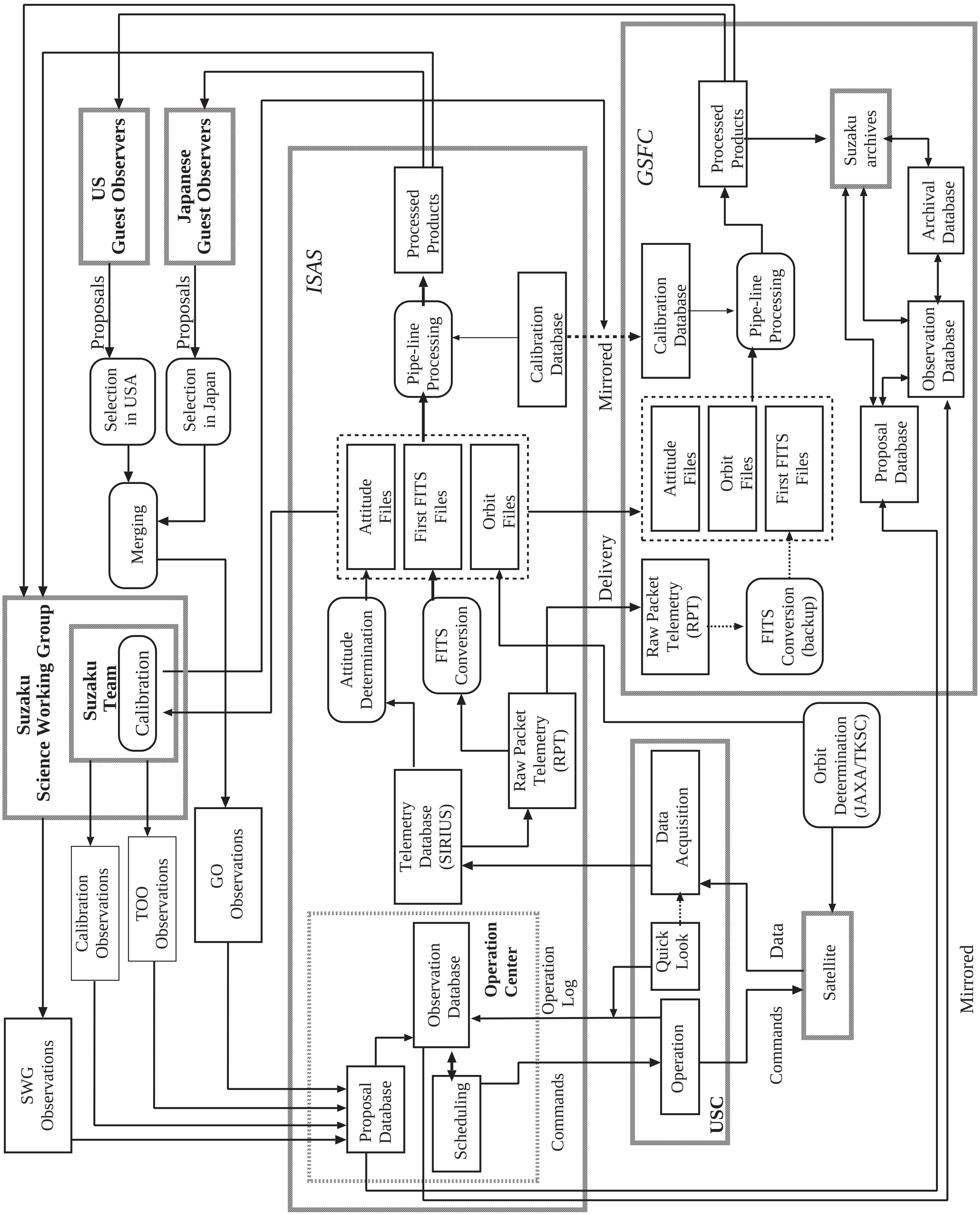

Figure 2.1: Overview of the *Suzaku* mission operation and observation program.

Chapter 3

Software Principles

In this chapter, we present the *Suzaku* software principles and agreements, which all the software developers need to follow throughout the *Suzaku* project.

3.1 General Software Design Principles

Suzaku data analysis system should share the same design principles with all the other projects conducted under OGIP. These design principles may be summarized as follows:

1. *Standard and portable data format* — FITS (Flexible Image Transport System) format is adopted for all the binary files. System dependent binary files will never be used. Moreover, the existing OGIP conventions should be followed wherever possible, and new conventions should be submitted to HEASARC FITS Working Group to check for consistencies with other missions. Use of ASCII format is allowed for small files.

2. *Universal and unique software* — There should not be multiple channels of the data analysis. Software releases are controlled, and the same routines used for the instrumental calibrations by hardware teams are used for the scientific data analysis by Guest Observers.

3. *Designed for multimission analysis* — Existing software infrastructures will be utilized as much as possible. Users will be able to analyze *Suzaku* data with standard high-level X-ray data analysis packages such as XSPEC, XIMAGE, XRONOS, etc.

4. *Easy to install and use* — The software will be easy to install and use, and extensive help, support and documentation will be provided. *Suzaku* specific software for low-level tasks are distributed in the standard FTOOLS package, providing user friendly interface on most standard platforms (section 3.3.3).

5. *Free and public software* — Users will not have to purchase any commercial software packages (such as IDL), and all the source codes will be open and easily available at free of charge. Users will not have to worry about license issues, and software authors shall not claim any privileges or credits. Users may modify and distribute *Suzaku* software freely on their responsibility.

3.2 *Suzaku* Specific Design Principles

In addition to the general design principles above, *Suzaku* GOF and ISAS propose the following design principles for the *Suzaku* software/data processing system. They reflect the experiences from the ASCA mission.

1. **The raw telemetry will be converted to FITS format before distribution.** There is only one set of software (*mk1stfits*; section 6.3.1) to access and interpret the raw telemetry data and to convert them to the FITS format (First FITS Files; section 6.3). Mk1stfits, as well as other processing software, must be fully tested and ready before the launch of the satellite.

2. **All the calibration and data processing should start from the First FITS Files.** To that end, the First FITS Files should reflect the original structure of the raw telemetry as much as possible.

3. **All the scientific analysis starts from the standard calibrated FITS files.** The First FITS Files are further processed by the standard software with instrumental calibration information, and the *Calibrated FITS Files* (section 6.3) are produced. Scientific outputs are produced always from the official Calibrated FITS Files, and there should not be other routes for scientific analysis.

4. **The same processing system to calibrate the First FITS files should run at GSFC and ISAS.** Thereby, US and Japanese *Suzaku* Observers shall receive the identical Calibrated FITS Files.

5. **Important calibration tools/software should be made promptly available to GOs.** At any given time, there shall be always a single version of the official instrument calibration files and software controlled by the *Suzaku* GOF and instrument teams. This ensures that the *Suzaku* Observers can apply the latest calibration information to the observing data.

6. *Suzaku* **software will be written by the** *Suzaku* **software and hardware teams at GSFC, ISAS and other institutions in Japan.** Tasks which require deep understanding of the *Suzaku* instruments, spacecraft and telemetry formats will be mainly written by the members of the hardware teams and ISAS. On the other hand, higher level tasks, in which user-friendliness, standardization and conformity with other high energy missions should have a high priority, will be mainly written by the software team at GSFC.

7. **All the software for public release will be delivered to** *Suzaku* **GOF before the release.** *Suzaku* GOF will ensure that the software follow the rules presented in this chapter, and will package them in a form which is suitable for general release. *Suzaku* GOF will be responsible for releasing and maintaining the packages. When modifications or bug fixes are necessary, the *Suzaku* GOF will be responsible for the fix and the re-release, contacting the original authors as needed. When significant changes are necessary, *Suzaku* GOF will always consult the original authors in advance.

8. **Tasks required for the Pipe-line processing should run in scripts.** In the automated pipeline processing system (section 6.6), series of data processing tasks are run as background jobs by scripts. Therefore, all the processing tasks including those which make use of GUI are required to run in scripts.

3.3 *Suzaku* Software Standards

3.3.1 Languages

Suzaku software will be mainly written in C. The use of C++ is allowed, but not encouraged. C++ will not be adopted throughout the project, but may be used within some small independent packages (e.g., ray-tracing program). Fortran77 is allowed, but Fortran90 shall not be used.

In the scripting tasks, use of system independent environments such as Perl or Tcl/Tk is recommended. Use of the shell languages (such as csh, bsh and tcsh) which do not run beside UNIX environment is forbidden.

3.3.2 Coding Rules and Compiler Requirements

Portable coding practices shall be adhered to, including the isolation of system dependencies. C programs will adhere to the ANSI C standard, while Fortran programs will follow the OGIP Fortran standards (Mukai 1993)[1] for Fortran programming.

The system-independence test for C shall be that the code can be compiled by gcc on the several supported architectures (see section 3.3.3); similarly g77 will be used to test Fortran programs. The cfortran package shall be used to combine C and Fortran routines when necessary.

To write and read FITS files, cfitsio (in C) or fitsio (in Fortran) should be used. The obsolete fitsio C-wrappers, which were developed to call fortran fitsio routines from C-codes, should not be used.

3.3.3 Systems Supported

All the *Suzaku* software intended to distribute shall run on the most popular systems of *Suzaku* users. The systems are likely to include Sun/Solaris, DEC/Alpha, Linux (Redhat, Power PC), and Apple/Darwin (Mac-OS X).

3.3.4 Coordination and Version Control

The Software Coordination Group consisting of members from each hardware team, ISAS, and the GOF shall meet regularly (at least twice a year until and soon after the launch) to ensure software coordinations. In addition, the GOF shall have one person attached to each hardware team with responsibility to help coordinate software development. The software coordination group shall also be responsible for ensuring consistency of FITS keyword naming across teams.

The 1st Stage Software (section 6.3) is maintained by ISAS. GSFC keep master copies of all the software except the 1st Stage Software under a control system. This control system shall ensure that a given file is only edited by one person at a time and also that previous versions are archived and can be recovered. The practical way that *Suzaku* FTOOLS will be developed and maintained globally is explained in section 3.4.

3.3.5 Documentation

All software intended for distribution should be fully documented in English. Comments in the source codes should be written in English, but Japanese translation might be added for convenience and may not have to be stripped when distributed.

All subroutines/programs of general use shall contain a standard header. The GOF will provide a script to strip out these headers and make them available over the Web. The GOF will also provide template routines containing the standard header.

The FITS file format of *Suzaku* related files is fully explained in a separate document maintained by the *Suzaku* GOF.

3.4 *Suzaku* FTOOLS Global Development Scheme

Many scientists and programmers in the United States and Japan are involved in the *Suzaku* FTOOLS development. Also, *Suzaku* FTOOLS users are located not only in the two countries, but also in Europe and the rest of the world. Therefore, version control will be very important so that no different flavors of the same FTOOLS be developed and proliferated.

In the early stage of the mission, as understanding of the instruments deepens and new data analysis techniques are getting established, it will be necessary to update and release the *Suzaku* FTOOLS promptly. We should be ready for the release cycle of a few weeks or less.

[1]See `http://heasarc.gsfc.nasa.gov/docs/journal/ogip_fortran3.html`. This is ANSI Fortran77 with some extensions. The extension includes the following: (1) Both upper and lower case letter are allowed. (2) END DO are allowed. (3) DO WHILE loops are allowed. (4) INCLUDE statements are allowed. (5) INTEGER*2 data type is allowed. (6) Variable can be up to 31 character long. (7) IMPLICIT NONE is allowed.

