Catching gamma ray bursts on the fly . . .

Swift
Project Data
Management Plan

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Goddard Space Flight Center
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This document is controlled by the Swift Ground NEtwork for SwifT (GNEST) Configuration Control Board (CCB). Proposed changes shall be submitted to the Swift GNEST CCB for approval

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OPEN ITEMS

This table lists the items that remain open as of the publication of this version of the document. As they are closed the resolutions will be incorporated into the body of the document.

ISSUE #	AFFECTED AREA	DESCRIPTION

OPEN ACTIONS

This table lists the action items that remain open as of the publication of this version of the document. As they are closed the resolutions will be incorporated into the body of the document.

ACTION #	ACTIONEE	DESCRIPTION

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1.0 INTRODUCTION

1.1 Mission Overview

The Swift mission is a multi-wavelength observatory for gamma ray burst (GRB) astronomy. It is a Medium-Class Explorer selected for study in response to AO-98-03-OSS-025 and subsequently approved for development in October 1999. It is scheduled to be launched in late 2004.

Swift has three instruments: a coded-mask detector (Burst Alert Telescope; BAT), an X-ray CCD camera (X-ray Telescope; XRT), and an UltraViolet and Optical Telescope (UVOT). The NASA/GSFC developed BAT; Pennsylvania State University (PSU), the University of Leicester, and the Brera Observatory developed the XRT; PSU and the Mullard Space Science Laboratory developed UVOT.

BAT surveys the sky with a 1.4-sr field of view in the hard X-ray band (15 – 150 keV). XRT and UVOT are co-aligned narrow field instruments. XRT covers the soft X-ray band (0.2 -- 10 keV) with an energy resolution about 140 eV (FWHM) at 6 keV. UVOT covers the wavelength range from 170 to 6000 nm with 6 selectable filters and a grism that can be inserted in the optical path. All the instruments operate simultaneously.

The major scientific goals of Swift are 1) to determine the sites and nature of GRB progenitors, 2) to explore the local environment near GRBs, 3) to pioneer the use of GRBs as probes of the early Universe, and 4) to provide a sensitive all-sky hard X-ray survey. These goals will be accomplished by detecting about 100 bursts per year with the BAT and then rapidly (within ~60 seconds) observing the burst with the XRT and UVOT. Within 20 seconds of the burst, the BAT will report the position and flux of the burst to the ground using TDRSS. Within a few minutes of the burst, BAT will report the burst light curve, XRT will report an improved position and the X-ray spectrum of the afterglow, and UVOT will report an optical finding chart. All of this information will be rapidly distributed to the astronomical community using the Gamma-ray Coordinates Network (GCN) to enable additional observations with other instruments. Swift will continue to observe the afterglow of GRBs for many days or weeks depending on the evolution of the flux of the afterglow. During these observations the BAT will search for new GRBs while simultaneously making a sensitive survey of the hard X-ray sky. All of the scientific data from the instruments will be converted into FITS files and be made available to the community within a few hours of each observation. In addition, the data will be processed with a standard set of analysis routines to provide initial results to guide decisions about future observations.

1.2 About This Document

This document describes the Swift data processing and software system that is used after the data is delivered to the SDC from the Swift MOC at PSU.

Readers are reminded that this document does not serve as the original source for the technical information such as instrumental specification and telemetry formats, or high-level agreements. These technical and/or political issues are defined and documented in the original documents maintained by the Swift Project Office and NASA HQ.

In Chapter 2, general aspects of the Swift satellite are discussed. In Chapters 3, 4, and 5 the Swift scientific instruments are described. An overview of the Swift ground system and mission operations are presented in Chapters 6 and 7. Swift software design principles and agreements are presented in Chapter 8. Swift software tasks required in the data processing and other aspects of the project are defined in Chapters 9 and 10. Important issues regarding the calibration are given in Chapter 11. Tasks regarding the Guest Investigator support are shown in Chapter 12, and the Swift archives are addressed in Chapter 13.

In Appendix A, acronyms often used in the Swift project are explained. Appendix B provides an index to this document.

1.3 Related Documents

Other important issues, which cannot be covered in this document, will be described in separate documents. The document sets will at least include the following issues:

- Swift FITS File Formats --- FITS Formats of the Swift HK and event files, calibration files and other important files (e.g., attitude files and orbit files) are explained.
- Swift Calibration Plan --- Documents calibration plan for Swift instruments and spacecraft.
- Data analysis manual -- A users guide to recipes and individual science analysis tools.

1.4 Reference Documentation

The following documents provide reference information. All documents with numbers that include "410.4" are available at the GSFC Data Management System web site (http://gdms.gsfc.nasa.gov/gdms/plsql/frontdoor).

1. "Swift Science Requirements Document", GSFC-661-Swift-SRD, 410.4-SPEC-0005, August 21, 2000.
2. "Swift Mission Requirements Document", 410.4-SPEC-0004, Version 1.4, October 10, 2000.
3. "Requirements of the Ground System for the Swift Mission", 410.4-SPEC-0007, Revision 0.07, September 11, 2000, v0.07.
4. "Swift Interface Requirements Document", 410.4-ICD-0001, Review Version 1.4d6a, November 3, 2000.
5. "Swift: A Panchromatic Gamma Ray Burst MIDEX Mission", Phase A Study Report, June 1999.
6. "Swift System Requirements Review", May 8, 2000.
7. "Swift Mission Preliminary Design Review", August 29, 2000.
8. "Swift GNEST PDR", September 13, 2000.
9. "Swift Mission Critical Design Review", July 12 and 13, 2001.
10. "Swift GNEST Critical Design Review", November 29, 2001.
11. "Swift GNEST Mission Operations Review", August 27, 2001.
12. "Swift Project Service Level Agreement", 451-PSLA-Swift, September 2002.
13. "Spacecraft/Ground Station ICD", CDRL 5.1, May 2001.
14. "Spacecraft/MOC ICD", CDRL 5.2, June 2002.
15. "MOC/Malindi ICD",
16. "MOC/SDC ICD", 410.4-OMI-0005, December 2001.
17. "MOC/IT ICD", 410.4-OMI-0006, August 2002.
18. "SDC/UKDC/ISAC ICD", 410.4-ICD-0020, July 2002.
19. "SSC/SDC ICD", 410.4-ICD-0015, November 2001.
20. "Swift Mission Operations Concept Document", Baseline Version 1.1, August 10, 2001.
21. "Swift Mission Operations Agreement", 410.4-AGMT-0004, August 2001.

22. “Swift-HEASARC MOU”, 410.4-PROC-0016, January 16, 2002.
23. “Swift Ground System Test Plan”, 410.4-PLAN-0028, Version 1.1, June 2002.
24. “Swift Observation Definition”, 410.4-AGMT-0011, October 16, 2002
25. “Swift Calibration Plan”, in preparation.
26. “Swift Users Guide”, in preparation.
27. “Onboard Operational Messaging Interface Document”, 410.4-ICD-0006, June 21, 2002.

1.5 Other References

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Murthy, J. and Henry, R. C. “A model of the Diffuse Ultraviolet Radiation Field”, Astrophysical Journal 448, 848-857, 1995

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Wells, A., et al., 1997, Proc. SPIE, 3114, 392

2.0 The Swift Mission

2.1 The Spacecraft

Spectrum Astro provides the spacecraft, which is based on their flight-proven SA-200 bus. Swift has a prime-mission lifetime of 2 years with a goal of 5 years and an orbital lifetime of ~8 years.

Most of the data will be downlinked in several passes each day over the ground station at Malindi, Kenya. TDRSS will be used to send burst alert messages to the ground. Similarly, information about bursts observed by other spacecraft will be uplinked through TDRSS for evaluation by Swift's on-board figure-of-merit software (see Section 2.4).

There will be no on-board propulsion system. Stable pointing and rapid maneuvering will be accomplished with 6 reaction wheels with their momentum unloaded by three magnetic torquers. Attitude determination will be accomplished using gyroscopes and star trackers. Sun sensors and magnetometers will be used for initialization and safe mode operations. A Predict Ahead Planner Algorithm (PAPA) will be used to check constraints for the duration of a maneuver before the maneuver starts.

2.2 Launch, Orbit and Operations

The Swift will be launched from Cape Canaveral, Florida, on a Delta 7320. The Swift orbit will be nearly circular with an altitude of ~600 km and an inclination of ~22 degrees.

Swift will be operated by the Mission Operations Center (MOC) at PSU. Contacts with the satellite will use either the NASA Space Network or a ground station. The prime ground station is near Malindi, Kenya, and back-up stations are provided by the Universal Space Network (USN). The ground stations act as a conduit for commands; they do not initiate commands to the spacecraft. Telemetry is captured by the ground stations and then transferred to the MOC. Data from the real-time channel of the spacecraft are sent immediately, while data from the other channels are recorded and then transferred after the contact.

Swift is expected to produce about 5 Gbits/day, and about 47 minutes per day will be needed to downlink a day’s worth of data. The capacity of the solid-state recorder on the spacecraft is 32 Gb, which can store several days of data. The plan is to schedule every contact with Malindi that lasts more than 5 minutes. This provides ample margin for getting all the data to the ground and also reduces the data latency.

By default, the Malindi station will be configured to be able to send commands on every contact. In normal operations a significant number of commands is expected for only one contact a day when the stored command processor is updated. The other contacts are available to respond to science opportunities or anomalies.

2.3 On-board Data System

The Swift on-board command and data handling system (C&DH) is based on an IEEE standard VME bus. The system includes the Sold-State Recorder (SSR), the Uplink/Downlink (UL/DL) board, the RAD-6000 Processor (CPU), and a Bus Transfer Function (BTF) board. Selective redundancy is employed to enhance reliability. The three instruments communicate with the spacecraft over a 1553 bus. Each instrument has a unique 1553 Remote Terminal address, and each data type has its own unique 1553 sub-address. The BTF polls the instruments to determine if new data are ready. The instrument State-of-Health (SOH) data are read and sent to the CPU where they are sampled and stored for later downlink. The science data are read by the BTF and stored in the SSR for later downlink. Commands and accurate timing information are sent from the spacecraft to the instruments over the 1553 bus.

The UL/DL provides the interface between the C&DH and RF subsystems. It receives commands and collects, prioritizes, and formats telemetry. It prioritizes the telemetry based on the virtual channel identification, which identifies the type of data. The UD/DL selects the highest priority data from the SSR, CPU, or PCMD, adds the appropriate CCSDS header, implements Reed-Solomon encoding to minimize transmission errors, and passes the data to the RF subsystem.

During normal operations, telemetry will be sent to the ground stations at a rate of 2.25 Mbps. There is also a lower rate of 35 kbps for contingency operations. Telemetry to TDRSS will be sent at much lower data rates. The minimum rate is 1 kbps, but higher rates can be selected if the actual performance of the system exceeds requirements. The data rate for commanding from the ground stations is 2 kbps. The CCSDS COP-1 protocol is used to assure retransmission when there are transmission errors. Commands can also be sent using TDRSS. The data rate is 125 bps, and the COPS-1 protocol will not be used.

Swift telemetry conforms to CCSDS protocols. The Application Process ID, or APID, identifies the data types in the CCSDS packet. A separate range of APIDs has been assigned to each of the instruments and the spacecraft.

When the telemetry from a ground-station contact is received at the MOC, the data are processed into packets, grouped by APID, sorted by time, and then made available to the SDC. The packet data will be archived at the MOC for the duration of the Swift mission. The SDC ingests the data from a single contact, accounts for packets that have already been received in previous contacts, and converts the data into FITS files. The fits files are delivered to the three Swift archive centers.

2.4 Science Operations

The Swift observing program will consist primarily of pointing the XRT and UVOT at recently discovered GRBs to observe the evolution of the burst afterglow. At the same time BAT will be searching for new GRBs and conducting its hard X-ray survey. Because of the observing constraints, there will always be multiple targets in each orbit. The sequence of targets will be decided in advance by the MOC based on an evaluation of the expected intensities and scientific attractiveness of recent GRBs. This schedule of pre-planned targets (PPTs) can be interrupted when a GRB is discovered with BAT.

The observatory can autonomously schedule observations based on either a GRB detection with BAT or a command from the ground. The Figure of Merit (FoM) software system, which is hosted on the BAT instrument computer, is responsible for deciding whether the new target should be observed instead of the currently scheduled target. The FoM obtains information from the spacecraft about when the target can be observed, sends an observation request to the spacecraft, and informs the instruments about changes to the schedule.