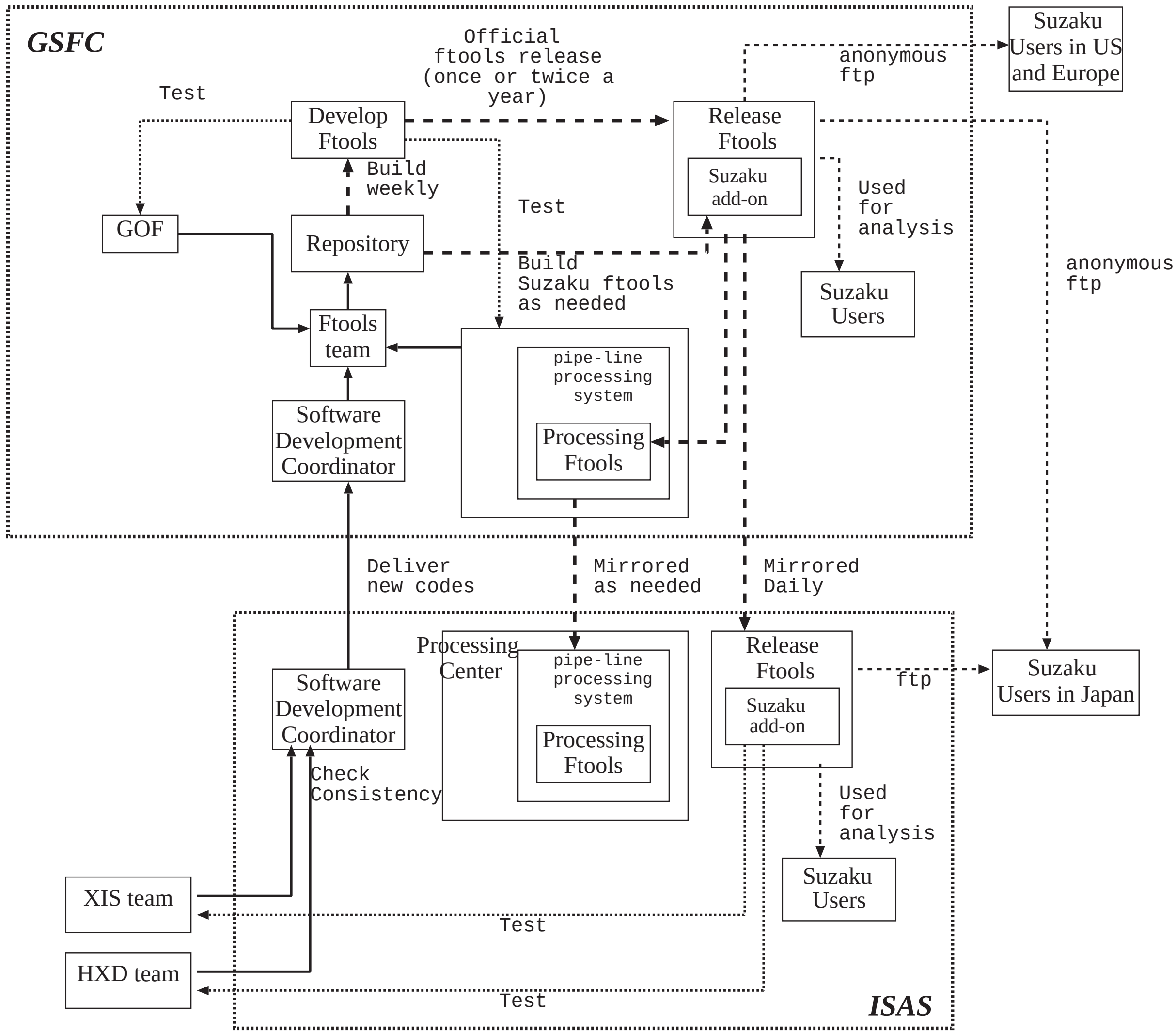

Figure 3.1: *Suzaku* FTOOLS global development and version control scheme.

To accommodate both requirements of the rigorous version control and prompt release, the following scheme, which is illustrated in figure 3.1, has been proposed and will be practiced for the *Suzaku* FTOOLS development, version control, and release.

1. At GSFC, the FTOOLS team maintains the FTOOLS "Repository", for which only the team members are granted the write permission. The FTOOLS team receives original source codes from the "Contact" groups (through ISAS when the Contact groups are in Japan; see 6 below), and put the codes in the Repository, after minimal programmatic changes if necessary. *The codes in the Repository should be considered the genuine copy of the latest official FTOOLS.*

2. The entire FTOOLS directory tree is built weekly from the Repository. This FTOOLS is called "Develop" FTOOLS, and only available inside GSFC. The Develop FTOOLS are tested at GSFC, and the codes will be fixed if any problems are found, and put in the Repository again. Note that the Develop FTOOLS reflect updates of all the FTOOLS including *Suzaku*.

3. From time to time, the entire FTOOLS package is released to public. This package is called the "Release" FTOOLS. Frequency of the release is typically once or twice a year.

4. In order to keep up with short development cycle, whenever *Suzaku* FTOOLS in the Repository are updated, the FTOOLS team will build the *Suzaku* FTOOLS against the Release FTOOLS, and install the "*Suzaku* add-on". Interval of the *Suzaku* add-on build will be as short as one week (= Develop FTOOLS build cycle). The Release FTOOLS with the *Suzaku* add-on is the one *Suzaku* users will use for their data analysis. The *Suzaku* add-on package will be promptly released to *Suzaku* users, so that they can install it on their own Release FTOOLS.

5. The Release FTOOLS with the *Suzaku* add-on will be mirrored daily to ISAS, and will be used for *Suzaku* data analysis at ISAS. Japanese *Suzaku* users outside of ISAS may obtain the original package from GSFC or mirrored one from ISAS.

6. Instrument teams in Japan will test and modify the source codes in the *Suzaku* add-on package to reflect the latest calibration, and they will deliver the new codes to the Software Development Coordinator at ISAS. The Software Development Coordinator will make sure that the codes from different groups are consistent and can be built cleanly using `gcc`. After that, he or she will deliver the codes to the FTOOLS team at GSFC (go back to step 1).

7. The Processing team at GSFC will obtain the Release FTOOLS with the *Suzaku* add-on, which will become the base of the pipe-line processing. The Processing FTOOLS, as well as the pipe-line processing scripts, will be mirrored to the ISAS processing center from GSFC, so that the data centers at GSFC and ISAS use the identical system to produce standard *Suzaku* data products.

8. The processing software should be built-in the software packages HEAsoft, and the processing should be performed with the the latest release (ver. 6.0.3 in November 2005).

3.5 *Suzaku* Ftools Release Plan

1. Ftools delivery should include .par files, .hlp files and unit test scripts following the templates provided by HEASARC.

2. Freeze dates of the *Suzaku* ftools on the GSFC CVS are the last days of January, April, July and October. *After the freeze, only bug fixes may be committed to the CVS.*

3. After the freeze dates, *Suzaku* ftools go through the multi-platform test at GSFC and ISAS, which takes maximum six weeks.

4. After the multi-platform test, *Suzaku* ftools release will be around March 15, June 15, September 15, and December 15. These release dates may be slightly shifted being affected by situations of other ftools development/release, because it is desirable that *Suzaku* ftools release be synchronized with other ftools release as much as possible.

5. *After the release*, new ftools, libraries or new functionalities may be committed to the GSFC CVS. Going back to 1 above, the next release cycle starts.

Chapter 4

Suzaku Function Libraries

There will be software modules that are used repeatedly in various stages of the *Suzaku* mission, from the satellite operation to the scientific data analysis. In order to avoid overhead and inconsistency, functions supposed to be used by two or more tools will be included in the *Suzaku* function libraries.

There will be at least three such function libraries for *Suzaku*; *aste_tool*, which includes functions for *Suzaku* specific tasks, *atFunctions*, which includes functions for generic attitude and orbital related tasks[1], and *xrrt*, which is for XRT ray-tracing. They are implemented in the FTOOLS package as `libastetool.a`, `libatFunctions.a`, `libxrrt.a`, respectively[2].

4.1 *Suzaku* Specific Tasks (aste_tool)

4.1.1 Time Conversion

Routines to carry out conversion between *Suzaku* time and other time systems will be necessary. *Suzaku* time will be defined as the elapsed time from the beginning of year 2000 in UTC. The leap second table is referenced to take into account the leap seconds.

4.1.2 Coordinate Conversion

Since the XIS is an imaging instrument, coordinate systems for XIS images are must be defined. Functions to carry out conversion between these coordinates will be necessary (e.g., when making observation plans and calibrating FITS event files), and will be included in aste_tool.

4.1.3 Energy Calibration

Suzaku instruments measure X-ray photon energy as pulse heights; the raw measurements are referred to as the Pulse Height Analyzer (PHA) channels. Although PHA values are roughly proportional to the input energies, they vary with several conditions such as time, location on the detector, temperature, etc. After correcting these effects, we may define *Pulse Invariant* (PI), which should be perfectly proportional to the energy.

We will need to calculate PI from PHA for all the three instruments to fill the PI columns in the event FITS files (section 6.4). The routines to calculate PI from PHA shall be included in aste_tool. These routines need to access calibration files to get calibration information (chapter 7).

[1] atFunctions has been used also for ASCA.

[2] On the Unix platforms. For other platforms, the names will be different.

4.1.4 HK Information Acquisition

All satellite and instrument housekeeping (HK) parameters are stored in the HK FITS files (sections 2.4.2 and 6.3), which can become huge. However, only a small fraction of the HK parameters will be actually required for scientific data processing. In order to facilitate the use of HK files, HK file access routines shall be provided in aste_tool. Note that HK access routines need to be built with efficiency in mind.

HK parameters in the telemetry are digitized at discrete intervals, thus aste_tool routines may have to convert them to physical values, and interpolate or smooth them as needed. For example, we may require an aste_tool routine which gives instrument temperatures in degrees continuously by interpolating discretely measured temperatures in digitized units.

Parameters for conversion from the digitized HK telemetry to the physical units are stored in the multimission database named *Satellite Information Base (SIB)* located at ISAS. Although SIB itself is not portable, *Suzaku* related information in SIB will be necessary to interpret HK parameters in the telemetry. Therefore, essential parts of the SIB will be extracted and put in the calibration files (section 7.4.1).

4.1.5 Other Tasks

Functions for other tasks will be included in aste_tool as needed. For example, a random number generation function will be required so that the same sequence of random numbers are always obtained from the same seed.

4.2 Attitude and Orbit Related Tasks (atFunctions)

The attitude and orbit related functions in atFunctions will be used in various purposes such as; command planning, assignment of SKY coordinates to events (section 6.4), creation the Filter files (section 6.4.1), calculation of the exposure maps, and barycentric corrections (section 6.5.3). They may require the attitude files, the orbit files, or both (section 6.2). The following are examples of the tasks in atFunctions.

4.2.1 Attitude Information

- Obtain q-parameters and/or Euler angles for a given time.
- Determine the pointing direction of each telescope/sensor for a given time.

4.2.2 Orbit Information

- Obtain satellite orbital position for a given time.
- Obtain magnetic cut-off rigidity for a given time.
- Determine if the satellite is in day (sun-lit) or dark (not sun-lit) for a give time. Also obtain the elapsed time after the last day-to-dark or dark-to-day transition.
- Determine if the satellite is in the South Atlantic Anomaly (SAA) or not for a given time. Also obtain the elapsed time after the last SAA passage.
- Obtain sidereal direction of the magnetic field line for a given time.

4.2.3 Attitude and Orbit Information

- Output the angles from the earth rim and sun-lit part of the earth for a given time.
- Determine if the pointing direction is blocked by earth or not. If it is, determine if the earth is sun-lit or not.

4.3 Ray-Tracing Function Library (xrrt)

The *Suzaku* ray-tracing package named `xrrt` has been written in C++, and is available as a function library. This library provides function to load mirror, obstruction, and reflection tables from FITS files, and then to trace photons through the mirror sets and collect statistics about the results. See section 5.2.3 for detail.

Chapter 5

Planning and Simulation Software

In this chapter, *Suzaku* software used for observation planning and simulation are explained.

5.1 Observation Planning Software

5.1.1 TAKO (Timeline Assembler, Keyword Oriented)

A planning software package named "TAKO" (for Timeline Assembler, Keyword Oriented) is developed for *Suzaku* by GSFC based on the methods used for ASCA and XTE.

This package is designed to accommodate *Suzaku* specific constraints. These constraints are determined in cooperation of ISAS and GSFC instrument and operations teams. Post-launch changes will be handled in a similar fashion. As has been the case for ASCA, a technician is employed by GSFC and stationed at ISAS to maintain and operate TAKO to produce regular observation schedules.

5.1.2 MAKI

MAKI is developed at GSFC for *Suzaku* and future multimission planning[1]. Users may run MAKI through a Web browser (users will need to obtain and install the "LHEA Plug-In"[2]). Users may place different satellite fields of view on a sky image to plan out observation (Euler angles are automatically calculated). These FOVs may be rotated, and MAKI will indicate if the roll is allowed or not by different colors for a given time period. Users can also view the sun angle visibility limits for several missions, as well as adding phase constraints. MAKI is expected to replace the ASCA command planning program "adcongra" which had similar but more primitive functions.

MAKI accepts a sky image file from "SkyView"[3], or almost any FITS image files. It also lets users save and reload the results. In figure 5.1, an example of MAKI output is shown.

5.2 Simulation Software

Suzaku simulation software will have the following purposes. First, simulation software will be used to study technical feasibility of planned observations. Second, they will be used to determine instrumental responses in order to simulate and understand physical processes in the instruments. Third, they may be used in data analysis when instrument responses are difficult to determine and Monte Carlo approach is

[1]See the MAKI home page `http://heasarc.gsfc.nasa.gov/Tools/maki/maki.html` for detail.

[2]The LHEA Plug-In is developed at LHEA at NASA/GSFC. It is a web plug-in that lets users use interactive astronomy tools via the simple interface of users' browser.

[3]SkyView is a "Virtual Observatory" on the Net generating images of any part of the sky at wavelengths in all regimes from Radio to Gamma-Ray. See `http://skyview.gsfc.nasa.gov/skyview.html` for details. MAKI can launch from the SkyView output page if "Advanced" interface is selected.

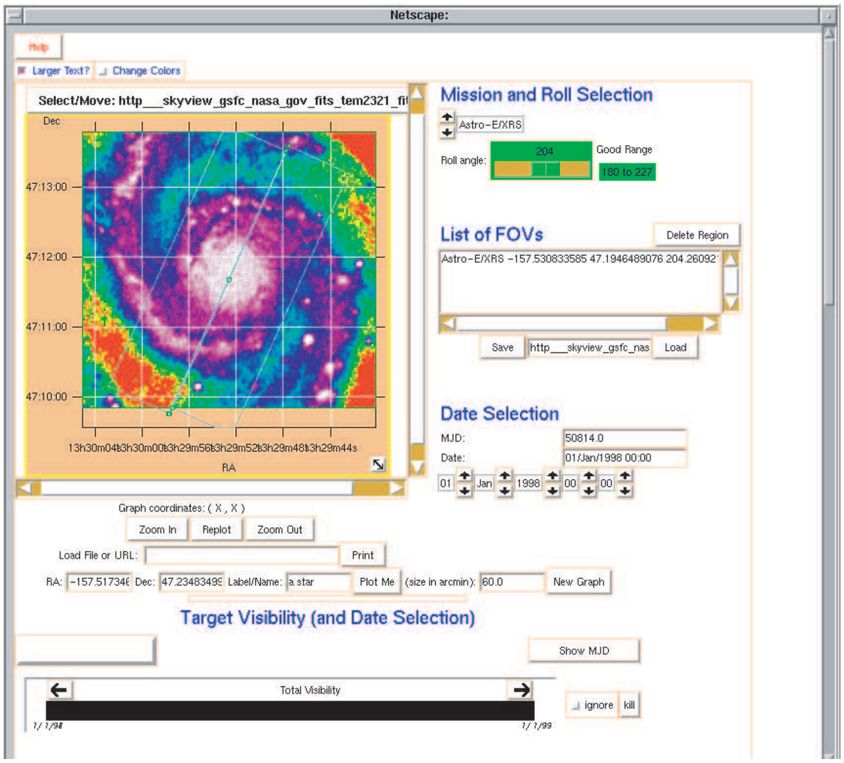

Figure 5.1: An examples of the MAKI plot. An XRS field of view is displayed on an optical image obtained from SkyView.

considered more effective. Finally, simulated data sets will be used to verify software for data analysis and processing.

5.2.1 Counting Rate Simulation – PIMMS

When planning observations, the first thing needed is to estimate the expected counting rates. For such a purpose, PIMMS (Portable, Interactive, Multi-Mission Simulator) has been developed at GSFC and already widely used in the community. Users will be able to estimate the expected counting rates for XIS and HXD by inputting the source flux and the spectral form. The source flux can be a physical unit (ergs s^{-1} cm^{-2}) or counting rates from other satellites/instruments.

As of ver. 3.6 released in late 2004, PIMMS calculates expected counting rates for *Suzaku*. See details at
`http://heasarc.gsfc.nasa.gov/docs/software/tools/pimms.html`[4].

5.2.2 Spectral Simulation – XSPEC

The XSPEC spectral fitting package has the capability to simulate instrument dependent pulse-height spectra for given input photon spectra[5]. To that end, XSPEC requires not only the effective area and efficiency (ARFs – Ancillary Response Files), but also the response matrices (RMF – Redistribution Matrix Files).

[4]The WWW version of PIMMS, *WebPIMMS* is also developed and available at
`http://heasarc.gsfc.nasa.gov/Tools/w3pimms.html`.

[5]The WWW version of the XSPEC spectral simulation, *WebSpec*, is available at
`http://heasarc.gsfc.nasa.gov/webspec/webspec.html`.

GOF has released a suite of the *Suzaku* response functions for spectral simulation purposes. See, `http://heasarc.gsfc.nasa.gov/docs/suzaku/aehp_prop_tools.html` for details.

5.2.3 XRT Ray-Tracing Library – libxrrt

The ray-tracing package, named "xrrt", was developed at GSFC ADF (Astrophysics Data Facility) in cooperation with ISAS, Nagoya University and GSFC mirror team (code 662). The package is written in C++. It is available as a function library (section 4.3) for use by other FTOOLS such as `xissim`.

The ray-tracing package will be used to determine physical parameters of the mirrors which are difficult to measure (e.g., surface densities), by comparing the actual data and simulations. XRT responses such as point spread functions and effective areas will be determined through iterations of the ray-tracing simulations and actual calibration data.

The ray tracing package is also useful to simulate observations when making plans or analyzing data. For example, if there are bright sources outside of the field of view, amounts of the stray-lights can be estimated through the ray-tracing simulations.

5.2.4 *Suzaku* XIS Event Simulator xissim

A simple simulation with XSPEC does not work in estimating contamination from nearby sources or a position dependent spectrum of extended sources, coupled with the image quality. Such estimates are sometimes necessary for proposing new *Suzaku* observations or comparing the observing data with the faked data of a complicated model through Monte Carlo simulations. The instrument team has developed the photon-by-photon simulator of XIS events, `xissim`[6]. The simulator is comprise of two tasks: `mkphlist`, which fakes incident photons from celestial sources in the XIS FOV, and `xissim`, which simulates XIS events of the faked photons, taking into account the XRT efficiency and the XIS response. The software outputs photon event files as the real observing data, so uses can analyze the simulated data with the generic XANADU software.

[6] the `xissim` software package can be downloaded from http://heasarc.gsfc.nasa.gov/docs/astroe/prop_tools/xissim/xissim_usage.html

Chapter 6

Data Analysis and Processing Software

In this chapter, we define and explain *Suzaku* software tasks that are used for the data processing at ISAS and GSFC and for the data analysis by *Suzaku* observers. The naming conventions of product files and directory structures can be found in more detail in the Interface Control Document (ICD)[1].

6.1 Overview

In figure 6.1, we provide an overview of the *Suzaku* data flow, which we divide into four stages: satellite specific calibration (Stage 0), production of the First FITS files (Stage 1), instrument specific calibration (Stage 2) and data analysis (Stage 3).

In general, software tools used in the earlier stages (Stage 0, 1) do not need to be portable since they run only at ISAS and/or GSFC, but they must be stable so that data need not be run through these stages repeatedly. On the other hand, software used in the later stages (Stage 2, 3) must be portable and flexible since they are distributed to *Suzaku* users for data analysis and for reprocessing when new calibration information becomes available. All distributable *Suzaku* software are built and distributed within the FTOOLS package (table 6.3 for a full list).

6.2 Stage 0 – Satellite Specific Calibration

In this stage, the *Suzaku* team at ISAS collects the orbital information, processes satellite specific calibration, and converts satellite raw telemetry data and satellite specific information to the Raw Packet Telemetry (RPT) files, attitude FITS and orbital FITS files. The output RPS files are regularly copied to the database at GSFC as back-up (figures 2.1, 6.1 and 6.2).

6.2.1 Orbit Determination

JAXA/TKSC determines the *Suzaku* orbit and sends the data regularly to ISAS. The data are converted to FITS format, containing both the orbital elements as well as explicit satellite positions as a function of time during the relevant period.

6.2.2 Attitude Determination

The NEC/Toshiba space system develops the attitude determination software as for the GINGA and ASCA satellites. ISAS hires technicians who will work full-time on the attitude determination. The *Suzaku* attitude files have the same FITS format as the ASCA attitude files.

[1] http://heasarc.gsfc.nasa.gov/docs/suzaku/archive/astroe_icd_sdc_v1.2.pdf

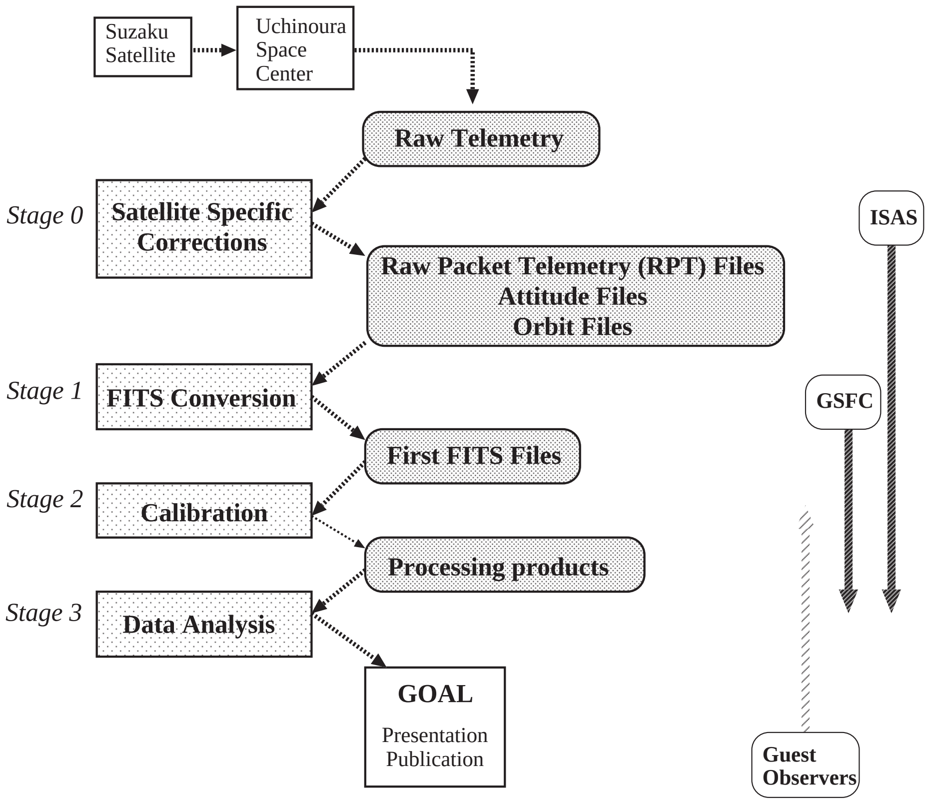

Figure 6.1: Overview of the *Suzaku* data flow.

6.2.3 Raw Packet Telemetry Files

The *Suzaku* data are downlinked at USC, sent to ISAS and stored in the telemetry database, SIRIUS, of the ISAS data center,[2] accessible through from UNIX workstations. SIRIUS embeds additional information into the original *Suzaku* telemetry when the *Suzaku* team accesses the data through the depacketer. The software `astetimeset` determines actual time corresponding to the satellite clock using the orbital information, and produces a timing correction ("tim") file. The final products of the processing are *Raw Packet Telemetry (RPT)* FITS files, which have formats almost identical to the SIRIUS output, wrapped by the FITS header, as well as an orbit file, an attitude file, and a tim file. The maximum data size of one RPT is set at ∼2GB, and multiple RPT files can be produced if the data size exceeds the limit. An RPT file has three columns; TIME when a packet was created in *Suzaku* time (see section 4.1.1), the APID and the CCSDS packet.

6.3 Stage 1 – Production of the First FITS Files

The ISAS *Suzaku* team processes RPT files with the *1st Stage Software* `mk1stfits` and produces the *First FITS Files* (FFF). The First FITS Files are composed of the event FITS files with the science data and HK files with the satellite and instrumental house keeping (HK) data. Since the electronic systems and coolers of the XRS are working and outputting the HK data through the *Suzaku* operation, the XRS HK data are generated regularly. Those files conform to the FITS standard defined by HEASARC.

The RPT files are used only to produce the First FITS Files at ISAS. Any other processes, such as the routine data reduction and the instrumental calibration, start with the First FITS Files. There are two exceptions of this rule.

[2]The ISAS data center manages data from all past and current ISAS missions.

- The hardware teams may test and debug the 1st Stage Software with the RPT files.
- The GSFC processing team may generate new version of the First FITS Files from the RPT files when the 1st Stage Software is revised.

ISAS shall routinely transfer to GSFC the RPT files, the 1st Stage Software and related files for back-up, the First FITS Files for the Stage 2 processing as necessary.

6.3.1 First Stage Software – mk1stfits

The 1st Stage Software is developed by the instrument teams, ISAS, and GSFC. It will not be distributed to the community, and therefore need not be portable. However, the 1st Stage Software shall be able to run both at ISAS and GSFC on some specific machines. The First Stage Software consists of the following components:

`mkcom1stfits` – binary executable for Common instruments (only create HK files)
`mkxis1stfits` – binary executable for XIS
`mkhxd1stfits` – binary executable for HXD
`mkxrs1stfits` – binary executable for XRS
`xissubmode.pl` – perl script for splitting the XIS data by the minor modes
`mk1stfits` – script to run the above software

The executables `mk[com,xis,hxd,xrs]1stfits` read a single RPT file, assign event time, reformat event data into standard FITS binary tables, convert raw digital HK readout to physical values and split a science FITS by major mode. The outputs are the First FITS files with the extension of "fff", except for `mkxis1stfits`, which generates Temporary First FITS files (TFF) of the XIS data with the extension of "tff". The perl script `xissubmode.pl` further splits the TFF files into different minor mode files, and output the First FITS files.

The major mode is defined as the modes with different event formats. For example, each of the 5x5, 3x3, 2x2 and timing modes corresponds to the XIS major mode, and each of the WELL main event data and WAM gamma-ray burst data does to the HXD major mode. Therefore, only from the event formats in the science data packet, the executable `mk1stfits` can split the data into the different major modes. The same major mode data in a single RPT file are put in one First FITS file even if they have time-gaps. For example, if the XIS major mode switches from the 5x5 mode to the 3x3 mode and then back to the 5x5 mode, the first and last 5x5 mode data are combined into one First FITS File. In other words, `mk1stfits` separates the input RPT file into different "major" observation modes, and generates a First FITS file for each major mode.