In a typical observing scenario, a new GRB will be discovered with BAT, the FoM will decide to request observations of the new burst, the spacecraft will accept the request after checking observing constraints, and a maneuver to point the XRT and UVOT at the new burst will begin within a few seconds. Once the narrow-field instruments (NFI) settle on the source, they will begin a pre-planned sequence of configurations. XRT will change configurations autonomously based on the intensity of the new source, and UVOT will run through a sequence of filters. The observation will continue until an observing constraint is encounter, and then a maneuver will be made to the originally scheduled PPT at that time. When observing constraints no longer prevent observing the source, a maneuver will be made to point the NFIs at the source again. At the end of the maneuver the NFIs will resume their pre-planned sequence of configurations. This pattern of observing the new source whenever possible will continue until the specified amount of time for viewing a new GRB has been achieved. The MOC will then schedule additional observations of the GRB.

2.5 Definition of Observation

Swift has adopted a set of terms to define observations and the numbers used to identify observations. This agreement is documented in "Swift Observation Definition" (410.4-AGMT-0011). A continuous viewing of the same target is a "snapshot." For convenience, the time during the maneuver to the target is also considered part of the snapshot. An "observation segment" is a collection of snapshots of the same target that is designed to carry out a science objective. Each observation segment of a specific target is assigned a unique 8-bit number. It is expected that observation segments of the same target will not overlap. Observation segments are limited to a duration of 48 hours. Each target has a unique 24-bit number called the "target ID", and different classes of targets are assigned specific ranges of numbers. The largest range of numbers has been allocated to new GRBs discovered on-board with BAT. The "sequence number" is the concatenation of the target ID expressed as an 8-digit, zero-filled decimal number and the observation segment expressed as a 3-digit, zero-filled decimal number. The Swift archive is organized by sequence number – all the data files of a specific sequence number are put in its own directory.

3.0 Burst Alert Telescope

The Burst Alert Telescope (BAT) is a highly sensitive, large FOV instrument designed to provide critical GRB triggers and 5-arcmin (99% confidence radius) positions. It is a coded aperture imaging instrument with a 1.4-steradian field-of-view (half coded). The energy range is 15-150 keV for imaging with a non-coded response up to 500 keV. Within the first 6 seconds of detecting a burst, the BAT will calculate an initial position and send information about the burst to the FoM.

In order to study bursts with a variety of intensities, durations, and temporal structures, the BAT must have large dynamical range and trigger capabilities. The BAT uses a two-dimensional coded aperture mask and a large area solid-state detector array to detect weak bursts and has a large FOV. Since the BAT coded aperture FOV always includes the XRT and UVOT fields-of-view, long duration gamma-ray emission from the burst can be studied simultaneously with the X-ray and UV/optical emission. The data from the BAT will also produce a sensitive hard X-ray all-sky survey over the course of Swift's two-year mission. Figure 3.1 shows a cut-away drawing of the BAT, and Table 3.1 lists the BAT's parameters. Barthelmy (2000) gives further information on the BAT.

3.1. Technical Description

The BAT's 32,768 pieces of 4 × 4 × 2 mm CdZnTe (CZT) form a 1.2 × 0.6 m sensitive area in the detector plane. Groups of 128 detector elements are assembled into 8 × 16 arrays, each connected to 128-channel readout Application Specific Integrated Circuits (ASICs) called the XA1s, which are designed and produced by Integrated Detector and Electronics of Norway. Detector modules, each containing two such arrays, are further grouped by eights into blocks. This hierarchical structure, along with the forgiving nature of the coded aperture technique, means that the BAT can tolerate the loss of individual pixels, individual detector modules, and even whole blocks without losing the ability to detect bursts and determine locations. The CZT array will have a nominal operating temperature of 20° C, and its thermal gradients (temporal and spatial) will be kept to within ±1° C. The typical bias voltage is –200 V, with a maximum of –300 V.

The BAT has a D-shaped coded aperture mask, made of ~54,000 lead tiles (5 × 5 × 1 mm) mounted on a 5 cm thick composite honeycomb panel, which is mounted by composite fiber struts 1 meter above the detector plane. Because the large FOV requires the aperture to be much larger than the detector plane and the detector plane is not uniform due to gaps between the detector modules, the BAT coded-aperture uses a completely random, 50% open-50% closed pattern, rather than the commonly used Uniformly Redundant Array pattern. The mask has an area of 2.7 m^2, yielding a half-coded FOV of 100° × 60°, or 1.4 steradians.

A graded-Z fringe shield, located both under the detector plane and surrounding the mask and detector plane, will reduce background from the isotropic cosmic diffuse flux and the anisotropic Earth albedo flux by ~95%. The shield is composed of layers of Pb, Ta, Sn, and Cu, which are thicker toward the bottom nearest the detector plane and thinner near the mask.

A figure-of-merit (FOM) algorithm resides within the BAT flight software and decides if a burst detected by the BAT is worth requesting a slew maneuver by the spacecraft. If the new burst has more "merit" than the pre-programmed observations, a slew request is sent to the spacecraft. Uploaded rapid-reaction positions are processed exactly the same as events discovered by the BAT. The FOM is implemented entirely in software and can be changed either by adjusting the parameters of the current criteria or by adding new criteria.

3.2. BAT Operations

The BAT runs in two modes: burst mode, which produces information about the bursts, and survey mode, which produces hard X-ray survey data. In the survey mode the instrument collects count-rate data in 5-minute time bins for 80 energy intervals. When a burst occurs it switches into a photon-by-photon mode with a round-robin buffer to save pre-burst information.

3.2.1. Burst Detection

The burst trigger algorithm looks for excesses in the detector count rate above expected background and constant sources. It is based on algorithms developed for the HETE-2 GRB observatory, upgraded based on HETE-2 experience. The algorithm continuously applies a large number of criteria that specify the pre-burst background intervals, the order of the extrapolation of the background rate, the duration of the burst emission test interval, the region of the detector plane illuminated, and the energy range. The BAT processor will continuously track hundreds of these criteria sets simultaneously. The table of criteria can be adjusted after launch. The burst trigger threshold is commandable, ranging from 4 to 11σ above background noise with a typical value of 8σ. A key feature of the BAT instrument for burst detection is its imaging capability. Following the burst trigger the on-board software will check for and require that the trigger corresponds to an un-cataloged point source, thereby eliminating many sources of background such as magnetospheric particle events and flickering in bright galactic sources. Time stamping of events within the BAT has a relative accuracy of 100 μsec and an absolute accuracy from the spacecraft clock of ~200 μsec. When a burst is detected, the sky location and intensity will be immediately sent to the ground and distributed to the community through the Gamma-Ray Burst Coordinates Network (GCN) (Barthelmy et al. 2000).

3.2.2. Hard X-ray Survey

While searching for bursts, the BAT will perform an all-sky hard X-ray survey and monitor for hard X-ray transients. The BAT accumulates detector plane maps every 5 minutes, which are included in the normal spacecraft telemetry stream. Sky images are searched to detect and position sources. The sensitivity of the survey is about 1 mCrab in the 15-150 keV band for 2 years. For regions where there are perpetually numerous strong sources in the BAT FOV (i.e. the Galactic Plane), the limiting sensitivity will be ~3 mCrab.

For on-board transient detection, 1-minute and 5-minute detector plane count-rate maps and ~30-minute long average maps are accumulated in 4 energy bands. Sources found in these images are compared against an on-board catalog of sources. Those sources either not listed in the catalog or showing large variability are deemed transients. A subclass of long smooth GRBs that are not detected by the burst trigger algorithm may be detected with this process. All observations of hard X-ray transients will be distributed to the interntional community via the Internet, just as for bursts.

3.3 Detector Performance

The measured spectrum of the 60 keV gamma-ray line from an ^{241}Am radioactive source for a typical individual pixel has a full-width-half maximum (FWHM) at 60 keV of 3.3 keV ($\Delta E/E$ = 5%), which is typical of CZT detectors. Simulations have calculated an average BAT background event rate of 17,000 events s^{-1}, with orbital variations of a factor of two around this value. This yields a GRB sensitivity of ~10^{-8} erg cm^{-2} s^{-1}, 5 times better than BATSE. The combination of the 4 mm square CZT pieces, plus the 5 mm square mask cells and the 1-m detector-to-mask separation gives an instrumental angular resolution of 20 arcmin FWHM, yielding a conservative 4 arcmin centroiding capability for bursts and steady-state sources given an 8σ burst threshold.

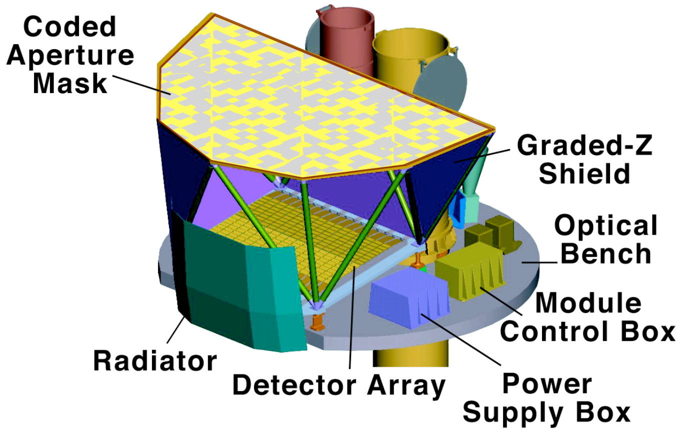

Fig. 3.1 — The Burst Alert Telescope cut away drawing showing the D-shaped coded aperture mask, the CZT array, and the Graded-Z shielding

TABLE 3.1

BURST ALERT TELESCOPE CHARACTERISTICS

BAT Parameter	Value
Energy Range	15-150 keV
Energy Resolution	~7 keV
Aperture	Coded mask, random pattern, 50% open
Detection Area	5240 cm^2
Detector Material	CdZnTe (CZT)
Detector Operation	Photon counting
Field of View	1.4 sr (half-coded)
Detector Elements	128 modules of 256 elements/module
Detector Element Size	$4 \times 4 \times 2$ mm^3
Coded Mask Cell Size	$5 \times 5 \times 1$ mm^3 Pb tiles
Telescope PSF	20 arcmin
Source Position and Determination	1-4 arcmin
Sensitivity	~10^{-8} erg cm^{-2} s^{-1}
Number of Bursts Detected	>100 yr^{-1}

4.0 X-RAY TELESCOPE

Swift's X-Ray Telescope (XRT) is designed to measure the fluxes, spectra, and light curves of GRBs and afterglows over a wide dynamic range covering more than 7 orders of magnitude in flux. The XRT will pinpoint GRBs to 5-arcsec accuracy within 10 seconds of target acquisition for a typical GRB and will study the X-ray counterparts of GRBs beginning 20-70 seconds from burst discovery and continuing for days to weeks. Figure 4.1 shows a schematic of the XRT, and Table 4.1 summarizes XRT parameters. Burrows et al. (2000) and Hill et al. (2000) give further information on the XRT.

4.1. Technical Description

The XRT is a focusing X-ray telescope with a 110 cm^2 effective area, 23 arcmin FOV, 15 arcsec resolution (half-power diameter), and 0.2-10 keV energy range.

The XRT uses a grazing incidence Wolter 1 telescope to focus X-rays onto a state-of-the-art CCD. The complete mirror module for the XRT consists of the X-ray mirrors, thermal baffle, a mirror collar, and an electron deflector. The X-ray mirrors are one of the units built, qualified and calibrated as flight spares for the JET-X instrument on the Spectrum X Gamma mission (Citterio et al. 1996; Wells et al. 1992; Wells et al. 1997). To prevent on-orbit degradation of the mirror module's performance, it will be maintained at $20 \pm 5°$ C with gradients of $<1°$ C by an actively controlled thermal baffle similar to the one used for JET-X.

A composite telescope tube holds the focal plane camera, containing a single CCD-22 detector. The CCD-22 detector, designed for the EPIC MOS instruments on the XMM-Newton mission, is a three-phase frame-transfer device, using high resistivity silicon and an open-electrode structure (Holland et al. 1996) to achieve a useful bandpass of 0.2-10 keV (Short, Keay, & Turner 1998). The CCD consists of an image area with 600×602 pixels (40×40 μm) and a storage region of 600×602 pixels (39×12 μm). The FWHM energy resolution of the CCDs decreases from ~190 eV at 10 keV to ~50 eV at 0.2 keV, where below ~0.5 keV the effects of charge trapping and loss to surface states become significant. A special "open-gate" electrode structure gives the CCD-22 excellent low energy quantum efficiency (QE) while high resistivity silicon provides a depletion depth of 30 to 35 μm to give good QE at high energies. The detectors will operate at approximately $-100°$ C to ensure low dark current and to reduce the CCD's sensitivity to irradiation by protons (which can create electron traps, ultimately affecting the detector's spectral resolution).

4.2. Operation and Control

The XRT supports four readout modes to enable it to cover the dynamic range and rapid variability expected from GRB afterglows, and autonomously determines which readout mode to use. Imaging Mode produces an integrated image measuring the total energy deposited per pixel and does not permit spectroscopy, so will only be used to position bright sources. Two Timing Modes sacrifice position information to achieve high time resolution and bright source spectroscopy through rapid CCD readouts. Photon-counting Mode uses sub-array windows to permit full spectral and spatial information to be obtained for source fluxes ranging from the XRT sensitivity limit of 2×10^{-14} to 9×10^{-10} erg cm^{-2} s^{-1} (0.2 to 10 keV).

4.3. Instrument Performance

The mirror point spread function has a 15-arcsec half-energy width, and, given sufficient photons, the centroid of a point source image can be determined to sub-arcsec accuracy in detector coordinates. Based on BeppoSAX and RXTE observations, it is expected that a typical X-ray afterglow will have a flux of 0.5-5 Crabs in the 0.2-10 keV band immediately after the burst. This flux should allow the XRT to obtain source positions to better than 1 arcsec in detector coordinates, which will increase to ~5 arcsec when projected back into the sky due to alignment uncertainty between the star tracker and the XRT.

The XRT resolution at launch will be ~140 eV at 6 keV. Fe emission lines, if detected, will provide a redshift measurement accurate to about 10%. Photometric accuracy will be good to 10% or better for source fluxes from the XRT's sensitivity limit of 2×10^{-14} erg cm^{-2} s^{-1} to $\sim 8 \times 10^{-7}$ erg cm^{-2} s^{-1} (about 2 times brighter than the brightest X-ray burst observed to date).

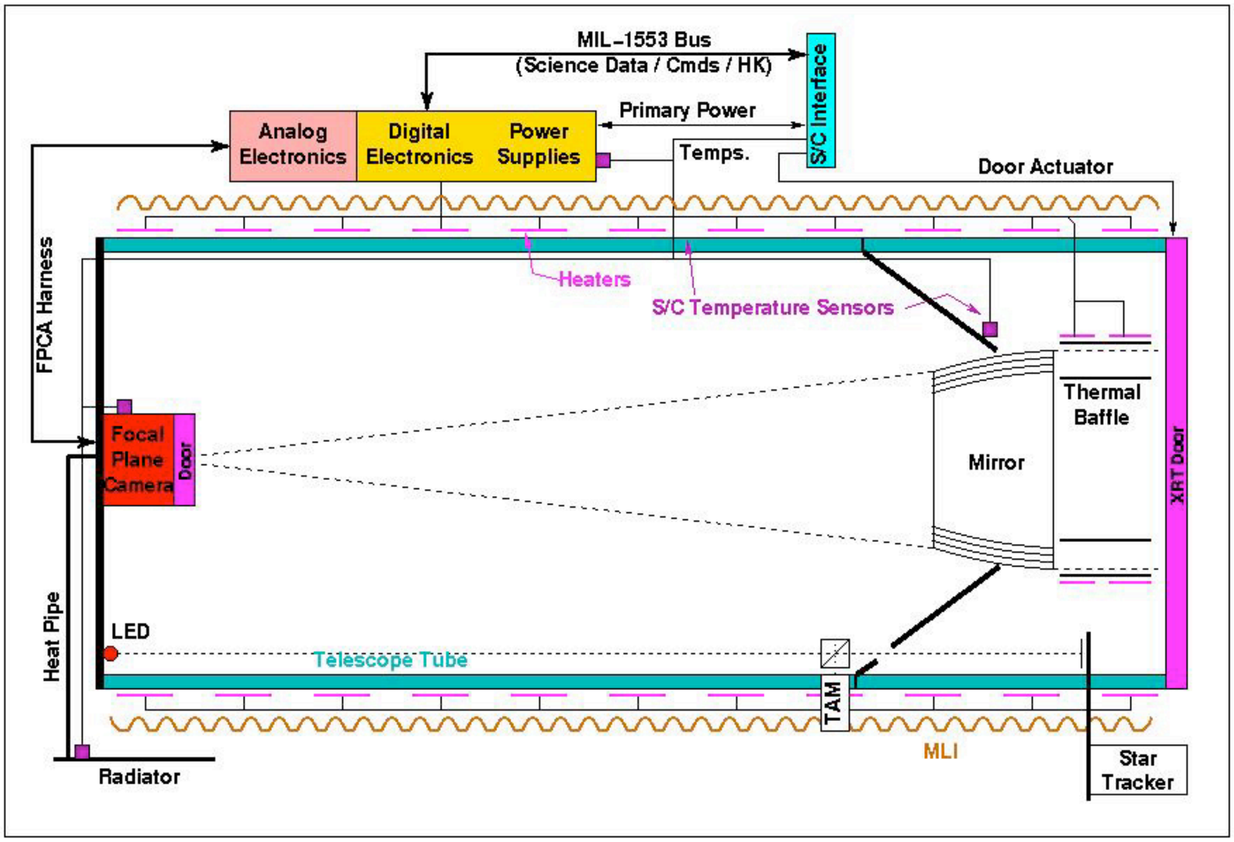

Fig. 4.1 — Block diagram of Swift's X-Ray Telescope

XRT Parameter	Value
Energy Range	0.2-10 keV
Telescope	JET-X Wolter 1
Detector	MAT CCD-22
Effective Area	110 cm^2 @ 1.5 keV
Detector Operation	Photon counting, integrated imaging, and timing
Field of View	23.6 × 23.6 arcmin
Detection Elements	600 × 600 pixels
Pixel Scale	2.36 arcsec
Telescope PSF	15 arcsec HPD @ 1.5 keV
Sensitivity	2×10^{-14} erg cm^{-2} s^{-1} in 10^4 s

Table 4.1. X-Ray Telescope characteristics

5.0 Ultra-Violet/Optical Telescope

The Ultra-Violet/Optical Telescope (UVOT) design is based on the Optical Monitor (OM) on-board ESA's XMM-Newton mission, with deviations from that design made only when necessary (see Mason et al. 1996 for a discussion of the OM). It is co-aligned with the XRT and carries an 11-position filter wheel, which allows low-resolution grism spectra of bright GRBs, magnification, and broadband UV/visible photometry. Photons register on the microchannel plate intensified CCD (MIC). Figure 5.1 shows a schematic of the UVOT, and Table 5.1 summarizes the UVOT parameters. Further information on the UVOT is given by Roming et al. (2000).

5.1. Technical Description

The UVOT's optical train consists of a 30 cm clear aperture Ritchey-Chrétien telescope with a primary f-ratio of f/2.0 increasing to f/12.72 after the secondary. The baffle system consists of an external baffle, which extends beyond the secondary mirror; an internal baffle, which lines the telescope tube between the primary and secondary mirrors; and primary/secondary baffles, which surround the secondary mirror and hole at the center of the secondary mirror. An INVAR structure used between the mirrors is intrinsically thermally stable and maintains the focus.

The UVOT carries two redundant photon-counting detectors. Each detector has a filter wheel carrying the following elements: a blocked position for detector safety; a white light filter; a field magnifier; two grisms; U, B, and V filters; two broadband UV filters centered on 180 and 260 nm; and a narrow UV filter centered on 220 nm. One grism on each wheel is optimized for the UV, the other for blue, and both offer a spectral resolution of ~1 nm/pixel. Diffraction-limited images in the blue can be obtained with the 4× magnifier; however, because of the limits of the transmission optics, the magnifier does not work at UV wavelengths. One of the two photon-counting detectors is selected by a steerable mirror mechanism.

The UVOT operates as a photon-counting instrument. The two detectors are MICs with 384 × 288 pixels, 256 × 256 of which are usable for science observations with each pixel corresponding to 4 × 4 arcsec on the sky. Photon detection is performed by reading out the CCD at a high frame rate and determining the photon splash's position using a centroiding algorithm. The detector achieves a large format through this centroiding technique, sub sampling the 256 × 256 CCD pixels into 8 × 8 virtual pixels each, leading to an array of 2048 × 2048 virtual pixels with a size of 0.5 × 0.5 arc seconds on the sky. This provides a 17 × 17 arc minute FOV. The frame rate for the UVOT detectors is 10.8 ms. These detectors have very low dark current, which usually can be ignored when compared to other background sources. In addition, they have few hot or dead pixels and show little global variation in quantum efficiency.

5.2. Operating Modes

The UVOT runs under four possible operational scenarios: slewing, settling, finding chart, and routine. During a spacecraft slew, no useful data can be obtained. Settling occurs when the target has entered the UVOT's FOV but pointing errors are still high. During this time, the target can be observed, but its position is only known to BAT accuracy. For a new GRB source, as soon as Swift's pointing errors are sufficiently small, the UVOT makes a 100-second observation in one filter to produce a finding chart to send to the ground. After making the finding chart or after settling on an old target, the UVOT makes routine observations.

There are five operating modes for the UVOT: event, imaging, transient, safe and engineering; the transient and safe modes were not included in the original OM instrument design.

In event mode, the UVOT telemeters time-tagged photon events as they arrive, and the FOV is windowed (to fit the UVOT's telemetry rate) and divided between the target and bright guide stars. The timing resolution is equal to the CCD frame time (minimum ~1 ms).

In imaging mode, photon events are summed into an image for a time period known as the tracking frame time (≤20 s). These tracking frame images are shifted (to compensate for spacecraft pointing drift) and added. In this mode, the FOV must also be windowed, but larger windows can be used than in timing mode.

In transient mode photon events are stored in memory as they arrive, without processing. This mode is best used during the settling period, when the full FOV is retained. Then after the target has been positioned accurately, those stored photons near the target can be extracted and telemetered.

To eliminate the need to pre-plan UVOT observations (as is necessary for OM observations), UVOT has a safe mode. In this mode, UVOT autonomously protects itself from bright sources by moving the filter wheel to the blocked position and/or by reducing the voltage on the photocathode and the microchannel plates. No scientifically useful data are produced in this mode.

Finally, engineering modes exist to monitor on-orbit performance and aid instrument testing and integration.

5.3. Instrument Performance

The top-level UVOT observational capabilities are to provide information on the short-term UV/optical behavior of GRBs, a finding chart for ground-based observers, and GRB follow-up observations. The UVOT must also be able to protect itself autonomously from bright sources that could damage the detectors.

The 100 second parameterized finding chart is used to construct an image on the ground and provide a ~0.3 arcsec position for the burst relative to the field stars close to the GRB. Redshifts can be obtained for brighter GRBs with grism spectra. For fainter GRBs, light curves and positions will be obtained by cycling through the 6 broadband filters. Event mode data will allow monitoring of source variability. Centroided positions of 0.3 arcsec will be found, allowing the UVOT to accurately position the burst relative to any host galaxy it may be associated with. The UVOT will have a 5σ sensitivity to a limiting magnitude of B = 24.0 in 1000 s.

The UVOT provides for its own detector safety to a greater extent than OM, as it must autonomously and quickly respond to new burst detections. If the detector is in danger of being overexposed, the instrument control unit (ICU) will drop the voltage. A catalog of bright sources will be included in the ICU, and will be consulted to protect the UVOT from bright sources whenever a slew is triggered.

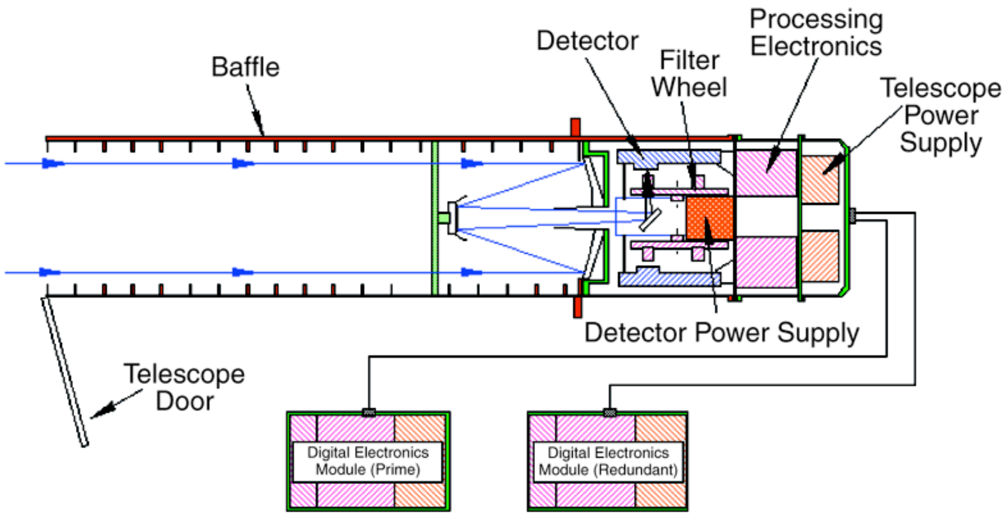

Fig. 5.1 — Diagram of Swift's Ultra-Violet/Optical Telescope.