The minor mode is defined as the data sets that have different characteristics and cannot be analyzed together. For example, differences in exposure time of the Burst mode, parameters of the Window mode and numbers of vertical lines added in the Timing/Psum mode represent the minor modes. Since the science data have no change between the minor mode changes, `xissubmode.pl` refers to the HK information for the minor mode split. The on/off of the area discrimination is not regarded as the change of the minor modes, and is recorded in the EXPOSURES extension (section 6.4.2). Though the HXD well data have the minor mode in the clocking rate (CLKRATE), they are split at Stage 3–1, when making the cleaned event files (section 6.5.1). Moreover, CLKRATE is not supposed to change in 1 observing sequence, and therefore no split should be necessary in the Stage 3–1, either.

Table 6.1 lists the observation data types for the XIS and the HXD.

`Mk1stfits` should not lose any information in the RPT files (i.e. original telemetry) including low level instrument data, which are difficult to understand for general observers. It should generate columns of the physical quantities such as `PI`, `GRADE` and `TIME`, which are calculated in Stage 2, and fills them with a temporary value of "−999." Likewise, the First FITS Files should contain all keywords necessary for analysis. The First FITS Files have a preliminary GTI table, which corresponds to the time intervals with the telemetry data, and does not depend on the instrumental status or observational conditions (see section 6.4.2 and 6.5.1). `Mk1stfits` internally calls functions in the standard FTOOLS package, so that the 1st stage processing should prohibit FTOOLS parameter files that it use to be overwritten by any other processes running in parallel.

Table 6.1: Observation data types

Instrument	Mode name
XIS	5x5, 5x5_burst
	3x3, 3x3_burst
	2x2, 2x2_burst
	timing_psum
	frame, frame_burst, frame_psum
	darkframe, darkframe_burst, darkframe_psum
	darkinit,darkinit_burst, darkinit_psum
	darkupdate, darkupdate_bst
HXD	wel, trn, bst_N

Note. — N is numbered as the order of burst signals detected in an observing sequence.

Table 6.2: The HK First FITS Files

Instrument	HK identifier	Meaning	Example
COM	none	common instrument HK	ae100037020.hk
	none	extended common HK	ae100037020.ehk
XRS	xrs	XRS HK	ae100037050xrs_0.hk
XIS	xi0,xi1,xi2,xi3	XIS HK for each sensor	ae100037050xi1_0.hk
HXD	hxd	HXD HK	ae100037050hxd_0.hk

6.3.2 Convention for naming First FITS Files

The First FITS Files consist of the science (event) files and the HK files. The root names of the First FITS Files are inherited from the RPT file name. For example, if a RPT file name is `ae100037050_0.rpt`, its First FITS File names always start with `ae100037050_0`.

Event Files (Science Files)

The RPT root name is followed by an instrument name, file number and a major mode name with underscores ("_") between them. The instrument name is either `xi0`, `xi1`, `xi2`, `xi3` or `hxd` and the major mode name is `5x5`, `3x3`, `wam`, or `well`, for example. The XIS major mode name is also followed by the onboard micro code number ranging from 0 to 255. The file number is 0 when a FFF is made from only one RPT or merged from multiple FFF files, otherwise 1 from the first RPT, 2 from the second FFF, and so on. The extension is "`.fff`".

Examples of the First FITS File names are shown below:

```
ae100037050xi0_0_5x5n000.fff
ae100037020xi0_1_3x3n000.fff
ae100037050hxd_0_wam.fff
ae100037050hxd_0_wel.fff
ae100037050xrs_0_ff.evt
```

HK Files

Instrument names are the same as the event files. Suffix of the HK files is "`hk`". The HK identifiers, their meanings and examples are shown in table 6.2.

6.4 Stage 2 – Instrument Specific Calibration

The *2nd Stage Software*, so called critical FTOOLS, apply the calibration information to the First FITS Files to generate the Second FITS Files (SFF). The major task is to populate columns of physical quantities, by referring to the calibration data. The critical FTOOLS are developed by the hardware teams in conjunction with the GSFC *Suzaku* GOF, and distributed to public as a part of the FTOOLS package (table 6.3). Both ISAS and GSFC run the pipe-line processing of this stage (section 6.6).

The 2nd Stage software may add new columns or keywords on the First FITS Files, but it should not remove any existing columns and keywords, so that the critical FTOOLS runs for the Calibrated FITS Files as well. This allows *Suzaku* users to re-calibrate the data from the Calibrated FITS files, without the First FITS files.

We explain the functions of the Critical FTOOLS by characteristics of tasks.

6.4.1 Stage 2-1 – Preprocess the Supplementary Data

- Determine the pointing direction

  The task `aeattcor` models the attitude wobbling due to the thermal distortion of the satellite body. Then, the task `aeaspect` calculates the average pointing direction from the corrected attitude file, and puts the result on the header keywords of the FFF products (event, hk, attitude and orbit). The result is later used as a reference point of the sky coordinate.

- Generate extended HK (EHK) files

  The task `aemkehk` extracts attitude and orbit information and generates "Extended HK (EHK) Files", which has the same format as the HK files, that is, a table of their physical value as a function of time.

- Produce a Filter file

  The analysis of the scientific data requires only a small part of the enormous HK information, such as detector temperature, count rates of the particle monitor, attitude and orbital information, magnetic cut-off rigidity, and intervals of the South Atlantic Anomaly (SAA) passages. The task `makefilter` extracts necessary HK items from the HK and EHK files into a filter file. Counting rates of the instruments and/or BGD monitors are also used for dead time correction (section 6.5.3).

6.4.2 Stage 2-2 – Refine the First FITS Event Files

- Correct event arrival time

  The task `xisucode` obtains information of XIS minor modes for the input 1st FITS files (FFFs) from a microcode list file in CALDB, and writes important parameters for calibration in header keywords of the input FFFs. Then, the task `xistime` corrects event arrival time in the normal, window and burst modes, which deviate $\lesssim$8 sec in the First FITS files. The timing mode data need further precise correction by referring to the RAWY coordinate with `xispsumtime` (TBD), which runs after the `xiscoord` populates the RAWXY columns.

  The task `hxdtime` calculates event arrival time from editing time of the event data packet.

- Update the GTI information

  The GTI extension in the First FITS File merely lists intervals with valid telemetry. It is updated in this stage with `xistime` for XIS and `hxdtime` for HXD, to list intervals when detectors are active and accumulating data from the Filter file. The `xistime` also lists exposure intervals of the burst mode. GTIs of the good observing condition such as low background and high elevation from the Earth rim are calculated in the Stage 3 (see section 6.5.1).

- Record the XIS exposure area

The task `xisexposureinfo` (TBD) records onto the EXPOSURES extension the XIS exposure area, or more precisely, the area the data are taken and downlinked. The area discriminated by the onboard processor is excluded from the list. The list is written in the RAWXY coordinate by each CCD exposure. This information is used for making the exposure map, for example (section 6.5.3).

6.4.3 Stage 2-3 – Apply the Calibration Data

The event data are calibrated with the CALDB information to physical quantities or equivalent, which are filled in the corresponding columns.

- Calculate sky coordinate of XIS events

  The scientific analysis requires the photon arrival direction on the sky. The task `xiscoord` converts the detector coordinate of each event to the sky coordinate, with the reference to the XRT and XIS alignment calibration in CALDB and satellite attitude at the photon arrival time in the attitude file. The sky coordinate of each event and the reference R.A, Dec. coordinate are filled in the X/Y columns and the FITS header, respectively.

- Calculate PI from PHA

  The scientific analysis requires the photon energy of the detected events. The tasks `xispi` for XIS and `hxdpi` for HXD convert PHA (pulse heights) values measured with each detector to PI (pulse invariant) values, which scale to the physical energy of X-ray photons and therefore which are invariant between detector units. The result is filled in the PI column.

6.4.4 Stage 2-4 – Classify Events

- Classify events from the event pattern

  Both XIS and HXD events are classified by event grades, which are defined as the pattern of pulse heights (PH) of 3×3 pixels for the XIS, and as the hit pattern of adjacent detector units and/or the coincidence with the anti-detector for the HXD. The grade information is used for particle background subtraction in Stage 3. The `xispi` and `hxdgrade` perform this task for the XIS and HXD data, respectively.

- Flag XIS events detected at certain pixels

  Events detected on certain pixels are likely to be non-X-ray events or X-rays from internal calibration source. The task `xisputpixelquality` flags those events in the STATUS column, some of which are removed in Stage 3. Pixels which are flagged are:

  Bad columns and flickering pixels: Some CCD pixels permanently or intermittently pour out or draw in charges by a defect of electronics on the CCD chips. Such pixels, called bad or flickering pixels, disguise their PH patterns as X-ray events. The XIS team also found from the on-ground calibration that the CCD pixels which are read after those bad or flickering pixels in the same CCD column are mostly insensitive to X-rays, and that the X-ray insensitive area appears as a column on the CCD chip.

  ^{55}Fe calibration source: ^{55}Fe calibration sources constantly illuminates two corners of each XIS detector. Background level of these areas is higher at around 5.9 and 6.4 keV.

  Segment boundary and rows with spaced charge injection and around: Rows with spaced charge injection (SCI) have charges artificially injected and do not have sensitivity to X-rays. Events detected at CCD segment boundaries and rows around the SCI rows do not have 5×5 pixel information, and therefore the background level is higher than those of normal pixels.

The final products of the 2nd Stage are the *Unscreened event files* (the file extension of "_uf.evt"). Those files are separated by instrumental modes and have all the necessary keywords and correct GTI extensions, which are required for extraction of the scientific data products. They still include intervals which is generally excluded for the scientific data analysis, such as high background and Earth occultation.

6.5 Stage 3 – Data Analysis

The *Suzaku* observers receive the Unscreened event files and supplementary files necessary for data analysis from ISAS or GSFC. For the scientific analysis, they need to be processed further: data screening to maximize data signal-to-noise ratio, event extraction from the aiming target and generation of the corresponding instrumental response. The instrument teams study the standard method of data screening and implement it in the pipe-line processing[3]. The users may skip those processes by using the pipe-line products.

6.5.1 Stage 3-1 – Screen the Data

Data used for the scientific analysis should be contaminated as little as possible by background events. Through ground and on-board calibration, the instrument teams have studied data screening criteria that maximize the signal-to-noise ratio of the science data. The pipe-line processing applies this screening criteria to the Unscreened event files and outputs the *Screened event files* with the extension of "_cl.evt". Here is the standard method of the data screening.

Split Data Sets by Minor Modes

The XIS can set on board different window, grade discriminator and event threshold, and the HXD can do on the clocking rate. The unfiltered files are not split for the different discriminators or threshold but this is taken into account in the stage 3 processing.

Generate Good Time Intervals using the Filter File

The users have to remove bad quality data taken in high particle background, inappropriate detector temperature, low elevation from the Earth rim, unstable satellite pointing, and so on. The generic task `maketime` calculates those intervals by referring to the HK parameters in the Filter file, and outputs Good Time Intervals (GTI), from which the users can extract events taken in the "good interval".

Filter XIS Data Based on the Frame or Exposure

The *Suzaku* onboard processor processes XIS events by the unit of discrete "frames", which corresponds to one CCD exposure in the normal mode and to multiple exposures in the Window modes. The maximum data capacity of the telemetry is limited per frame, and any overflows are is automatically discarded. Data in such a frame, so called telemetry saturated frame, are useless without special treatments, and are removed from the dataset by the tool `xisgtigen`.

Filter Events

The instrument teams have studied detector signals through ground and on-board calibrations and found that certain types of events are more likely to be due to X-rays than others. Events satisfying such criteria are selected as X-ray events.

- Select XIS and HXD events from their event patterns

  X-ray or gamma ray events from the observing sources tend to fall in certain event grades, so that events with the other grades are discarded. The task `fselect` selects events with good grades (The XIS standard analysis picks up events with the grade 02346. The HXD grade selection is different between PIN and GSO and is complicated.)

- Remove flagged events

  The users may discard events flagged in the STATUS column (see section 6.4.4) using `xselect`. Events on the bad columns and flickering pixels simply increase the background level, and should

[3]The ASCA pipeline processing took almost 4 years to implement the automated data screening, extraction and response generation into the pipe-line processing.

be removed in any scientific analysis. While the ^{55}Fe illumination produces strong background at ∼6 keV, it is almost negligible in the other bands. Therefore, events on the masking area can be useful for soft source analysis, for example. Those events are not removed in the Cleaned Event Files in the pipeline processing at ISAS and GSFC.

- Select HXD events in the Fast vs. Slow decay-time plane

  Fluorescent lights from both GSO and BGO scintillators in the WELL unit are detected with one PMT at the bottom. Since GSO has faster fluorescence decay time-scales than BGO, signals from GSO can be discriminated using the pulse shape. Practically, the analog electronics has Fast and Slow integration circuits with decaying time-scales of GSO and BGO, respectively. Pulses from GSO and BGO fall onto different regions on the two dimensional Fast vs. Slow circuit pulse height plane. With those information, the on-board PSD (Pulse Shape Discriminator) can discriminate and flag the GSO events. However, to check the on-board algorithm and to optimize the region in the Fast vs. Slow decay-time plane in on-ground data screening, the `flookup` task is available.[4].