UVOT Parameter	Value
Wavelength Range	170-600 nm
Telescope	Modified Ritchey-Chrétien
Aperture	30 cm diameter
F-number	12.7
Detector	Intensified CCD
Detector Operation	Photon counting
Field of View	17 × 17 arcmin
Detection Elements	2048 × 2048 pixels
Telescope PSF	0.9 arcsec FWHM @ 350 nm
Colors	6
Sensitivity	B = 24 in white light in 1000 s
Pixel Scale	0.5 arcsec

Table 5.1 UltraViolet/Optical Telescope characteristics

6.0 The Swift Ground System

The Ground Network for Swift (GNEST) is being developed to provide mission and science operations support to the Swift mission. The GNEST is scheduled to be operationally ready no later than 60 days before launch.

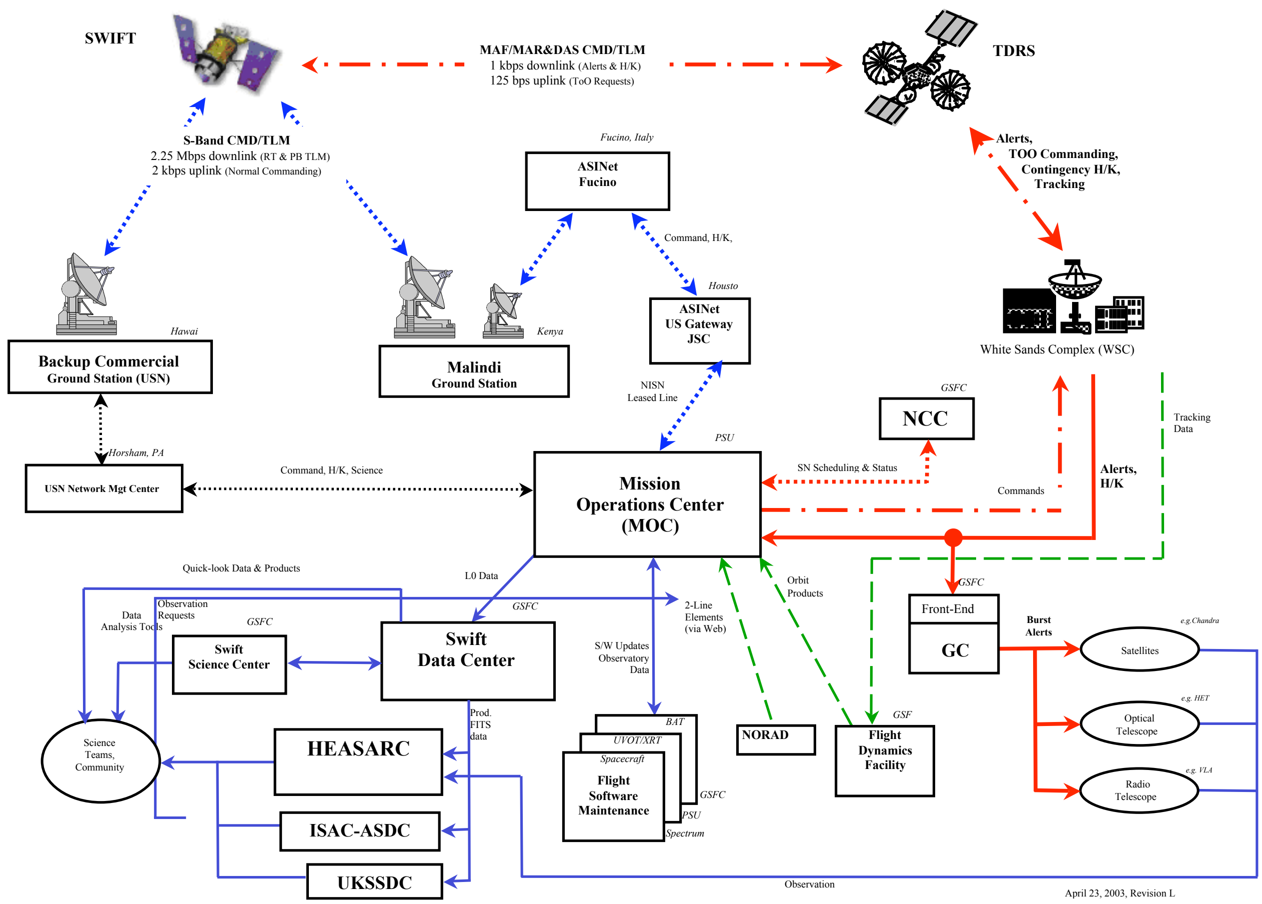

Fig. 6.1 Swift Ground System Architecture

Interfaces between the major elements of the GNEST are controlled by interface agreement documents or other documents. These documents are listed in Section 1.5. The sections that follow provide a brief description of the major ground system elements.

6.1 Malindi Ground Station

The Malindi Ground Station (MGS) in Kenya, Africa, provides the primary space-to-ground RF communications link with the Swift spacecraft. It supports simultaneous S-band return link at 2.25 Mbps and S-band forward link command functions at 2 kbps. The ground station uplinks spacecraft commands received from the MOC, receives spacecraft real-time housekeeping data and forwards to the MOC in real-time, and receives and records high rate spacecraft dump data, and forwards the dump data to the MOC after each contact.

The Italian Space Agency (ASI) provides the MGS. The MGS is operational and was used to support the BeppoSAX mission.

6.2 Space Network (SN)

The Space Network (SN) is an existing NASA institutional space communications system that consists of a collection of Tracking and Data Relay Satellites (TDRS's), the White Sands Complex (WSC) in New Mexico, and the Network Control Center (NCC).

Swift will be supported by both the first generation (pre-TDRS-H) and second generation (TDRS-H, I & J) sets of TDRS satellites. They will provide two telemetry and command Multiple Access (MA) services for the Swift mission, namely the Demand Access Service (DAS) and the scheduled legacy MA service. The DAS provides near continuous MA S-band downlink coverage for low rate housekeeping telemetry and Gamma Ray Burst (GRB) alerts. This provides the ability for the spacecraft to initiate downlink communication with the ground system when needed, such as when a GRB or an on-board anomaly is detected. The ground system may also utilize the standard MA services, which are scheduled as needed. This allows support for commanding over S-band at 125 bps for contingency, L&EO, and Target of Opportunity (ToO) support. It also provides for orbit tracking support, which provides the tracking data needed by the ground system to perform definitive orbit determination.

The WSC in White Sands, New Mexico is the facility that uplinks and downlinks commands and data to / from the TDRS satellites and interfaces with the Mission Operations Center (MOC) and GRB Coordinates Network (GCN).

The Network Control Center (NCC) located at NASA/GSFC is responsible for scheduling the use of TDRS services through the Satellite Web-based Scheduling Interface (SWSI). The MOC will use the Web-based SWSI interface to schedule use of the legacy MA services. The NCC will automatically schedule use of the TDRS satellites for support of the DAS, and provide the TDRS allocation scheduled to the MOC via the SWSI.

6.3 Mission Operations Center (MOC)

The Mission Operations Center (MOC), located at PSU in State College, PA, will operate the Swift satellite and instruments. It supports pre-launch, launch, early orbit activation, normal and contingency operations. The MOC performs all spacecraft and instrument mission planning, commanding, monitoring, and Level 0 data processing. The processed data is made available to the Swift Data Center (SDC). The MOC provides rapid response for the follow-up of new GRBs detected by the FoM software on-board and Targets of Opportunity (ToO) inputs from the science team or science community.

PSU is responsible for implementing the MOC, and is using Omitron Corporation as its prime contractor. The MOC design is based on the Integrated Test and Operations System

(ITOS), a Goddard-provided command and control system that is also being used in all phases of instrument and spacecraft testing.

6.4 GRB Coordinates Network (GCN)

The GCN rapidly distributes information about GRBs to interested members of the science community. For Swift, a GCN front-end will receive the Burst Alert Messages from the TDRSS DAS, perform the necessary processing and filtering, and pass appropriate messages on to the GCN. The rapid dissemination of Swift alerts and finder fields will enable ground observatories and operators of other spacecraft to plan correlative observations.

The GCN is an existing system at GSFC with sufficient capacity to support Swift. The Laboratory for High Energy Astrophysics operates the GCN and is implementing the Swift GCN front-end.

6.5 Swift Data Center (SDC)

The SDC, located at NASA/GSFC, converts Swift Level 0 data products received from the MOC into Flexible Image Transport System (FITS) files and standard data products using a processing pipeline. As part of this process, the SDC checks the format of the telemetry and checks for missing data. The format of the FITS files is consistent with Office of Guest Investigator Programs (OGIP) standards. The SDC pipeline generates level 1, 2, and 3 data products. The data sets are organized by observation to facilitate later scientific analysis. Quick-look data products are made on a shorter time scale using less complete telemetry and the same processing pipeline.

The Space Science Data Operations Office, Code 630, at GSFC is implementing the SDC. Additional development support is provided from the Information Systems Center (Code 580) at GSFC.

6.6 Swift Science Center (SSC)

The SSC assists the science community in the scientific analysis of Swift data. The SSC coordinates the development of the software tools needed to perform scientific analysis of the Swift data. Many of these tools are also used in the pipeline processing in the SDC. The instrument teams and the ASDC support this effort. After launch, the SSC coordinates updates to the analysis tools as the understanding of the techniques utilized improves with experience. In addition, the SSC maintains documentation of the Swift data and analysis techniques for the use of the science community. The SSC also produces documentation in support of the Swift GI program and provides technical support for reviewing GI proposals.

The SSC is part of the Office of Guest Investigator Programs (OGIP), which also contains the High Energy Astrophysics Science Archive Research Center (HEASARC) and similar support centers for other high-energy astrophysics missions. The Information Systems Center is supporting the software effort in the SSC.

6.7 HEASARC

The High Energy Astrophysics Science Archive Research Center, located at NASA/GSFC, is the archive for Swift data products, calibration data, software, and documentation. The SDC provides the HEASARC with the FITS file data products for archiving. The HEASARC will archive Swift data for the life of the mission and many years beyond in support of astronomical research by the science community. The HEASARC is responsible for a number of aspects of management of the Swift data, including: populating and maintaining the Swift science and calibration data archives, giving public access to the Swift data, serving as the active and long-term archive for software and data after the end of the mission operation, providing and maintaining the software infrastructure used in the development of the Swift software and for data distribution between the archives and the SDC, providing multi-mission analysis tools, distributing the Swift software, providing a Web server facility for the SDC, providing a database system for the Swift tables, providing scientific expertise to help the community use the Swift archive, and generating the GRB summary products.

6.8 International Data Centers

The United Kingdom Swift Science Data Center (UKSSDC) at the University of Leicester and Italian Swift Archive Center (ISAC) at the OAB and the ASI Science Data Center (ASDC) in Frascati archive the FITS files and standard products. These products are made available by the SDC. The two data centers provide ready access to the data and expertise in the analysis for local users. The United Kingdom and Italy are responsible for implementing the two international data centers. As part of the GNEST ground system, they will be included in the test activities described in Section 4. The ISAC is also providing the science analysis software for the XRT.

6.9 Flight Dynamics Facility (FDF)

The Flight Dynamics Facility (FDF), located at NASA/GSFC, provides orbit determination support to the MOC for the first one to two weeks of the mission. The data is derived from TDRS tracking data and provided as two-line elements to the Penn State University (PSU) MOC. Following the two-week period, the FDF will provide the PSU MOC with NORAD provided two-line element orbit data via an existing institutional Web interface.

FDF support will be provided from the existing Multi-Mission Flight Dynamics (MMFD) facility at GSFC. The FDF will not require any significant modifications to support the Swift mission.

6.10 Ground Communications Network

The Swift ground communications network is a collection of different open and closed networks that provide data transport among the elements of the ground system. The MOC interfaces with the SN WSC via a NISN-provided dedicated link to NASA/GSFC, which will provide access to the existing institutional IONET closed network. This network provides the MOC with access to the FDF. The interface between the Malindi Ground Station and the MOC uses a combination of ASINET connections and a dedicated line. ASINET provides the link between Malindi and the ASINET node at NASA/JSC. A NISN-provided dedicated line connects the MOC to the ASINET node at JSC. All other data communications among the Swift ground system elements will use the Internet.

6.11 Other Related Entities

In this section we briefly describe other entities that are important parts of the Swift mission, but are not part of the Swift ground system.

6.11.1 Project Office

GSFC is responsible for the management of the Swift mission. The Project Office is part of the Explorers Program (Code 410) of the Flight Programs and Projects Directorate (Code 400). Its responsibilities include managing the schedule and resources and verifying that all requirements have been met.