- Select HXD PIN and/or GSO events

  An HXD Unscreened event file include all events which hit PIN, GSO, or both. The users can choose any sets of these events from the grade information using the task `fselect`.

Data Screening Script – `aescreen` [TBD]

The *Suzaku* data processing team will develop the Perl script `aescreen` [TBD], which carries out the sequence of the above data screening tasks automatically. The script will have options of the built-in tasks, which allow users to screen data with their own criteria. The script will run in the pipe-line processing with the standard criteria to produce the Screened event files (section 6.6). The script is also available for *Suzaku* users.

6.5.2 Stage 3-2 – Extract Scientific Products

The users finally extract events from the processed event files with their own scientific interest. They can produce images, light curves and spectra, which are time, energy or spatially-sliced in need. For such purposes, `xselect`, which calls the task `extractor` inside, is available.

The extraction conditions should be recorded on the produced FITS file header since they may be needed by downstream software, for example by the instrumental response generator. `xselect` and/or `extractor` may be modified for *Suzaku* specific requirements.

6.5.3 Stage 3-3 – Generate Analysis Specific Data Sets

The users may generate instrumental response matrices or correct the produced data (e.g. barycentric corrections and dead-time corrections). The results depend on instrumental conditions, analytical methods, and the coordinate of the observing target. The users may need to feed the FITS file and/or input instrumental or physical parameters, so that the software knows specific information of the data, such as observation date, detector temperature, event extraction region, sky coordinates of the target, and so on.

Generate Response Matrices for Spectral Analysis

To carry out spectral analysis, users need to know detector response to the incident X-rays.

From ground and onboard calibrations, the XRT and XIS teams have extracted information necessary to build two types of XIS spectral response matrices, RMF (Redistribution Matrix File) and ARF (Ancillary Response File), as for earlier X-ray satellites with CCD instruments, ASCA, XMM-Newton and Chandra. The two dimensional matrix, RMF, describes pulse heights of the CCD signal against the irradiated X-rays onto the CCD chip through the XIS optical blocking filter (OBF), whose flux is normalized at unity. The

[4] The `flookup` implemented on gisclean is used for screening ASCA GIS data, with the discrimination criteria on the PHA vs. Rise Time plane.

one dimensional matrix, ARF, describes the combination of telescope effective area and transparency of the XRT thermal shield and of contamination onto the OBF by X-ray energy.

The HXD team have generated on-axis detector response files. The flux from the source at off-axis is corrected by the auxiliary file, which describe the efficiency ratio relative to the on-axis source.

- Generate XIS RMFs

  High energy particles constantly bombard CCD chips and damage CCD pixels. The damaged pixels reduce charge transfer efficiency between CCD pixels, and a certain percentage of electron charges is lost before readout. This appears as an increase of noise so that the spectral resolution gradually deteriorates. Because the amount of charge loss during the charge transfer depends on both number of pixel transfers on a CCD chip and extent of damage of a pixel, which is proportional to the amount of irradiation of charged particles, detector responses are a function of the observation date and the detector coordinate. The RMF generator `xisrmfgen` feeds the extracted spectral FITS and the calibration files from CALDB, and outputs a RMF.

- Generate XIS ARF

  Observed photon counts depend on the shape of the source extracting region, the source position in the source region, off-axis angle of the source in the XRT field of view, and the shape of the X-ray source (ex. point or diffuse source). The ARF generator `xisarfgen` and `xissimarfgen` feed these information from the spectral file, response file and optional parameters, and output an ARF file.

- Generate HXD Response

  The HXD team have prepared on-axis response matrices, which include information of both the detector effective area and detector efficiency. Since it corresponds to the combination of RMF and ARF, the extension is "`rsp`", as the convention of the response file combining RMF and ARF.

  The ARF file is not necessary for an on-axis point source. For an off-axis point source or diffuse source, the arf generator `hxdarfgen` calculates the observed flux ratio against the on-axis source and outputs an ARF file (section 7.4.4).

Generate XIS Exposure Maps and Vignetting Maps in Sky Coordinates

The exposure map describes exposure time of each pixel on the celestial (sky) coordinate system. The map is used when the users measure count rates of sources on an image or make a mosaic image from multiple images, along with the telescope vignetting map. The users first produce the exposure map of each pixel on the detector coordinate, from the exposure information in the EXPOSURES extension of the event file, bad column locations and the calibration-mask-area in the CALDB. From these information, the task `makeexposuremap` (TBD) converts the exposure map on the detector coordinate to the sky coordinate, by referring to the attitude file or the average Euler angle.

The *vignetting map* describes the telescope effective area and optionally instrumental efficiency. The telescope effective area on the detector coordinate in CALDB (section 7.4.2) has to be converted to the sky coordinate, to make a mosaic image.

Generate Background Files

The screened data still have a part of particle background and cosmic X-ray background, whose effect needs to be estimated from the off-source data. Generally, it is best to take the background from the same observation, to safeguard against possible background variation. Thanks to the imaging capability, the XIS data can easily provide a off-source region if an imaging size of an X-ray source is enough smaller than the XIS FOV. However, the HXD data without imaging information, or the XIS data of diffuse sources that cover the entire XIS FOV, need background from the other off-source observations. *Suzaku* observers may take an individual background data if they need a careful study of background contamination specific to the source, but the background data or model studied by the instrument team would be enough for most of the observations.

The instrument teams study the HXD and XIS background from the blank sky, the night Earth and day Earth data. For the XIS, non-X-ray background is accumulated from the night Earth data and the database is available from the trend archive. The users can extract background image or spectra from the event files using `xselect`. A task generates NXB spectra optimized for the observing and analyzing conditions such as exposure distribution against COR in an observation and event extracting regions (TBD). The database for this task will be stored in CALDB (TBD). For the HXD, the background level strongly increases after the SAA passage and internal background will gradually increase with time since high energy particles radio-activate PIN and GSO. The instrument team studies behavior of the background spectra in various conditions, generates database of events during earth occultation sorted with parameters sensitive to the background level, and reproduces background events for each observation from the database. The HXD team will prepare archives of background event files for each observation, or develop a tool to reproduce background events (`hxdbackest`: TBD).

Correct the HXD Dead Time

The HXD detector has non-negligible dead time in observations of X-ray sources at any flux level, because of the significant amount of particle background events at all times. The task `hxddtcor` derives correct exposure time, by counting pseudo events regularly generated by the onboard electronics.

Correct Event Arrival Time to the Solar System Barycenter

In the precise timing analysis such as the pulse search, event arrival time should be measured at the barycenteric frame of the solar system. The task `aebarycen` will convert event arrival time from the satellite frame to the barycentric frame.

6.5.4 Stage 3-4 – Derive Scientific Results

Suzaku users derive scientific results from these above products. For the analysis, the XANADU packages, XIMAGE (image), XRONOS (light curve) and XSPEC (spectrum) are available. If users need to re-extract scientific data or to change data screening criteria, they may return to Stage 3−2 or 3−1. Users may even go back to Stage 2 to recalibrate the data. However, there will never be the need to go back to Stage 1 (figure 6.1).

6.6 Pipeline Processing System

Most processing tasks in Stage 1–2 run automatically with a Perl script, whose system we call the *pipeline processing* (Figure 6.2). The script, developed at GSFC, runs at both GSFC and ISAS with the same versions of software and calibration files.[5] Consistency of the products between GSFC and ISAS are regularly checked, using the checksum keywords in the FITS header. The pipeline processing mainly handles tasks in Stages 1, 2 and of the standard screening in Stage 3 (figure 6.1). *Suzaku* observers receive Unscreened event files and Screened event files and are expected to carry out the latter half of Stage 3.

When software or calibration files are revised significantly, the pipeline reprocesses all earlier *Suzaku* data. The new products are shipped to *Suzaku* observers if the data are still proprietary, or they are updated in the *Suzaku* archives (chapter 9). Version names of the products are, for example, ver 0.1, ver 1.0, ver 2.0.

[5]The ASCA pipeline processing scripts was developed at GSFC ADF and ran only at GSFC. It contains over 14,000 lines of ksh code.

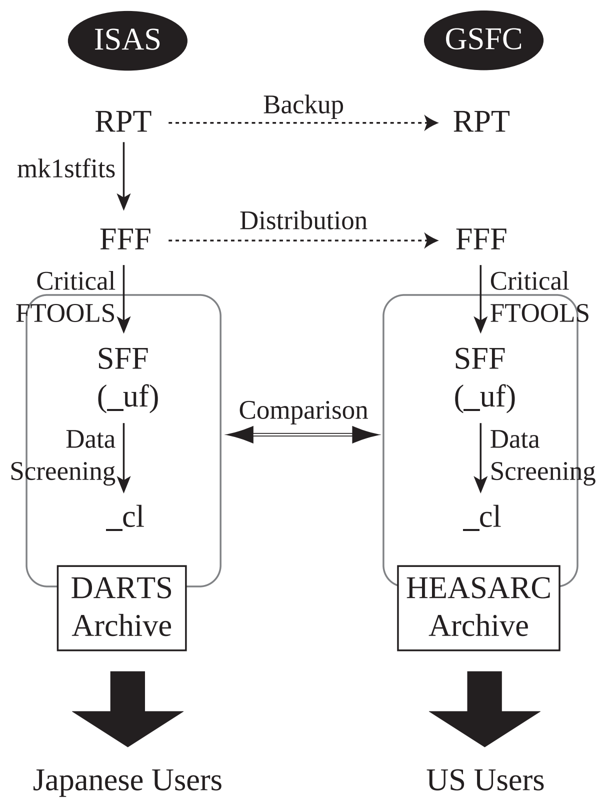

Figure 6.2: Overview of the *Suzaku* data pipeline processing at ISAS and GSFC.

Table 6.3: *Suzaku* FTOOLS list

Name	Order	Function
Attitude/Orbit		
aemkehk		Generate attitude and orbit Extend HK (EHK) files
aemkreg		Generating region files of the XIS and HXD field of views
Common/Processing		
makefilter		Generate a Filter file from HK and EHK files
Common/Analysis		
aeattcor		Model the attitude wobbling due to the thermal distortion of the satellite body
aeaspect		Calculate the mean satellite Euler angle
aebarycen		Apply barycentric correction to *Suzaku* EVENT and HK files
aecoordcalc		Calculate coordinates
aetimecalc		Calculate mission time
suzakuversion		Report the version string for *Suzaku* package
aescreen		Carry out standard data screening of event files (under development)
mkphlist		Photon list generator for xissim
XIS		
xisucode	XIS_S1	Fill the microcode information in the FITS header
xistime	XIS_S2	Fill the time column and the EXPOSURES column
xisgtigen	XIS_S3	Generate a FITS file with time interval without telemetry saturation
xiscoord	XIS_S4	Fill the sky coordinate columns
xisputpixelquality	XIS_S5	Fill the STATUS column
xispi	XIS_S6	Fill the XIS PHA, PI and GRADE columns
xisllefilter	XIS_T1	Read information of light leak from fff or sff and output to files
xisexpmapgen		calculate a detector mask image and an exposure map in the sky coordinates
xisputhkquality		Output an HK file without unimportant HK data (under development)
xisexposureinfo		Fill the EXPOSURES extension (under development)
xispsumtime (TBD)		Fill the time column for the timing mode data (under development)
xiscontamicalc		Calculate the XIS OBF contamination
xisrmfgen		Generate a detector response matrix
xisarfgen		Generate an auxiliary response matrix (under development)
xissim		XRT+XIS photon simulator
xissimarfgen		Generate an auxiliary response matrix from the XRT+XIS photon simulation
HXD-WPU		
hxdtime	Well_S1	Fill the TIME column of the Well event file
hxdmkgainhist†	Well_S2	Generate a gain history FITS file
hxdmkgainhist_gso		Generate a HXD-well PMT gain history file
hxdmkgainhist_pin		Generate a HXD-well pin gain history file
hxdpi	Well_S3	Fill the PI column of the Well data using the gain history file
hxdgrade	Well_S4	Fill the GRADE column of the Well data
hxddtcor		Calculate the dead time correction for PHA files
hxdgtigen		Give the GTI to remove the telemetry saturation intervals
hxdarfgen		Generate a list of the ratio of efficiency at off-axis
hxdwamtime	Wam_S1	Fill the TIME column of the Wam event file
hxdmkwamgainhist†	Wam_S2	Generate a gain history FITS file of the WAM data
hxdwampi	Wam_S3	Fill the PI column of the WAM data using the gain history file
hxdwamgrade	Wam_S4	Fill the GRADE column of the WAM data
hxdmkwamlc		Make lightcurve(s) from the HXD WAM event file
hxdmkwamspec		Make spectra from the HXD WAM event file
hxdwambstid		
hxdbsttime		Fill the TIME column of the gamma-ray burst event files
hxdmkbstlc		Make lightcurve(s) from the HXD Burst event file
hxdmkbstspec		Make spectra from the HXD Burst event file
hxdscltime	HK_S1	Assign time of the scaler HK data

The 2nd column shows the order to run tools in Stage 2 for S*number* and Stage 3 for T*number*.

†: `hxdmkgainhist` and `hxdmkwamgainhist` read the SFF.