6.11.2 Instrument Teams

Each instrument team is responsible for designing, building, testing, and delivering one of the three Swift instruments. Each team is also responsible for providing documentation of the telemetry produced by their instrument. In addition, each team is responsible for calibrating their instrument, maintaining the calibration throughout the mission, and delivering calibration files to the HEASARC through the SSC.

6.11.3 Follow-up Team

The follow-up team is responsible for augmenting the science return from the Swift mission by observing bursts and their afterglows with other instruments. Results from these observations will be used to help plan additional Swift observations. The Swift Science Team is responsible for organizing the activities of the follow-up team.

6.11.4 Burst Advocates

The Burst Advocates are responsible for rapidly analyzing the initial Swift data for each burst, collecting available results from other instruments, and advising the Science Operations Team about plans for future observations of the burst afterglow. The Burst Advocates are members of the Swift Science Team.

7.0 Mission Operations

This chapter explains how the Swift mission is operated, the observation program is conducted, and the data are processed. Many important issues for individual processes outlined in this chapter are explained in greater detail in later chapters.

7.1 Observation Program

7.1.1 Definition of the Mission Phases

The Launch and Early Orbit (LEO) phase consists of the first 45 days of the mission. During the first 30 days the spacecraft will be activated and its performance verified. During this time, the instruments will begin their activation and verify their interfaces with the spacecraft. At the end of 30 days, the spacecraft will be officially delivered to NASA. The instruments will complete their activation and verification at the end of LEO.

The next 3 months of the mission constitutes the verification phase. During the first part of this period, the instruments will complete their activation. Calibration of the instruments will follow their activation. This period will also be used to adjust the many parameters of the BAT triggering algorithm for GRBs to improve the sensitivity. The strategy for observing GRB afterglows will be refined. Burst alert messages, which are sent to the ground using TDRSS, will be distributed to the community using GCN once the Swift team is confident of the information in the messages. No other Swift data will be released to the community during the verification phase.

The normal operations phase begins after the verification phase and lasts until two years after the launch of Swift. All data collected by the observatory in this phase will be made available to the community immediately after they are processed. The data from the verification phase will be re-processed and made available to the community. It is expected that the BAT triggering algorithm will be relatively stable although some adjustments may be made as experience is gained.

The prime mission ends 24 months after launch, and the extended mission is expected to begin. Operations are expected to be similar to those during the prime mission, but observing strategies may change and the priority of the science goals may be modified.

7.2 Types of Observations

The Swift mission is unusual because most of its observations will be of sources whose positions, identifications, and characteristics are unknown at the start of the mission. Many of the observations will be initiated autonomously by the spacecraft to study newly discovered GRBs and their afterglows. The science team will schedule additional observations of these targets during the days and weeks that follow.

An 11-digit sequence number is assigned to each observation. Pre-determined ranges of numbers are reserved for different types of targets. The plan for assigning observation numbers is described in the “Swift Observation Definition” document and is summarized in Section 2.5.

7.2.1 Activation Observations

The first part of the mission life will be devoted to the activation and performance verification of the observatory by the Swift team. Although celestial targets may be observed, meaningful scientific results may not be obtained.

7.2.2 BAT Survey Observations

A survey of the hard X-ray sky is a major goal of the mission. The survey also provides the opportunity to discover hard X-ray transients. Observations will be carried out to improve the uniformity of the survey and to improve the speed with which new transients are discovered. Specifically, it is anticipated that targets will be chosen so that each day BAT surveys a great circle of the sky.

7.2.3 GI Observations

As described in Section 12, guest investigators (GIs) may submit proposals to NASA in response to NASA Research Announcements (NRA's) for funding to carry out scientific investigations aimed at enhancing the scientific return from Swift. Proposers are not permitted to specify observations in the first round of proposals. Proposals specifying observations may be permitted in later rounds.

7.2.4 Calibration Observations

The Swift team will regularly carry out calibration observations to determine the performance of the instruments throughout the mission. Calibration observations will be emphasized during the verification phase of the mission.

7.2.5 Target of Opportunity Observations

Target of Opportunity (ToO) observations may be carried out to respond to rare observational opportunities with high scientific merit. Opportunities for which Swift is uniquely qualified are mostly likely to be done. Anyone is allowed to suggest ToO observations. At present data from ToO observations are treated the same as any other observation, and the person suggesting the ToO has no proprietary data rights.

7.3 Proprietary Data Rights

There are no proprietary rights to any of the data from the Swift observatory. After the verification phase of the mission, all data will be released to the community as soon as it has been processed. Data from the verification phase will be released as soon as it has been re-processed.

7.4 Satellite Operations

7.4.1 Scheduling the Observations

The staff at the MOC will be responsible for scheduling observations and operating the satellite. In general, observations for the next week will be planned a few days to a week in advance, but the plan will be revised as new GRBs are discovered or sufficiently interesting ToOs become available. The observing plan will be made available to the community on the MOC Web site.

The science planning software package named ``TAKO'' (for Timeline Assembler, Keyword Oriented) will be used. It was originally developed by GSFC to be used for Astro E, and Omitron has modified it for use with Swift.

7.4.2 Operating the Satellite

Staff at MOC will be responsible for the operation of the observatory. The staff consists of the Flight Operations Team (FOT) and the Science Operations Team (SOT). The FOT is responsible for sending commands to the spacecraft, monitoring the health and safety of the observatory, responding to anomalies, managing the spacecraft data recorder, and scheduling contacts with ground stations. The SOT is responsible for planning observations, monitoring the science return, and evaluating requests for ToOs. Burst Advocates from the Swift science team will assist the SOT. A burst advocate will be assigned to each GRB, will coordinate the scientific analysis for the burst, and provide a point-of-contact for the SOT regarding the burst.

7.5 Data Flow

7.5.1 Data Retrieval and Raw Data Archives

The bulk of the telemetry will be acquired using the STDN ground station at Malindi or part of the USN. The relatively small amount of telemetry acquired using TDRSS consists mostly of GRB alerts and low-rate housekeeping data. Real time housekeeping data are obtained by the MOC during contacts with the spacecraft. Most of the data will be obtained by the MOC after the contact using ftp. The MOC is responsible for scheduling STDN contacts and managing the spacecraft data recorder so that the telemetry produced by Swift is captured on the ground and delivered to the Swift Data Center for processing.

7.5.2 Data Processing

Swift *data processing* means conversion from the raw telemetry data to the high-level calibrated data that are delivered to the Swift archive centers. Details of the data processing are explained in Chapter 10, and only an outline is given here.

The MOC gathers the telemetry from each STDN contact, converts the telemetry frames into files of telemetry packets, and delivers the packet files to the SDC. The packet files are converted into FITS files by the SDC and organized by observation. The FITS files are then processed into higher level products. The resulting quick-look FITS files are made available to the community at the SDC web site. The files for a particular observation are updated as additional packets become available. After all the data from an observation are available, the final versions of the FITS files will be delivered to the three archive centers and removed from the quick-look web site. The final version will be produced about a week after the observation is finished.

While it will be possible to run the processing pipeline at the SDC, the UKSSDC, or the ISDC, it is nominally expected that the processing will be done at the SDC.

7.5.3 Data Access by the Community

Swift data are available to the community either as quick-look data at the SDC or in final form at any of the three Swift archive centers. All the data will be in FITS files. The usual tools for searching for and retrieving data will be available for accessing data at the data centers. During the verification phase, the data will be encrypted to restrict data access.

7.5.4 Swift Archives

Swift data will be delivered to and archived at the three Swift data archive facilities -- the HEASARC, the UKSSDC, and the ISDC. Details of the Swift archives are provided in Chapter 13.

8.0 Software Principles

In this chapter, we present the Swift software principles and agreements, with which all of the software developers must comply throughout the Swift project. A top-level description of the FITS files on which the Swift software operates is included.

8.1 General Software Design Principles

The Swift data analysis system shares the same design principles as all of the projects conducted under OGIP. These design principles may be summarized as follows:

- *Standard and portable data format* --- FITS 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 the HEASARC FITS Working Group to check for consistencies with other missions. Use of ASCII format is allowed for small files.
- *Designed for multi-mission analysis* --- Existing, fully tested software infrastructures will be made use of as much as possible. For example, users will be able to analyze all Swift data with standard high-level X-ray data analysis packages such as XSPEC, XIMAGE, XRONOS, etc. Data files and products will be constructed with the appropriate keywords so that they may be analyzed across a broad array of packages such as IRAF (in particular for UVOT analysis), DS9, etc. General FITS utility programs (e.g., fv, FTOOLS/futils, HEAdas/heatools) will be compatible with all Swift FITS-formatted data files. All Swift analysis tools are written as FTOOLs in the HEAsoft environment.
- *Easy to install and use* --- The software will be easy to install and use, and extensive help, support and documentation will be provided. Swift-specific software for low-level tasks is distributed in the standard FTOOLs package, providing a user-friendly interface on most standard platforms (Section 8.3.3).
- *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 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 Swift software freely on their responsibility. Modified versions should not, however, be distributed to others without the consent of the SSC.

8.2 Swift Specific Design Principles

In addition to the general design principles above, the Swift software/data processing system will also adhere to the following design principles:

- **The raw telemetry will be converted to FITS format before distribution.** There is only one set of software (e.g., *UVOT2FITS, HK2FITS*) to access and interpret the raw telemetry data and to convert them to the FITS format (Level 1 FITS Files; Section 10.4). These and other processing software (written and maintained by the SDC) will be fully tested and ready before the launch of the satellite.
- **The calibration and data processing will start from the Level 1 FITS Files.** To that end, the Level 1 FITS Files should reflect the original structure of the raw telemetry as much as possible.

- **The scientific analysis will start from the standard calibrated (Level 2) FITS files.** The Level 1 FITS Files are further processed by the standard software with instrumental calibration information, and the *Calibrated (Level 2) FITS Files* (Section 10.5) are produced. Scientific outputs will always be produced from the Level 2 FITS Files.
- **Important calibration tools/software will be made promptly available to the community.** At any given time, there shall be always a single version of the official instrument calibration files and software controlled by the SSC and instrument teams and distributed by the HEASARC.
- **Swift software will be written by the Swift software and hardware teams at GSFC and ISAC.** The BAT instrument team, the ISAC, and the SSC will write analysis software for the BAT, XRT, and UVOT, respectively. The SDC will write the software to convert the telemetry data to FITS files.
- **Software intended for public release will be delivered to the SSC before the release.** The SSC will ensure that the software follow the rules presented in this chapter, and will package them in a form that is suitable for general release. The SSC will be responsible for releasing and maintaining the packages. Software distribution and any necessary integration into the larger FTOOLs package will be handled by the HEASARC. When software is required to be modified or fixed, the SSC will be responsible for coordinating the fix and the re-release, contacting the original authors as needed. When significant changes are necessary, the SSC will always consult the original authors in advance.
- **Tasks required for pipeline processing should run in scripts.** In the automated pipeline processing system (Chapter 10), a series of data processing tasks are run as background jobs by scripts. Therefore, all of the processing tasks including those that make use of a GUI are required to run in scripts.

8.3 Swift Software Standards

8.3.1 Languages

Swift data analysis software will be written in ANSI C. The use of Fortran77 is allowed, but discouraged.

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

8.3.2 Coding Rules and Compiler Requirements

Portable coding practices shall be adhered to, including the isolation of system dependencies. The ANSI C standards shall be adhered for C-programming. The OGIP provides the Fortran standards (Mukai 1993), which is available at http://heasarc.gsfc.nasa.gov/docs/heasarc/caldb/docs/caldocs_summary/node16.html. This is ANSI Fortran77 with some extensions.

The system-independent test for C shall be that the code can be compiled by gcc on the several supported architectures, and by g77 for Fortran. The cfortran package must be used to combine C and Fortran routines when necessary.

To write and read FITS files, CFITSIO should be used. The obsolete fitsio C-wrappers, which were developed to call Fortran fitsio routines from C-codes, should not be used.

8.3.3 Systems Supported

All the Swift software intended for distribution shall run on the most popular systems of Swift users including Sun/Solaris, DEC/Alpha, and Intel/Linux. While there is no requirement for the Swift package to operate on Mac OS X, it is a reasonable goal, and each new science software build is tested (and has been shown to run) on OS X. However, should platform problems be encountered, OS X is a lower priority that Linux and Solaris.

8.3.4 Documentation

All of the software intended for distribution will be fully documented in English.

8.3.5 FITS files top-level description

Swift observers will need quick, straightforward access to data from the three onboard instruments. Accordingly, much effort is being put into standardizing the file names, file formats, and file structures for BAT, XRT and UVOT. While each instrument produces images, spectra and event files, they utilize three fundamentally different detectors with widely varying operating modes, and finalization of the FITS files is ongoing.

Beyond this, the FITS file format of Swift-related files will be fully explained in a set of separate documents maintained by the SSC (for UVOT) and by the instrument teams for their respective instruments. The SDC will also generate documentation of the conversion of Swift telemetry to FITS once the codes have stabilized. Once the FITS files have frozen for all Swift data, the SSC will take responsibility for maintaining a unified FITS format document, incorporating any necessary updates from the instrument teams and software developers. The SSC will host these documents on their Web pages, once they are finalized and ready for public dissemination.

8.4 Swift FTOOLS Global Development Scheme

To accommodate rigorous version control and prompt releases, particularly during the early stages of the mission, the following scheme will be practiced during the Swift data analysis software development, version control, and release cycle.

- At GSFC, the core HEASARC FTOOLs programming staff jointly maintain several interlocking CVS (Concurrent Version System) repositories, including those comprising the HEAdas/Swift software. Developers from the instrument teams and from the SSC are granted write permission only to the appropriate sections of the repositories. *Only the code in the GSFC repository should be considered the genuine copy of the latest official Swift data analysis software*
- The entire FTOOLs directory tree, including the Swift package, is built regularly (typically weekly) from the CVS repository and installed internally at the GSFC/LHEA. This “develop” version of the software is available for testing at GSFC by the SSC. Any problems in building or running the software will be reported to the responsible developer and a fix may be checked into the repository by the SSC, the FTOOLs team, or by the tool developer as appropriate.
- Any necessary version numbering (which is essentially transparent to users) will be handled by the SSC and/or the core FTOOLs team at GSFC prior to release.

- Public software releases will occur as called for in the official SSC schedule and/or as post-launch requirements necessitate. All public releases will be preceded by a complete integration and test cycle performed by the SSC, during which all relevant unit tests will be run on all supported platforms. The instrument teams and/or the tool developers must also approve releases.
- The SDC will obtain each new release of the Swift software, which then becomes the base of the pipeline processing. The processing team will carefully control any updates to the software used in the pipeline. Rapid fixes to problems, which are often necessary to accomplish the demanding data processing tasks in a timely manner, will be accomplished using patches delivered to CVS by the maintainer of the relevant software. The patch will then be made publicly available by the HEASARC. The SDC will not use versions of any FTOOL (Swift or general) that is not available to an end user.

9.0 Swift General Software Tasks

We expect some software functions to be used repeatedly in various stages of the Swift mission, from satellite operation through scientific data analysis. These involve the general tasks of translating spacecraft time into various standard time systems, converting raw instrument coordinates into detector and sky coordinates, and making use of some basic satellite housekeeping parameters. In order to avoid unnecessary duplication, these functions are being written as Swift general tools.

9.1 Swift General Tools

The following table shows which tools in the Swift software package are intended for general purposes.

Tool	*Purpose*
Utcf_cor	Apply clock corrections to s/c time
Coordinator	Convert raw event positions to detector and sky coordinates
Imagexform	Convert raw image positions to detector and sky coordinates
Prefilter	Derive s/c environment quantities from position and attitude data
Exp_map	Create exposure maps for images based on window information and attitude knowledge

Table 9.1 Swift General Tools

9.1.1 Time Conversion

All time columns in Swift FITS files will contain times in spacecraft clock seconds, in mission elapsed time (MET), measured as seconds elapsed since Swift Day 0 (January 1, 2001 at 00:00:00 UTC; MJDREF=51910.0). The Swift spacecraft clock is calibrated with respect to Universal Time (UTC) by specifying a Universal Time Correction factor (UTCf) which must be added to the Mission Elapsed Time (MET) in order to recover UTC. The Spacecraft can be commanded to update the UTCf value at regular intervals, and its value can also be commanded directly.

Tools will be provided so that users can convert MET to other time systems including UTC, TT, and TDB.

9.1.2 Coordinate Conversion

Science data from the three Swift instruments are telemetered with positions given in raw coordinates (rawx, rawy). These positions must ultimately be converted to sky coordinates (RA, Dec) for scientific analysis. There is an intermediate transformation between raw and detector coordinates (detx, dety) which removes detector distortion. The Swift project has adopted the mission-independent **coordinator** tools to perform all necessary coordinate transformations between raw, det and sky coordinates. The **coordinator** tool operates on event files. The tool **imagexform** is a modification of coordinator that operates on image files. Both coordinate conversion routines rely on the information provided in an accompanying "teldef" file. The teldef file contains the form of the detector distortion map, as well as the parameters that allow for the correct alignment of the detector with the spacecraft axes.

9.2 Obtaining Detailed Information from Attitude and Orbit Housekeeping Data

Knowledge of spacecraft attitude and orbit related quantities are important in various stages of the Swift mission such as command planning, assigning sky coordinates to events and images, creating the filter files used to screen data, calculate exposure maps for images, and carry out barycentric time corrections. Such tasks may require either or both of the attitude and orbit file.

9.2.1 Attitude Information

Attitude information from the Swift satellite's Attitude Control System (ACS) is included in the telemetry as ACS packets and is placed at several locations in the science telemetry. The BAT instrument telemeters the ACS messages containing the spacecraft attitude at various time resolutions. Immediately after a burst, during the slew, ACS messages appear at the rate of 1 Hz. This changes to 5 Hz during settling and eventually to 0.2 Hz, which is the nominal ACS message rate during normal operations (burst and survey mode). During a GRB, ACS data arrives as one or more LDPs, sampled at 5 Hz, and overlapping the pre-, during-, and post-burst time intervals.

The ACS information is extracted by the SDC, and is used to produce a Swift-wide single attitude file for any burst or survey observation. This is used for the time filtering of science data, and for the determination of the nominal pointing direction of the spacecraft during an observation.

This file contains the time of an ACS report and the attitude expressed both as a quaternion and as RA, Dec and Roll. The latitude, longitude and altitude are also included, as well as flags recording the source of the data (ACS packets or LDPs), the s/c bus voltage and other information (within 10 arcmin, settling, SAA).

9.2.2 Orbit Information

The SDC receives from the MOC the North American Aerospace Defense Command Two Line Element (NORAD TLE) data files, which contain orbit information for the Swift satellite, and converts these to FITS files. The orbit parameters are designed to be propagated using the SGP4 model described in http://celestrak.com/NORAD/documentation/spacetrk.pdf. The propagation is done in the SDC using the tool prefilter. The orbit data is used to produce time resolved FITS files for each observation, which can be used for the time filtering of science data based on orbit location.

9.2.3 Combined Attitude and Orbit Information

The Swift processing pipeline captures and writes all instrument housekeeping parameters to a number of FITS Housekeeping (HK) files. The HK FITS includes numerous satellite and instrument HK parameters, in several separate files. However, only a small fraction of these HK parameters are required for screening the raw data into meaningful scientific data. In addition, certain important quantities needed for selecting good events, such as the time since the most recent passage of the spacecraft through the South Atlantic Anomaly (SAA) or the value of the magnetic cut-off rigidity (COR) must be derived from knowledge about the position and attitude of the spacecraft. In order to facilitate the easy access of such spacecraft quantities, the Swift SC has provided the tool **prefilter**. The tool makes use of the existing atFunctions attitude library where possible. The inputs to **prefilter** are the NORAD two-line elements (TLE) for satellite position and the attitude files for pointing information. The TLE nearest in time to the output start time will be used in the SGP4 model to find the position and velocity at the desired time stamp.

9.3 Correcting attitude information using the XRT TAM

In order to improve the accuracy of GRB positions the XRT employs a Telescope Alignment Monitor (TAM) designed to provide the means of measuring distortion and alignment errors within the XRT and between the XRT and star tracker to < 1 arc second. The primary role of the Optical Bench remains to provide co-alignment of the XRT with the UVOT (and BAT). The alignment time series from the TAM will be used in the pipeline when correcting positions on the XRT position to sky coordinates.

9.4 Creating Exposure Maps for Images

The BAT, XRT and UVOT will each keep track of bad and/or corrupted pixels on the detectors and store these as quality maps. During long image exposures, the pointing of the spacecraft can be expected to drift slightly, which leads to slightly different exposure times for various parts of the detectors (particularly the edges). In order to reliably convert an image in counts into one in counts per second, a map must be generated which effectively rescales all parts of the image to the same relative exposure.

10.0 Data Analysis and Processing Software

Swift telemetry (Level 0 data) is received from the MOC at the SDC. This triggers a run of the Swift processing pipeline—a detailed script of tasks that operate on the telemetry resulting in its faithful translation into FITS files (Level 1 data) using the SWIFT2FITS software, calibrated event lists and cleaned images (Level 2 files), and finally higher level science products such as light curves and spectra (Level 3 files) for all Swift instruments.

In this chapter, the Swift software tasks needed to produce scientifically useful data files from BAT, XRT and UVOT are defined and explained. Initial data products appear on the Swift Quick Look Data public Web site. When processing is complete, the products are delivered to the HEASARC. The process is shown in Figure 10.2.

10.1 Pipeline Processing System

The purpose of the pipeline processing system is to implement, in a nearly automated way, the tasks of the Science Data Center, as outlined in section 6.5, and described in more detail in sections 7.5.2, 7.5.3, and 10.3 through 10.6. This allows the data to be rapidly made available to the public.

A diagram of the high-level structure of the pipeline is illustrated in Figure 10.1. The pipeline infrastructure is implemented as a group of Unix shell and Perl scripts, which run as daemons, as CRON jobs, or are activated by the receipt of input into the system. Wherever possible, the identical code is used to perform common tasks on the three scientific instruments. While each data stream (BAT, XRT and UVOT) is processed independently, a common interface is used for file naming, FTOOL execution, FITS access and error handling.

10.1.1 Pipeline Features

The Processing pipeline script is designed to be nearly automated for 24/7 operation. It is composed of automated daemons, and benefits from the legacy from ASCA/Astro-E. Much of the code in use is mission independent.

10.1.2 Receiving data from the MOC

To transfer data to the SDC for processing, the MOC first copies a signal file to the SDC using ssh. This initiates a task in the SDC that copies data listed in the signal file using ssh. No confirmation is sent to the MOC from the SDC. Data are transferred over the public Internet at a rate of ~1 megabyte/second. One delivery will be received per Malindi pass (~7 per day). Incremental deliveries will occur so the SDC can start ingesting telemetry before pass dump is complete. Redundancy is built into the system – the MOC will signal once for each partial delivery and again when the delivery is complete. Since Swift performs autonomous mission planning onboard, the MOC also generates a timeline based on the ACS packets and delivers this to the SDC. Each new delivery of data from the MOC initiates a reprocessing of the entire observation in question. The MOC data delivery process is depicted in Figure 10.1.

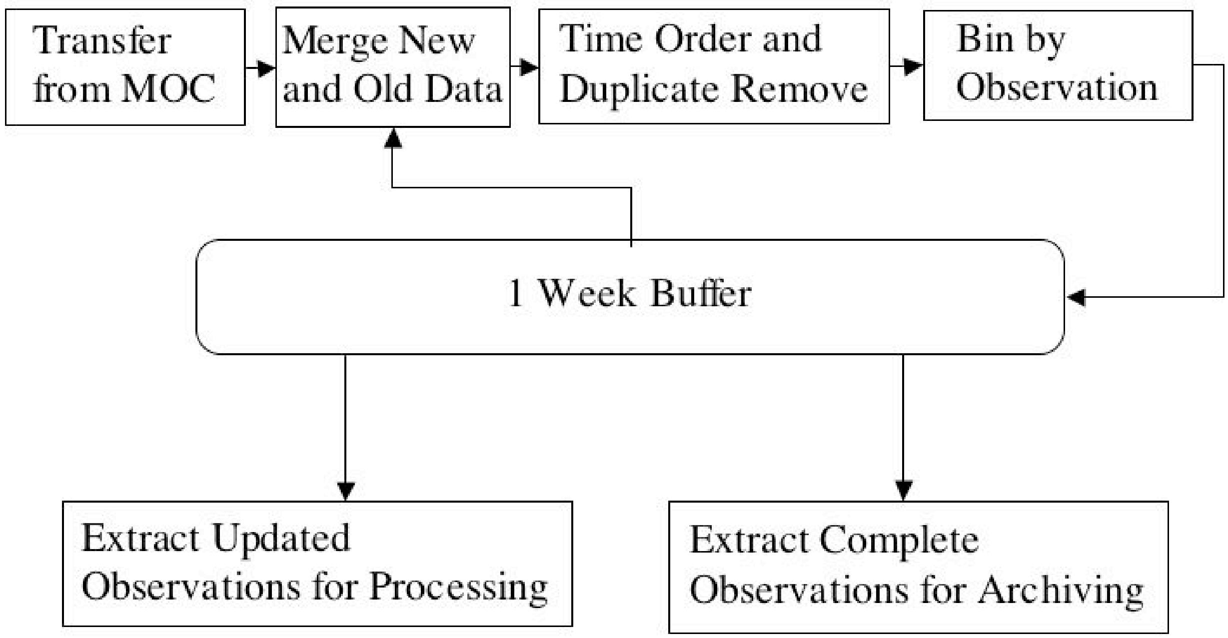

Fig. 10.1 Data transfer to the SDC from the MOC, including the merging of old and new data.