Chapter 7

Calibration

The instrument teams are responsible for the calibration of instruments, which they will release in the form of documents, software, and calibration files. The latter are released to the public through the calibration database (CALDB; section 7.3). *Suzaku* GOF is responsible for obtaining the calibration products from the instrument teams and providing them to GOs.

7.1 Documentation

In cooperation with the instrument teams and the OGIP CALDB team, *Suzaku* GOF will provide a set of documents which describe the *Suzaku* calibration. These documents should be public and available on-line in text, postscript, pdf or HTML format. At minimum, the document set should cover the following subjects:

- Explain ground and in-orbit calibration

  Suzaku GOF will help the hardware teams document the calibration activities. It will be necessary to document when and how the ground and in-orbit calibrations are conducted, and which parameters are determined. Configuration of the calibration experiments should be illustrated.

- Explanations of the calibration files

  Origins, formats, meanings, and usages of the calibration files stored in the CALDB (section 7.3 and 7.4) should be explained.

- Algorithms for building responses and making corrections

  The algorithms for constructing instrumental responses and perform instrument specific corrections using calibration files and software should be explained. For example, it should be explained how RMFs and ARFs are created from spectral files, and how exposure maps are made from event files and attitude files.

- Summarize important calibration parameters

  Important satellite and instrument parameters determined through calibration should be summarized. These parameters include, for example, positions of the optical axis for each sensor.

- Calibration uncertainties

  The instrument teams are responsible for documenting the limits of current calibration, such as the systematic uncertainties in the latest spectral responses.

7.2 Calibration Software

Calibration software are developed by the instrumental teams, and will be incorporated into the function libraries (section 4), simulation software (section 5.2), and response generators (section 6.5.3). *Suzaku* GOF will make the calibration softwares conform to the *Suzaku* software conventions (chapter 3).

When constructing instrumental responses or carrying out instrument specific corrections, it is important that algorithms and parameters be separated as much as possible. The calibration software should not include hardwired parameters, instead reading instrumental parameters from the calibrations files. This ensures that, when parameters are updated by a new calibration, only calibration files need be changed, and will make it possible to test different responses simply by changing parameters.

7.3 Calibration Database (CALDB)

Suzaku calibration files shall be put in the HEASARC Calibration Database (CALDB)[1], which also contains calibration files for other high energy missions. All the calibration files in CALDB should conform to the OGIP standard FITS format.

7.3.1 Structure and Organization

The master copy of the CALDB is located at GSFC under the anonymous ftp directory, `ftp://legacy.gsfc.nasa.gov/caldb/`. There are two sub-directories, `docs` and `data` (for documents and data respectively), and those for a particular mission are stored in `docs/[mission]` and `data/[mission]`, where `[mission]` is the mission name. There are instrument directories `data/[mission]/[instrument]` for each instrument, and each directory contains three sub-directories, `pcf`, `bcf` and `cpf`, which respectively stands for the primary calibration files, basic calibration files and calibration product files.

Primary calibration files are raw or almost-raw calibration data, and will not be directly used to construct instrument responses. Ground calibration data will be archived and regarded as Primary calibration data. Calibration files used to perform instrument specific corrections or to construct responses are called basic calibration files. Responses themselves or calibration files used in the Stage 3 data analysis (section 6.5.4) are called calibration product files.

In the case of ASCA, we did not have primary calibration files. The GIS and SIS *teldef files*, which carry important instrumental parameters such as dimensions, misalignments and positional gain variations of the sensors, are examples of the basic calibration files. SIS and GIS RMFs are categorized as calibration product files and put under the `cpf` directory. In the case of *Suzaku*, we may archive ground calibration data under `pcf`. Most of the important calibration files listed below (section 7.4) are considered basic calibration files.

7.3.2 Time-Dependent Calibration Files

Some calibration files will be time-dependent. If the variation is long enough ($\gtrsim$ a few months) and/or the results should be checked by an expert of the instrument, the calibration files may be put in CALDB. The HXD gain history and XIS CTI correction are such calibration data. If the variation is as short as the span of a single observation, the calibration files are created in the pipeline processing although there are no current examples for *Suzaku*[2]

7.3.3 Calibration File Name

Calibration files should be given unique names to indicate their contents and dates of the release, and a file name and the physical file should have one-to-one correspondence; hence symbolic links should not be used. The calibration files must have the mandatory CALDB keywords which describe the nature of the

[1]See `http://heasarc.gsfc.nasa.gov/docs/heasarc/caldb/caldb_intro.html`.
[2]The XRS gain history was one.

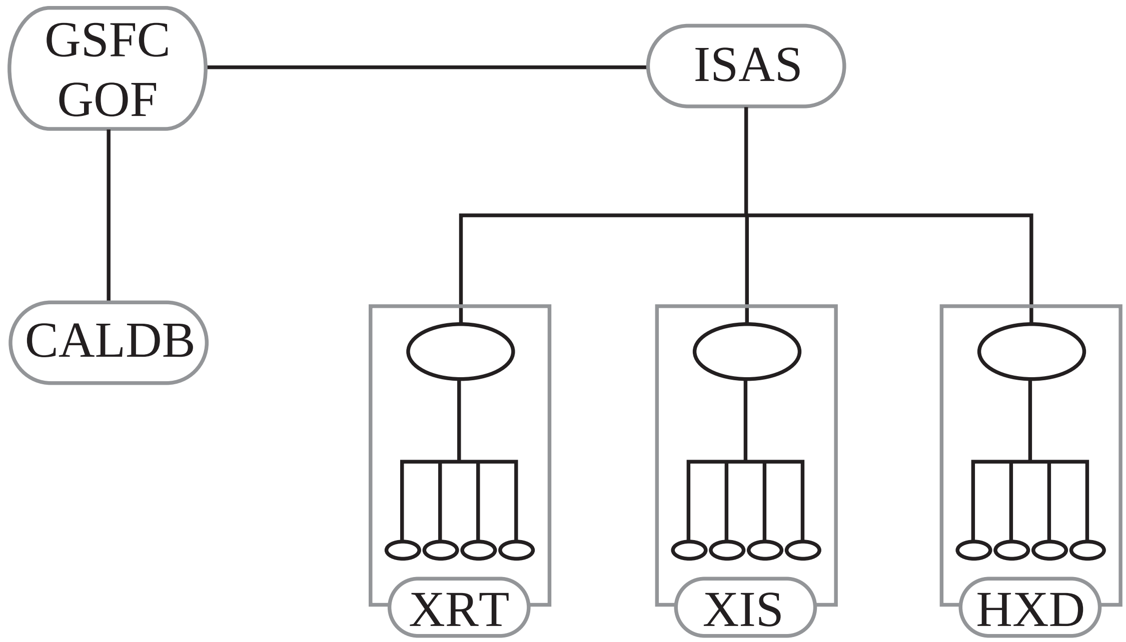

Figure 7.1: Delivery of CALDB files between GSFC and ISAS.

files and are referenced by CALDB softwares. Recommended naming convention for the *Suzaku* calibration files is the following:

`ae_inst_kind_yyyymmdd.ext`

where `inst` is the name of the instrument[3] , `kind` is brief description of the file contents, and must be less than 8 characters, `yyyy`, `mm` and `dd` are year, month and day of the release, respectively. `ext` is the file extension, which can be `fits` or any other letters to describe the nature of the file (e.g., `rmf` or `arf`). Both `inst` and `kind` should not include hyphens ('-'), underscores or periods ('.').

7.3.4 Version Control

It is essential that the calibration files be under version control and releases be conducted using a well established procedure. *Suzaku* GOF and instrument teams have established the standard procedure for the delivery and release of calibration files. For each calibration file, there shall be a contact person in the instrument team and in GOF. To avoid confusion, those files are passed through contact persons in GOF and ISAS. After they checked the validity of the file and agreed to release, the file will be shipped to CALDB (Figure 7.1).

CALDB already has an established scheme of the version control. Each instrument directory (`/caldb/data/[mission]/[instrument]`)
has the index file named `caldb.indx` which contains brief descriptions for all the calibration files included in this directory and the sub-directories. These information are taken from the mandatory CALDB keywords in each calibration file. Also in the `caldb.indx` file are quality and validity flags of all the calibration files which are to be judged by *Suzaku* GOF and instrument teams. The CALDB access software, provided by the CALDB team, can choose the appropriate file based on the validity date and other information in `caldb.indx`.

The identical CALDB tree is mirrored to ISAS regularly, although the primary copy of the CALDB is maintained at GSFC. GOs can obtain and install the entire CALDB on their machines, obtain the subset necessary for their analysis, or remotely access CALDB at GSFC or mirror sites.

[3]Either `xrs`, `xis`, `xi0`, `xi1`, `xi2`, `xi3`, `hxd`.

7.4 Important Calibration Files

Suzaku GOF and the instrument teams will determine the types of calibration files that are necessary. Important calibration files are listed below.

7.4.1 General

- Telescope definition files

  Alignments between the telescopes and instruments are described. In addition, parameters of the instruments and the coordinate systems, such as focal lengths and detector pixel sizes are written. There may be separate telescope definition files for different detectors.

- Satellite Information Base (SIB)

  Parameters for conversion from the digitized HK telemetry to the physical units are stored in the multimission database named Satellite Information Base (SIB) located at ISAS. Essential parts of the SIB will be extracted and put in the calibration files. These calibration files are used to interpret HK parameters in the telemetry (section 4.1.4).

7.4.2 XRT

- Effective area

  The XRT effective area corresponding to a certain encircled radius is given as a function of energy for different off-axis and azimuthal angles. Separate files are made for XRT-I and XRT-S. If the four XRT-Is have different effective areas, there shall be more than one file for XRT-I.

  These files are made from calibration measurements and ray-tracing simulations (section 5.2.3), and used to calculate ARFs and vignetting maps (section 6.5.3).

- Point spread functions

  Although point spread functions can be created from ray-tracing simulations, a set of ready-made point spread functions for different off-axis and azimuthal angles, and possibly for different photon energies, will be provided for convenience.

  Point spread functions are necessary when making ARFs (section 6.5.3) and for image analysis such as image fitting and image deconvolution.

- Files for the ray-tracing simulations

  The ray-tracing program (section 5.2.3) requires two calibration files describing the telescope parameters, one for reflectivity and the other for geometrical structure of the foils.

7.4.3 XIS

- Time variable XIS calibration files

  Variable instrumental parameters required to calculate PI from PHA for building spectral responses and effective area are written as functions of time. Gain history (pulse-peak of the calibration source), Charge Transfer Inefficiency (CTI), quantum efficiency and the OBF contamination will be such examples.[4] Positions of the bad pixels and columns may also slowly vary with time. The μ code database is updated when an observation uses a new CCD clock pattern.

- Time invariant XIS parameter files

  Important time invariant XIS parameters such as area of calibration masks and DAC setup are written.

[4] In the case of ASCA SIS, RDD (Residual Dark-current Distribution) and *echo* parameters are also variable, and time history of these parameters are also saved in the individual calibration files. RDD should not be present for XIS.

7.4.4 HXD

- HXD collimator transmission map

  Energy dependent collimator transmission is written as a function of the pointing vectors on the satellite frame. The direction which gives the maximum transmission becomes the bore-site. This file will be necessary to make HXD ARFs.

- HXD detector parameter file

  Important detector parameters required to build responses are written. These parameters should include, e.g., dimensions of the GSO crystals, silicon PIN diodes and the detector assembly. This file will be necessary to make HXD RMFs.

- HXD gain history table (GHT)

  History of the energy gain of the PIN, GSO, and WAM detectors are written.

  Process to generate GHT: There are two types of GHTs, GHT_daily and GHT_caldb. GHT_daily is automatically generated with `hxdmkgainhist` every observation (one file for each detector – PIN, GSO – per observation, not per FFF) and stored in the Trend Archive. GHT_caldb is generated from GHF_daily by the HXD team and stored in CALDB. The task `hxdpi` calibrates the data with the latest GHF_caldb in any processing. The update intervals are TBD (possibly, ∼1 month).

- HXD background parameter file (TBD)

  The HXD background is modeled empirically (section 6.5.3). Model parameters necessary to construct HXD background will be stored in the calibration file.

7.5 *Suzaku* Calibration File Release Plan

1. *Suzaku* calibration files may be delivered from ISAS to GSFC *on the last working day of each month.*

2. When a new microcode file is made (`ae_xis_ucodelst_YYYYMMDD.fits`), the file may be implemented into the GSFC and ISAS pipelines immediately, independent of CALDB update. At the end of each month, the new microcode files introduced during the month are delivered to CALDB.

3. Should there be occasional delays of CALDB file delivery, ISAS shall give advance warning toward GOF.

4. When calibration files require new tasks or new functionalities, *these calibration files must be delivered with the corresponding tasks*; namely the delivery may be made on the last working day of January, April, July or October.

5. When existing files are updated, the format and keywords *must* not be changed, except for those keywords that are associated with a particular release (FILENAME, VERSION etc).

6. When new types of the calibration files are created by the instrument teams, their formats and keywords must be agreed to between ISAS and HEASARC before being ingested into the CALDB.

7. For each delivery of the calibration files, reason of the new delivery and difference from the previous version should be explained.