The processing pipeline takes observation-binned telemetry and ancillary data (calibration files and NORAD TLEs) as input, and outputs Level 1-3 FITS files. Other output includes log files in HTML of the inputs and outputs, processing details, as well as any errors encountered during the processing run. Finally, ASCII data base files are generated in the pipeline for delivery to the HEASARC.

10.1.3 Error Handling and Verification

All FITS files are verified at the end of the processing run. The processing script recognizes three levels of errors. Level 1 errors are simply logged and the processing script continues. Level 2 errors are more serious; they are logged, and the processing script continues but a human is informed of the event. For the most serious errors (Level 3), the error is logged, the processing script aborts and a human informed. This person must resolve the error before processing on the data set in question can continue.

10.1.4 Processing Approach

The processing script is where the actual science processing of the data takes place. The processing script fully completes the tasks in Levels 1, 2, and 3 processing described in the previous sections. Where a high-confidence GRB position is available to the pipeline, additional

Level 3 processing tasks are run in the processing script as well. The processing script is implemented as a suite of object-oriented Perl scripts.

10.1.5 Verification of Updates to the Processing Script

As the calibration and software are updated, the processing script will be revised, and earlier data will be reprocessed with the new system. Before running data through an updated processing script, the output of updated tools used in the pipeline will be compared to the previous pipeline output, on the same standard input data. The new products will be delivered by the SDC to the data centers to replace old products in the Swift archive. Version numbers, which will be included as keywords in the FITS products, will be used to distinguish between different revisions of the processing script.

10.1.6 Processing Hardware

The processing pipeline is designed to operate using a limited number of network visible machines. Processing takes place at GSFC on a hidden LAN. The actual processing work is distributed across multiple machines to improve reliability and increase timeliness so multiple observations can be processed simultaneously. Systems administration is provided by the LHEA.

Four dual processor processing machines and three archive servers are planned to serve the Swift pipeline and archive data, based on the current best estimates of data volume. Additional machines will be procured if the complete processing scripts and actual data volume after launch are found to tax the current system.

10.2 Swift Software Overview

All pipeline software operating on Level 1 FITS files to produce the Level 2 and Level 3 FITS data files and products will be FTOOLs, distributed to Swift users. The SDC can and will make modifications to the processing scripts to optimize the pipeline performance, though the algorithms of the analysis tasks themselves remain unchanged. This way, Swift users can reprocess/reanalyze data by themselves, and reproduce the pipeline processing results if using identical input and calibration information. Swift users can also quickly re-analyze their data when new calibration information is made available, instead of needing to wait for eventual reprocessing.

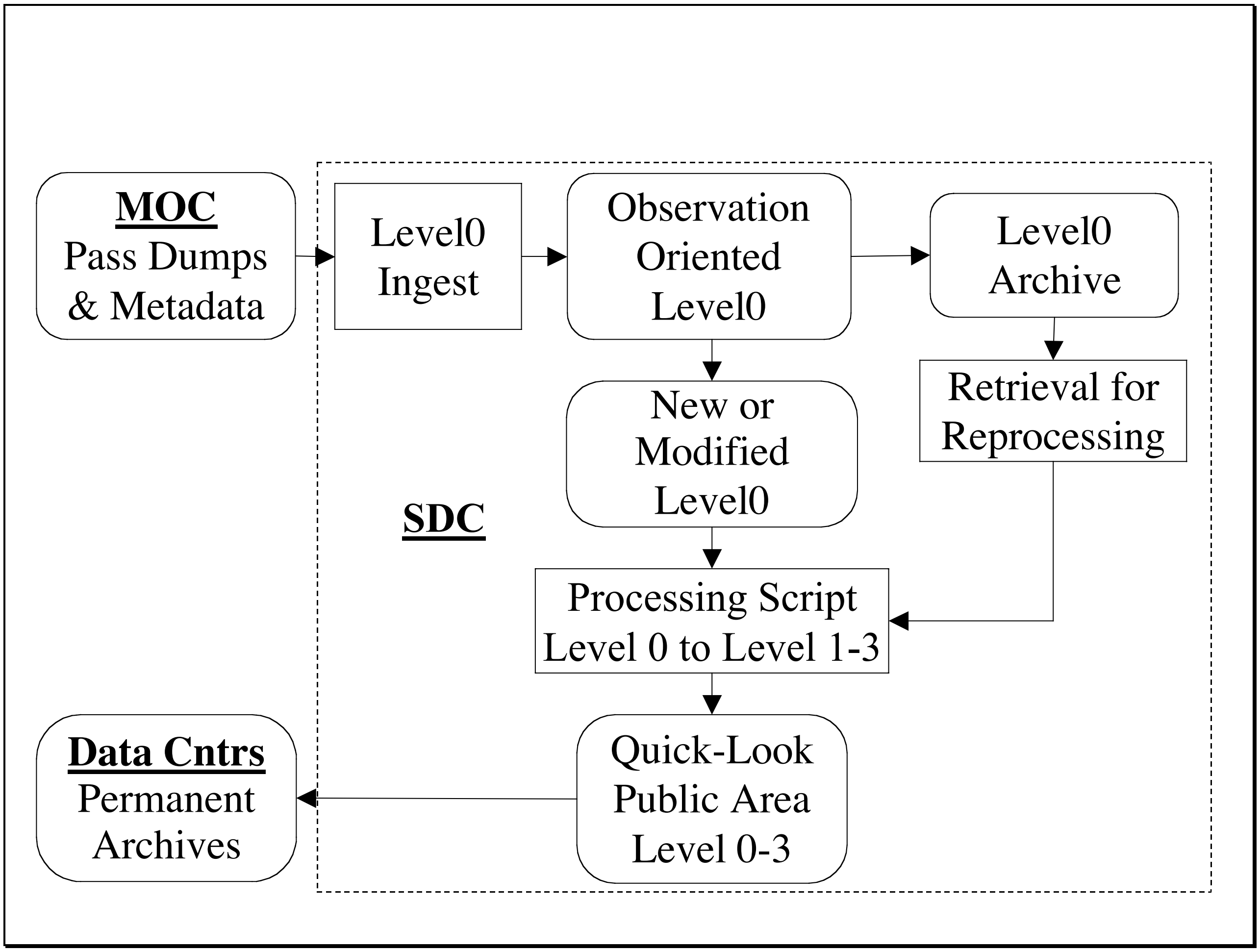

Fig. 10.2 Top-level diagram of the flow of Swift Data from the MOC to the SDC. Telemetry-to-FITS conversions and subsequent pipeline processing produce Level 1-3 FITS files for each instrument.

10.3 Satellite Specific Ancillary Data

As well as the raw telemetry, the SDC receives from the MOC ancillary data files which contain information used for orbit and attitude determination and timing. These steps are described in detail in Chapter 9.

10.4 Level 1 -- Telemetry to FITS Files Conversion

The SDC receives raw telemetry files from the MOC, and is responsible for providing the software (Swift2FITS) for converting these into Level 1 FITS files. Due to the nature of Swift operations, the telemetry that is received may not be time ordered and could contain duplications of data. Thus, before the telemetry is converted to FITS, it is sorted and duplicates are removed using the SDC pipeline front-end software. Three software programs, one for each of the instruments, are then used to convert the science telemetry to FITS files. Information on telemetry formats necessary for this software is provided to the SDC by the instrument teams. The HEASARC provides guidelines for the format of the FITS files and approves the Swift formats.

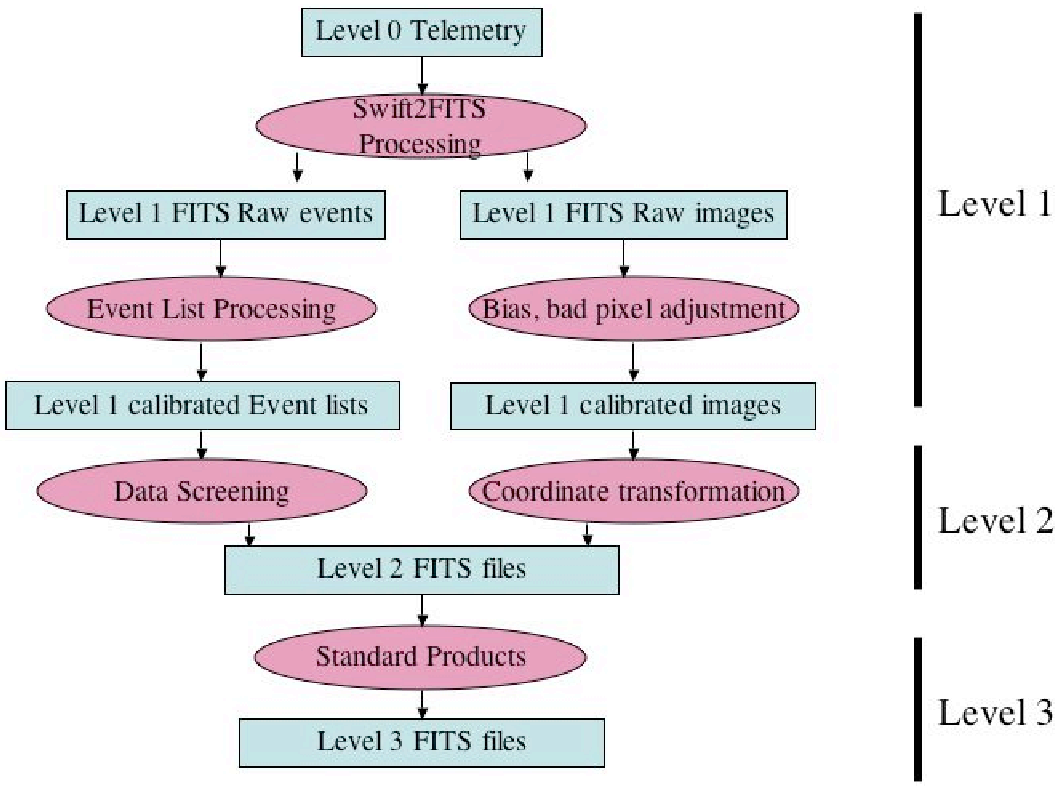

Fig. 10.3 Top-level flow diagram delineating the Swift processing Levels described here. Raw Swift telemetry is converted to Level 1 FITS files. Some processing is done to Level 1 files in place. Data screening and coordinate transformation result in Level 2 calibrated event lists and sky images. Standard products are run on Level 2 files to produce spectra, light curves and combined sky images.

10.4.1 Science data files

The results of the Telemetry to FITS conversion for event files are the raw *unscreened event files*. For images, the result is *uncalibrated images*. All Level 1 files include the necessary OGIP keywords, correct basic GTI extensions, and are split when there are changes in modes of the instruments. They are ready for extraction of the scientific data products, except that they still include data taken during periods of time when some undesirable events, such as particle background events, may have occurred.

Level 1 UVOT image files contain one image extension for every exposure performed by UVOT, even when an exposure is performed in event mode. In this case, an image is extracted from this in raw coordinates and deposited in the image file appropriate to the filter used. Level 1 UVOT event files contain one or more GTI extensions. Each GTI extension corresponds to either a change in science window or a new exposure. Level 1 UVOT event files also contain a window mode extension that describes the window mode associated with each GTI extension.

The XRT Level 1 FITS files consist primarily of raw images and calibrated event lists. Housekeeping data and other ancillary data products are also produced as needed. For each observation segment (see Section 2.5), there is a subdirectory that contains calibrated, unfiltered events lists (one event file for each data mode), another subdirectory that contains raw images (one file for each data mode), and another subdirectory that contains housekeeping data. The files contain multiple image extensions if needed.

The BAT Level 1 FITS files contain a one-second light curve for the entire BAT array and a 64-ms light curve for each of the 16 BAT blocks. Light curves with 1.6-second time resolution in four energy ranges are produced for each array quadrant. Light curves with 8-second time resolution in four energy bands record the maximum count rate in each of nine array regions, on 5 time scales. Mask-tagged light curves with 1.6 s time resolution are generated for each of three mask-tagged sources. Light curves of GRBs derived from event data and five-minute light curves derived from the survey data for each source detected by the BAT are also generated in the pipeline. These files are referred to collectively as the BAT raw rate files.