Chapter 8

Guest Observer Support

In this chapter, we describe *Suzaku* GOF's primary functions for Guest Observer (GO) support. GOF focuses its effort on supporting professional astronomers located in the United States who submit *Suzaku* proposals and analyze *Suzaku* data. *Suzaku* observers in Japan and other countries and the *Suzaku* archives users all over the world are also within the scope of the *Suzaku* GOF support, though their primary contact should be the Japanese help desk at RIKEN laboratory.

In order to perform the following GO support tasks, *Suzaku* GOF in cooperation with other groups under OGIP will develop infrastructures such as software, documents and database systems.

8.1 On-Line Service and Help

Suzaku GOF release most updated information through WWW at the *Suzaku* GOF home page,
`http://suzaku.gsfc.nasa.gov/`.
On-line help desk is available via the Feedback feature of the GOF web site, to which GOs can ask any questions regarding *Suzaku*. Recipients will be the *Suzaku* GOF members. *Suzaku* GOF shall have a rota system so that, at any given time, a single GOF scientist is responsible for all incoming questions.

There shall be extensive *Suzaku* on-line databases with which GOs can retrieve various *Suzaku* information as well as the archival data. Details on the *Suzaku* database and archives are explained in the next chapter.

8.2 Proposal Support

NASA releases NRAs (NASA Research Announcements) for US based astronomers to obtain *Suzaku* data, currently as an element of an omnibus announcement. *Suzaku* GOF is responsible for preparing technical information associated with such NRAs, including instrumental specs required for GOs to prepare proposals. *Suzaku* GOF will supply simulation tools (section 5.2) and observation planning tools (section 5.1) which are intended to be used by prospective GOs in the course of preparing proposals.

GO proposals will be submitted electronically through the multi-mission Remote Proposal Submission (RPS) system.

8.3 Observation Planning

Suzaku GOF will give expert advice to GOs how to plan their observations, such as best instrumental modes, observational constraints, pointing directions, roll angles and so on. Preliminary observational plans should be given in the proposals, and the final plans must be confirmed by GOs prior to the observations. The procedure is that GOF members contact GOs when the short term observation schedule is released, and ask GOs if there might be any changes from the observations plans in the proposals. If necessary, GOs may make small changes at this stage (e.g., slight change of the roll-angle) consulting GOF advice. *Suzaku* GOF conveys the final GO observation plans to ISAS, and the ISAS satellite operation team incorporates the final plans into the command stream.

8.4 Pipeline Processing and Data Distribution

Suzaku GOF receive data from ISAS and process them by adding calibration information so that the processed data are ready to be reduced to the scientific information (section 6.1). The software for processing will be mainly developed by *Suzaku* GOF in cooperation with the instrument teams (section 6.1). The US GOs receive the processed data from GSFC. By default, data will be encrypted and made available for download, and the encryption key will be communicated to the GOs. Under exceptional circumstances, other distribution methods (such as using a CD-ROM) may be considered.

8.5 Data Analysis Support

It is expected that GOs would obtain data analysis softwares from OGIP/*Suzaku* GOF through Internet, install them, and use them to analyze their data on their own computers. The analysis software will be developed and supplied by *Suzaku* GOF and OGIP, and should be simple to install and use (section 3.1). Extensive documents and on-line help should be provided to assist software installation and use, and a standard and thorough data analysis manual should be written by *Suzaku* GOF. The primary method for GOs to submit questions is via the Feedback feature of the GOF web site.

8.6 Community Oversight

A *Suzaku* Users Group has been established to provide advise on the *Suzaku* GOF services. The *Suzaku* Users Group will have regular meetings to discuss guest observer support issues.

Chapter 9

Suzaku Database and Archives

9.1 *Suzaku* Databases

The *Suzaku* team at ISAS, the *Suzaku* GOF, and the HEASARC will maintain a set of databases both for internal and external purposes. Internal databases are stored on secure machines for scheduling, satellite operation, and data processing purposes. They are maintained at ISAS within the framework of observation database (ODB) and copies are made available to, e.g., the processing pipeline at GSFC, as appropriate.

Public databases are provided for external users, including both GOs and archive users, so they can obtain public information and archival data. The latter will be the responsibility of the HEASARC, where the original will be kept, and can be accessed using the "Browse" interface. By inputting target names or coordinates, Browse users can seek specific information in the databases and retrieve archival data for the desired targets. ISAS PLAIN center will copy the public *Suzaku* databases from the HEASARC and make them accessible through their own interface. The primary *Suzaku* database within Browse is known as `suzamaster`.

9.1.1 Proposal Database

US GO proposals are submitted to and recorded at GSFC, while ISAS handles Japanese proposals separately. Both US and Japanese proposals are submitted electronically through RPS and all the accepted proposals are put in the proposal database. Such databases are used in the proposal review processes and the review results are recorded. The entire electronic records for accepted targets become part of the ODB. Accepted proposals are considered to enter the public domain, and the abstracts and target information for accepted targets are included in the `suzamaster` database. This allows Browse users to check if objects of interest have been already observed with *Suzaku*, for example.

9.1.2 Observation Database

The ODB is in fact a set of databases, containing proposal information, observation plans, observation logs, and processing logs. The ODB includes information necessary for the satellite operation, hence access is strictly controlled.

Each GO observation, IOC observation, TOO observation and calibration observation is given a unique sequence number, which is used as the primary key in the ODB. The ODB also includes such items as dates and time of the observation, instrument modes and pointing directions . At ISAS, the scheduling and command generation software access the ODB to to construct observation schedule and to construct operation commands.

After observations have been performed, the ODB is used to check the completion of the observations at ISAS, and the observation logs are made and stored. Status of data processing are also recorded in the ODB, so that it is readily seen if the telemetry data are received and archived at ISAS, gone through the Stage 1 and 2 processing, and shipped to GSFC (section 6.1).

9.1.3 Processing Database

The *Suzaku* processing pipeline uses an internal database to track the status of data processing. Starting with the input from the ODB, the processing logs are entered into the processing database and then results are sent back to the ODB.

The processing date is used to determine the public release date of GO observations.

9.2 *Suzaku* Archives

9.2.1 Policy and Responsibilities

All *Suzaku* data taken with XIS and HXD (including the WAM gamma-ray burst data; section 2.1.7) are made public after the proprietary period.

The High Energy Astrophysics Science Archive Research Center, HEASARC, which belongs to OGIP, supports multi-mission X-ray and gamma-ray archival research. The *Suzaku* GOF is responsible for delivering processed *Suzaku* data to the HEASARC. The HEASARC will then maintain the archives, while the *Suzaku* GOF will support archival research while the mission is active. At the end of the mission, the HEASARC takes over the archival user support responsibility.

9.2.2 Contents

The outputs of the pipeline processing are immediately delivered to the HEASARC kept encrypted until the end of the proprietary periods, when the data are decrypted.

The products produced in the pipeline processing will be put in subdirectories of each observation sequence.

9.2.3 Archival Access

The *Suzaku* data are placed in the HEASARC anonymous ftp area directory, `ftp://legacy.gsfc.nasa.gov/suzaku/data`. There will be no restriction on the data access so that any user may access and retrieve the data through anonymous FTP.

The data will be sorted by sequence numbers, and users may directly go to the desired directories if they know the sequence numbers. However, we anticipate that most users will access the archives through the Browse interface by inputting source names or coordinates (section **??**).

Appendix A

Acronyms

Acronyms often used in the *Suzaku* project are summarized with their full-names and related items.

Acronym	**Full Name**	**Related Item**
ADF	Astrophysics Data Facility	GSFC
AE	Analogue Electronics	
AO	Announcement of Opportunities	
APID	Application Process ID	
BGO	$Bi_4Ge_3O_{12}$	HXD
CALDB	Calibration Database	
CCSDS	Consultative Committee for Space Data Systems	
CTI	Charge Transfer Inefficiency	XIS, ASCA SIS
DE	Digital Electronics	
DP	Data Processor	
ESA	European Space Agency	
FTP	File Transfer Protocol	
FITS	Flexible Image Transport System	
FFF	First FITS files	
FOV	Field of View	
GHF	Gain History File	
GO(s)	Guest Observer(s)	
GOF	Guest Observers Facility	
GSFC	Goddard Space Flight Center	
GSO	Gd_2SiO_5	HXD
GTI	Good Time Intervals	
GUI	Graphic User Interface	
HEASARC	High Energy Astrophysics Science Archive Research Center	GSFC
HPD	Half Power Diameter	
HK	Housekeeping	
HTML	Hyper Text Makeup Language	
HTTP	Hyper Text Transfer Protocol	

HXD	Hard X-ray Detector	
IOC	In Orbit Check-out	
ISAS	Institute of Space and Astronautical Science	
JAXA	Japan Aerospace Exploration Agency	
NASA	National Aeronautics and Space Administration	
NRA	NASA Research Announcement	
OGIP	Office of General Investigator Programs	
PGP	Pretty Good Privacy	
PSF	Point Spread Function	
PHA	Pulse Height Analyzer	
PI	Pulse Invariance	
PI	Principle Investigator	
PIN	Positive Intrinsic Negative	
PIMMS	Portable, Interactive, Multi-Mission Simulator	
PPU	Pixel Processing Unit	
PSD	Pulse Shape Discriminator	HXD
RDD	Residuals of Dark Distribution	ASCA SIS
RIKEN	Japanese acronym for Institute of Physics and Chemical Research	
ROM	Read Only Memory	
RPS	Remote Proposal Submission system	
RPT	Raw Packet Telemetry	
SI	Scientific Instruments	
SIB	Satellite Information Base	
SWG	Science Working Group	
TAKO	Timeline Assembler, Keyword Oriented	*Suzaku* planning
TBD	To Be Determined	
TI	Time Counter	
TOO	Target Of Opportunities	
USC	Uchinoura Space Center	
WAM	Wide-band All-sky Monitor	HXD
WCS	World Coordinate System	
WWW	World Wide Web	
XIS	X-Ray Imaging Spectrometer	
XRS	X-Ray Spectrometer	
XRT	X-Ray Telescope	

Appendix B

FTOOLS developers guideline

Here is a guideline by the GSFC FTOOLS team for the programmers developing *Suzaku* FTOOLS. This guideline is particularly aimed for Japanese instrument members who are developing in the ANL environment and going to convert ANL modules into FTOOLS.

B.1 Items to be Delivered

The delivery to the GSFC *Suzaku* GOF/FTOOLS team should include the software and test example(s).

- Software
  - Source Codes
  - Parameter files (default)
  - Makefile
  - Documents: in plain ASCII text and IRAF "lroff" format.
- Examples:
  - Relevant input files and resulted output files.
  - Test parameter files or test script.

B.2 Source Codes

- Useful informations can be found at:
  `http://heasarc.gsfc.nasa.gov/ftools/others/develop/develop.html`
  (FTOOLS developer's guide, slightly outdated).
  `http://heasarc.gsfc.nasa.gov/docs/software/fitsio/fitsio.html`
  (CFITSIO HTML guide) and
  `http://heasarc.gsfc.nasa.gov/docs/software/fitsio/c/c_user/cfitsio.html`
  (CFITSIO manual for C programmer)
- Use the languages of ANSI C, ANSI C++ and FORTRAN 77 only.
- For scripts, use Perl 5.0 or Tcl/Tk 8.0.
- Comply with the standards of ANSI C, ANSI C++ or Fortran 77; do not use system-dependent extensions or features.
- For codes of mixing FORTRAN and C(i.e, C calls Fortran and Fortran calls C), use cfortran.h from CERN.

- For C or FORTRAN FTOOLS, use the cdummyftool and fdummyftool as templates. They can be found in src/examples/src in FTOOLS release.
- Subroutine or function name must be unique. This is a requirement of packaging the FTOOLS.
- Do not use the hard-coded "scanf" or command line options to read in the parameter in C or Fortran codes. Use XPI parameter interface. The routines are documented in pfile.h for the C FTOOLS.
- Do not directly write the message to stdout, use the fcecho or fcerr routines in cFTOOLS and xpi libraries. Put messages into the stdout directly will prevent the task from being used in a pipeline. In case the use of fcecho/fcerr is undesirable in the development environment, as a compromise, a centralized output routine should be used whenever "printf" is necessary.
- Provide the English translations for the important comments written in other languages.
- For handling of FITS files, use cfitsio. Do not try to read/write the files using specialized routines.
- In C FTOOLS, do not use the obsolete fcfitsio routines, which are the wrapped Fortran fitsio routines, which are the wrapped cfitsio routines.
- Before calling the cfitsio routine, make sure the error status is set to zero, otherwise, the routine returns immediately.
- After calling the cfitsio routine, make sure that the error status still stays at zero. If not, provide the error handling and return gracefully.
- CFITSIO routine "ffopen" automatically handles the filename parsing, file existing tests etc. Do not use any parsing routine or file open routines before ffopen. It can hinder the abilities of cfitsio to open a network file or compressed file.
- "stderr" should only be used to output critical error messages, since the presence of stderr messages are used by many scripts as part of the error handling mechanism. This restriction does not apply to "stdout," but even this should be used with restraint.
- The *Suzaku* FTOOLS defines the chatter levels in the softwares from 0 (min) to 5 (max) as does the Swift package. Each chatter level displays 0: critical error messages only, 1: warning messages, 2 (default): useful information, 3: debugging level 1, 4: debugging level 2, 5: maximum debugging level.
- Finally, do not try to be fancy and clever, do not reinvent the wheel, and KISS (Keep It Simple, Stupid).

B.3 Parameters

It is well documented in URL: http://heasarc.gsfc.nasa.gov/ftools/others/pfiles.html

B.4 Makefiles

For FTOOLS development, "hmake" is used, which is a version of the "make" utility developed locally by the HEASARC. It is not necessary for the developers to write the "hmake" style make file. However, developers should provide a makefile in one of the popular Unix platforms (OSF, Solaris, SunOS, HPUX, Linux or SGI, Apple/Darwin). the software and understand the dependencies between modules.

B.5 Documents

The help file should be provided in a plain ASCII text file with the extension .txt and a file with the IRAF “lroff” format and extension .hlp. The “lroff” format is quite similar to the UNIX nroff/troff. You can find it in any .hlp files in FTOOLS distribution.

The help file should include the following sections:

- Name: Name plus a one sentence description.
- Usage: Synnopsis of the tool
- Description: Detailed description of the tools.
- Parameters: Descriptions for parameters.
- Examples: Examples of using the tool.
- Bugs: Known bugs or features of the tool.
- See Also: References to other relevant tools.
- Author: Authorship, credits and e-mail address for questions and bug reports (It is usually ftoolshelp@olegacy.gsfc.nasa.gov or the help desk of the mission).

Appendix C

Flow Chart of the Pipeline Processing

```
Legend
========================================
[ ] critical ftools
( ) user data
" " outputs to trend area
** CALDB access
========================================


=== 0. Common ===

NOTE: The Common processes MUST be executed before HXD and XIS processings.
-----------------------------------------------------------------------------
Attitude file: aeXXXXXXXXX.att

(Attitude file) --> [aeattcor] --> [aeaspect] --> (New attitude file)
                       ^
                       |
        (orbit file) --+
    (common HK file) --'

- The original attitude file is supersedesed by the new one.
  The ae1 script is expected to take care of this.
- This procedure can be carried out multiple time (i.e. loop) safely.
-----------------------------------------------------------------------------
Orbit file: aeXXXXXXXXX.orb

(Orbit file) --> [aeaspect] --> (Orbit file)
                     ^
                     |
           (New attitude file)

- Some header keywords will be filled.
-----------------------------------------------------------------------------
```

```
Tim file: aeXXXXXXXXX.tim

(Tim file) --> [aeaspect] --> (Tim file)
                    ^
                    |
         (New attitude file)

- Some header keywords will be filled.
-------------------------------------------------------------------------------
Ehk file: aeXXXXXXXXX.ehk

                  [aemkehk] ----> [aeaspect] --> (Ehk file)
                      ^              ^
                      |              |
       (Orbit file) --+    (New attitude file)
(New attitude file) --'
-------------------------------------------------------------------------------


=== 1. HXD ===

-------------------------------------------------------------------------------
(WEL FFF) -->
[hxdtime] --> [hxdmkgainhist] --> [hxdpi] --> [hxdgrade] --> (WEL UFF)
    **          |    **              **            **
                +--> "aeXXXXXXXXXhxd_0_gso.ghf"
                `--> "aeXXXXXXXXXhxd_0_pin.ghf"
-------------------------------------------------------------------------------
(WAM FFF) -->
 [hxdwamtime] --> [hxdmkwamgainhist] --> [hxdwampi] --> ...continue...
     **             |                         ^  **
                    |                         |
                    +--> "aeXXXXXXXXXhxd_0_wam.ghf"

  ...--> [hxdwamgrade] --> (WAM UFF) ---> [hxdwambstid]
                                            |
                                            `--> "aeXXXXXXXXXhxd_0_bstidt.fits"
-------------------------------------------------------------------------------
(BST FFF) --> [hxdbstid] --> (BST UFF)
                 **
-------------------------------------------------------------------------------
(HXD HK) --> [hxdscltime] --> (HXD HK)
                 **
-------------------------------------------------------------------------------
Note for HXD diagram:
 - Before starting the HXD processing, aemkehk and aeattcor have to be
   run to prepare proper EHK and attitude files.
   (The XIS tools should also require them.)
 - hxdmkgainhist and hxdwambstid extract the data sets that will be
   sent to the trend area after the pipeline.  Their products, i.e.,
       aeXXXXXXXXXhxd_0_pin.ghf, aeXXXXXXXXXhxd_0_gso.ghf and
       aeXXXXXXXXXhxd_0_bstidt.fits
```

```
   are not used in the pipeline.
 - On the other hand, aeXXXXXXXXXhxd_0_wam.ghf generated by hxdmkwamgainhist
   will be used by hxdwampi.
 - Pin- and gso-ghf required by hxdpi are retrieved from CALDB.
   Bstidt required by hxdbsttime is also retrieved from CALDB.
-----------------------------------------------------------------------------


=== 2.XIS ===

-----------------------------------------------------------------------------
XIS hk file: aeXXXXXXXXXxiN_0.hk

(XIS hk file) --> [aeaspect] --> (XIS hk file)
                      ^
                      |
            (New attitude file)
-----------------------------------------------------------------------------
XIS frame FFF: aeXXXXXXXXXxiN_n_f[nbp]MMMiNN.fff

(XIS frame FFF) --> [aeaspect] --> [xisucode] --> (XIS frame SFF)
                        ^
                        |
              (New attitude file)
-----------------------------------------------------------------------------
XIS darkframe FFF: aeXXXXXXXXXxiN_n_dfiNN.fff

(XIS darkframe FFF) --> [aeaspect] --> (XIS darkframe SFF)
                            ^
                            |
                  (New attitude file)
-----------------------------------------------------------------------------
XIS darkinit, darkupdate FFF: aeXXXXXXXXXxiN_n_d[iu][nbp]MMM.fff

(XIS darkinit/update FFF) --> [aeaspect] --> [xisucode] --> ...continue...
                                  ^
                                  |
                        (New attitude file)

 ...--> [xiscoord] --> (XIS darkinit/update SFF)
             ^
             |
   (New attitude file)
-----------------------------------------------------------------------------
XIS normal, burst event FFF: aeXXXXXXXXXxiN_n_{5x5,3x3,2x2}[nb]MMM.fff

(XIS event FFF) --> [aeaspect] --> [xisucode] --> [xistime] --> ...continue...
                        ^                             ^
                        |                             |
              (New attitude file)              (Tim file)

 ...--> [xiscoord] --> [xisputpixelquality] --> [xispi] --> (XIS event SFF)
             ^                                      ^
```

```
             |                                      |
   (New attitude file)                       (XIS hk file)
-------------------------------------------------------------------------------
XIS psum FFF: aeXXXXXXXXXxiN_n_timpMMM.fff

(XIS psum FFF) --> [aeaspect] --> [xisucode] --> [xistime] --> ...continue...
                        ^                              ^
                        |                              |
              (New attitude file)              (Tim file)

 ... --> [xiscoord] ------> [xispi] --> (XIS psum SFF)
             ^                  ^
             |                  |
   (New attitude file)    (XIS hk file)
-------------------------------------------------------------------------------
XIS telemetry unsaturated GTI file: aeXXXXXXXXXxiN_0_telem.gti

[xisgtigen] --> (temporary_xiN_n_ZZZ[nbp]MMM.gti)
     ^
     |
 (one of XIS event SFF {normal,burst,psum} x {5x5,3x3,2x2,tim} )

     :
     :

[xisgtigen] --> (temporary_xiN_n_ZZZ[nbp]MMM.gti)
     ^
     |
 (one of XIS event SFF {normal,burst,psum} x {5x5,3x3,2x2,tim} )


                                 [mgtime] --> (aeXXXXXXXXXxiN_0_telem.gti)
                                    ^
                                    |
(temporary_xiN_n_ZZZ[nbp]MMM.gti) -+
     :                              :
(temporary_xiN_n_ZZZ[nbp]MMM.gti) -+
(temporary_xiN_n_ZZZ[nbp]MMM.gti) -'

- mgtime is operated with "merge=OR".
-------------------------------------------------------------------------------
```

Appendix D

Definition of the Coordinate System used for *Suzaku*

D.1 Definition of the Coordinates

The following coordinates are defined to describe event locations in the telemetry, on the detector, or on the sky. All the coordinates are written in the *Suzaku* event files.

- RAW coordinates:
  Original digitized values in the telemetry to identify pixels of the events. May not reflect physical locations of the pixels on the sensor. For example, XIS RAW X and Y coordinates will have values from 0 to 255 on each Segment[1].

- PPU coordinates:
  Coordinates system used for the Dark Frame mode of the XISs. The PPU coordinates add copied pixels (2 pixels) at the front and back of the RAW X coordinate.

- ACT coordinates:
  ACT is defined only for XIS. The ACT X and Y values are defined to represent actual pixel locations in the CCD chips. ACT XY will take 0 to 1023 to denote the 1024×1024 pixels in the chip. The XIS RAW to ACT conversion depends on the observation modes (such as Window Options) and will require housekeeping information. The XIS ACT coordinates is defined by looking-down the sensors.

- DET coordinates:
  Physical positions of the pixels *within* each sensor. Misalignments between the sensors are *not* taken into account. The DETX/Y coordinates are defined by looking up the sensor, such that the satellite +Y direction[2] becomes the −DETY direction (the same as the ASCA convention). The DET X and Y values take 1 to 1024 for XIS.

- FOC coordinates:
  Focal plane coordinate common to all the sensors in unit of arcmin. Misalignments between the sensors as well as the difference of the focal length *are* taken into account so that the FOC images of different sensors can be superposed. FOC is calculated from DET by linear transformation to represent the instrumental misalignment, i.e., the offset and the rotation angle, and the focal length of the XRT. Information of these misalignment and the focal length are written in the teldef files.

- SKY coordinates:
  Positions of the events on the sky. The conversion from FOC to SKY is made using the satellite

[1]Each of the four XIS sensors has a single CCD chip, and a single chip is divided into four Segments.
[2]Satellite Z-axis points the telescope direction, and +Y direction is toward the solar paddle.

attitude in the attitude file and the alignment matrix (3×3) written in the teldef file. For each XIS event, the equatorial coordinates of the pixel center projected on a tangential plane are given[3].

In this scheme, it is important that the conversion from RAW to DET does *not* depend on the misalignments between the sensors. Therefore, DET XY, as well as RAW XY, can be written in the event FITS files without having the calibration information. The DET to FOC conversion requires information of the focal length and the misalignment between the sensors. The same routines/functions can be used for FOC to SKY conversions for different sensors not depending on the individual characteristics.

D.2 Implementation to the FITS Event Files

D.2.1 Names of the Columns

	XIS	HXD
SENSOR	SENSOR	SENSOR
RAW	SEGMENT, RAWX, RAWY	–
PPU	SEGMENT, PPUX, PPUY	–
ACT	ACTX, ACTY	–
DET	DETX, DETY	–
FOC	FOCX, FOCY	–
SKY	X, Y	–

D.2.2 Type and Range of the Columns

XIS

	Type	Minimum	Maximum	Origin	Size of the Pixel
SENSOR	Integer	0	3	–	–
SEGMENT	Integer	0	3	–	–
RAWX/Y	Integer	0	255/1023	–	0.024 mm
PPUX/Y	Integer	0	259/1023	–	0.024 mm
ACTX/Y	Integer	0	1023	–	0.024 mm
DETX/Y	Integer	1	1024	512.5	0.024 mm
FOCX/Y	Integer	(1	1536)[a]	768.5	0.0174 arcmin
X/Y	Integer	(1	1536)[a]	768.5	0.0174 arcmin

[a]: Default image region.

The DETXY pixel sizes correspond to the physical pixel size of the XIS CCD. The XY pixel size corresponds to the angular size of a single XIS CCD pixel. To allow rotation of the image and some shift of the pointing direction during the observation, the XY range is taken slightly bigger than $\sqrt{2} \times 1024$.

HXD

	Type	Minimum	Maximum	Origin	Size of the Pixel
SENSOR	Integer	0	15	–	–

HXD is not an imaging instrument and will not have coordinate columns. The average pointing direction may be written in the event FITS file header.

[3]There are several projection methods, such as -TAN, -SIN, -ARC and -STG.
See `http://www.cv.nrao.edu/fits/documents/wcs/wcs.all.ps` for details. The tangential projection (-TAN) is widely used, and will be adopted for *Suzaku* event files too.

Bibliography

[1] "The Scientific Satellite Astro-E Interim Report" ("Kagaku Eisei Astro-E Chuukan Houkokusho"), ISAS, 1998, in Japanese

[2] Serlemitsos, P. J. et al. 1995, PASJ, 47 105

[3] Serlemitsos, P. J. and Soong, Y. 1996, Astrophys. Sp. Sci., 239, 177

[4] Serlemitsos, P. J. 1997, "The Next Generation of X-ray Observatories", p. 123

[5] Kamae, T. et al. 1996, SPIE, vol. 2806, 314

[6] Takahashi, T. et al. 1996, A&A, 120, 645

[7] Mukai, K. 1993, in *Legacy*, p. 65, (`http://heasarc.gsfc.nasa.gov/docs/journal/ogip_fortran3.html`)

Index