For survey mode, Detector Plane Histograms containing spectra in one or more energy bands for each detector in the BAT array are produced. The number of spectral channels for the survey is typically 80.

10.4.1.1 FITS File Names

The FITS science files are named accordingly with the following convention:

sw*{obs_id}I{submodes}*_*{lev}.ext*

where sw indicates Swift; *obs_id* is an 11 digit number that identifies the observation (see description in Section 2.5) ; *I* is a single character identifying the instrument (x=XRT, u=UVOT, b=BAT, t=TAM) or subsystem (s=spacecraft, f=FoM) ; *submodes* is a collection of two string characters identifying the data operating mode and other sub-parameters relevant to that mode and to how the data were collected; *lev* is a string indicating the stage of the processing (this is omitted if data are stored in the archive as they were telemetered); *ext* identifies the type of data in the file as an image or an event file.

While the XRT and UVOT always follow the above syntax, for the BAT there are exceptions mainly for the data taken in survey mode where the *submodes* string has a different syntax and includes numerical values to identify the gain and offset. As example the file names of the cleaned event (Level 2, *cl*) for the three instruments are:

- XRT sw00073434001xlrw1po_cl.evt

  where *lrw1po* indicates that the data are taken in low rate photodiode mode (*lr*) with the standard window (*w1*) and the spacecraft in pointing position (*po*).

- UVOT sw00073434001uvvpo_cl.evt

  where *vvb1po* indicates that the data are taken with the V filter (*vv*) and the spacecraft in pointing position (*po*)

- BAT sw00073434001bevshsp_cl.evt

  where *evshsp* indicates that the data are taken in event mode (*ev*) containing short events (*sh*) when the spacecraft is in slewing and pointing positions (*sp*).

10.4.2 HK Files

Almost all of the housekeeping (HK) telemetry is converted to FITS format using software separate from that used to convert the science telemetry. The format of the HK files is taken from the ITOS database used at the MOC for satellite operations. A code generation program reads the information in the database and generates the software used for converting the HK telemetry to FITS tables containing the appropriate columns.

10.5 Science Processing (Level 2 FITS files)

Each of the three Swift science software teams has developed a processing pipeline to generate Level 2 FITS files from the Level 1 FITS files. Each pipeline is composed of software tools that apply instrument-specific calibration information and filtering criteria to arrive at calibrated images and screened event lists.

In general, the individual Swift instruments will perform similar filtering on orbit, attitude and time quantities, so a single filter file is generated per observation. After this point, science data from each instrument proceeds through its own pipeline. Below, we discuss the generation of the filter file and the instrument pipelines separately.

10.5.1 Common Processing

10.5.1.1 Produce Spacecraft Attitude (ACS) files from BAT data

Selected ACS packets are included in the BAT telemetry as discussed elsewhere. The pipeline recognizes all ACS packets in BAT data and generates an ACS file for an observation. All tools requiring spacecraft attitude knowledge will access this attitude database in the pipeline.

10.5.1.2 Produce a Filter File

While the entire satellite and instrument HK information can be large, the HK information typically needed for science data processing will be limited. Therefore, the pipeline will extract only the HK items needed for later processing, and collect them in a separate *Filter file* to distribute to Swift users. The Filter file is made with the FTOOL **makefilter** operating on the output file from the Swift general task **prefilter** (see below). Examples of the items to be included in the Filter file are the following: temperatures of the detectors, particle monitor counting rates, attitude, stability of the pointing direction, and orbital information such as magnetic cut-off rigidity and times of the South Atlantic Anomaly passages. A single Filter file will be made from a single observation sequence. Total event rates of the instruments may also be needed to correct for dead time. Instrument specific items will be also included in the Filter file so that the three scientific instruments need access only one filter file to screen event lists.

10.5.1.3 Create Good Time Intervals using the Filter file

Good Time Intervals (GTI) suitable for scientific analysis are calculated based on the HK parameters in the Filter file, by excluding time intervals when, for example, instrumental background is high, or the operating temperature of the instrument is not appropriate, elevation from the Earth’s limb is too low, or satellite pointing direction is not stable. The generic **maketime** FTOOL is used for making GTI files. The GTI files are used to extract Screened event files or other scientific products such as images, spectra and light curves. All necessary information for such time filtering will be put into a single Filter file. Selection expressions specific to the each instrument will then be used to operate on this file and produce the instrument-specific GTI files needed for the pipeline processing.

10.5.2 UVOT pipeline

The UVOT instrument produces event and image data taken through any one of six broadband filters or two grism filters, as described in Section 5.2. During an observation, the size and location of the window can change, as can the on-chip binning. The UVOT pipeline will produce cleaned, calibrated event list files, calibrated image files and standard products for each observation, starting from the UVOT Level 1 FITS files.

The UVOT pipeline and the FITS files produced as a result are documented in the UVOT Data Handbook, which can be obtained in HTML and other formats at the SSC Web Site.

10.5.2.1 UVOT Level 2 Processing

Level 2 data files are calibrated files that have undergone a number of data reduction steps and standard screening procedures. The majority of science users can begin their data analysis using the Level 2 files. (It would be advantageous to begin at Level 1 if there have been some updates to the calibration files in the caldb since the last time the data were reprocessed or if the science would benefit from non-standard screening.)

The Level 2 files have undergone pipeline processing using FTOOL tasks operating on the Level 1 UVOT files. For images, the steps in this chain are

1) the flagging of bad pixels in the images due to defects in the detector itself or those introduced by the data compression algorithm;
2) a modulo-8 correction which redistributes counts to remove the detector-induced fixed-pattern noise;
3) dividing through by a flat-field image to remove pixel-to-pixel and large-scale variations, and
4) translation of the raw x and y coordinates first to detector coordinates (which take the distortion of the detector into account) and finally to sky coordinates.

Exposure maps are also generated at this step, and mirror the Level 2 image file structure. The exposure map tool uses the quality map and the drift data from the attitude history file to calculate an image of exposure factors used to translate images in counts to counts per second.

The Level 2 event files undergo pipeline processing using FTOOLS tasks operating on the Level 1 UVOT files. For events, the steps in this chain are

1) correcting raw coordinates for distortion, boresight offset and spacecraft drift, and then converting to sky coordinates,
2) applying a screening based on time-tagged data contained in the Level 1 HK files. This step determines time intervals of bad data, removes the appropriate rows from the event table, and writes extra START and STOP times to the appropriate GTI extensions.

Step 2 also inserts extra keywords to the Level 2 event files, so that UVOT event files also comply with Chandra and XMM-Newton analysis package standards.

10.5.2.2 UVOT Level 3 Processing

To provide the archive user with some reference data products, the pipeline performs a number of higher-level data reduction steps. The result is a set of Level 3 data files that include average images, light curves and grism spectra of candidate targets. These files are the result of non-interactive pipeline processing using standard algorithms and hard-coded parameters.

Consequently, they should not be accepted as science-grade results. Level 3 files are not substitutes for the scientist's fully interactive data analysis. The number and type of Level 3 products generated will depend on whether a detection of a candidate source has been made. Products such as source lists and summed images will always be constructed, but files such as source light curves and grism spectra require the source position to be known.

Both the TDRSS and full-resolution finding charts are provided in epoch 2000 SKY coordinates as GIF images.

In order to provide a high signal-to-noise image of the field all individual images obtained using the same filter are combined. Exposure maps are constructed for each combined image. Source lists are derived from the combined images. A separate source list is provided for each available filter. Provided an optical counterpart to the target has been identified, light curves for each available filter are extracted from all available image and event data.

Grism spectra of the candidate counterpart are obtained from each available grism image (some of which may originate from grism event data, combined with the images prior to the Level 1 stage). Two files are created for each grism filter. One contains images of the 1st order light of the source in detector coordinates, within a spatial mask appropriate for the source position. The images have been rotated so that the dispersion direction is parallel to the ordinate axis. One image extension is written per grism observation. The second file contains the grism data in the form of a FITS table. This is the image, collapsed along the cross-dispersion axis. Total spectra for each grism are also provided in separate FITS files. These will provide the best signal-to-noise data, but time variability is lost. The total spectra will also be provided in GIF format.

Grism source event tables will be generated, containing an extra column for the wavelength of each photon. They will be screened according to a spatial mask so that only those events likely to be associated with the candidate counterpart remain. Contamination from neighboring sources is possible, depending on the field and position angle of the telescope. A response matrix will be generated to facilitate the analysis of grism data within XSPEC. A "response matrix" will also be provided so that broad-band fluxes through the standard filters can be fit simultaneously with XRT and BAT data.

10.5.3 XRT Pipeline

As described in Section 4.2, the XRT instrument supports several readout modes to cover the large dynamic range and rapid variability expected from GRB afterglows, and the instrument is capable of autonomously changing the readout mode when the source flux changes. For all XRT data modes, the XRT pipeline will produce cleaned, calibrated event list files and standard products for each observation, starting from the XRT Level 1 FITS files. Flickering pixels, dark frame errors, light leaks and radiation damage are expected to be largely eliminated with the new technology present in the XRT CCDs. Nevertheless, the XRT software development team has taken all known effects into account while planning the pipeline tasks so that all known corrections can be applied if and when needed. The steps are:

1) Create GTI file based upon data in the HK file, the quality of these data and the offsets of the data from the nominal pointing.
2) Flag bad frames based on rate increase, FIFO overflow, dead time from a cosmic ray interaction, and create a GTI file based on good frames.

3) Identify bad pixels to be flagged for screening (hot, dead or flickering).

4) Reconstruct photon arrival times for various instrument readout modes.

5) Identify X-ray events split between pixels for reconstruction of the total event energy value

6) Convert pulse height to energy, taking into account any non-linearities between signal size and photon energy.

10.5.3.1 XRT Level 1.5 Files

The XRT pipeline performs the following tasks on Level 1 files: Flag Bad Pixels, PHA Correction, PHA to PI Transformation, Timing Reconstruction (timing), Bias Map Subtraction (PD), Event Recognition (timing), Hot and Flickering Pixels identification, Centroid Computation, TAM correction, and Imaging Processing.

An XRT task performs event reconstruction for Windowed Timing Mode event files. A PHA value is computed and a grade assigned to each event. Next, a task processes the Imaging Mode event files, performing bias subtraction, screening for saturated pixels, for bad pixels included in the CALDB bad pixels file and for Hot Pixels. An XRT task performs bias subtraction on Photodiode Mode event files using a bias value included in a calibration file.

For data from timing modes some essential information must be reconstructed early in the pipeline. Examples are the actual arrival time of the photon and its PHA value. The results of this reconstruction alter the original Level 1 FITS file that contains only the telemetry converted to FITS. Thus for timing modes, two event files are archived: the Level 1 event file generated by xrt2fits and the "Level 1.5" event file which contains the reconstructed time and PHA information in the same format.

10.5.3.2 XRT Level 2 Processing

In the next step of the XRT pipeline, filter files are made for screening event files, and GTIs are generated. Data are then screened based on the values in these files. The standard screening criteria for XRT will rely on grade, temperature, attitude and GTI information.

10.5.3.3 XRT Level 3 Processing

The Level 3 XRT Pipeline includes tasks that generate the Standard Products (spectra, images and light curves), the ARF files for spectroscopy, and an exposure map appropriate for converting counts in an image to flux.

The Level 3 XRT FITS files that are archived are mode dependent. For Photon Counting Mode, light curves and spectra are delivered as FITS files, with an ASCII region file describing the position of the X-ray afterglow (two dimensional filters used by CIAO and SAOImage ds9 to include and exclude data) and GIF image included. For windowed timing mode, the same products are included except for the image file. For imaging mode data, a FITS image, exposure map and GIF file of the image result. Finally, for photodiode mode data, light curves and spectra are delivered as FITS files.

The next step is coordinate transformation from raw to detector to sky coordinates, accomplished via the coordinator package. Sky coordinates use the World Coordinate System (WCS) standards.

Computation of an appropriate exposure map for images results in the net exposure time per pixel taking into account attitude reconstruction, spatial quantum efficiency, filter transmission, vignetting and FOV. For spectra, a Redistribution Matrix File (RMF) that specifies the channel probability distribution for a photon of a given energy and an Ancillary Response File (ARF) specifying telescope effective area and window absorption will be calculated.

10.5.4 BAT Pipeline

The BAT instrument produces event files for each BAT event data type (long, short, long calibration, short calibration), as well as rate files for the entire BAT array, mask-tagged light curves for each of three sources, and light curves of GRBs. The BAT also produces Detector Plane Histograms (DPHs) in survey mode. The pipeline operates on BAT Level 1 FITS files to produce standard Burst Mode data products: burst spectra on various time scales, response matrices, light curves, and images. Because of the way the instrument operates and the Level 1 data is organized, it is often possible for a BAT Level 3 file to be produced by one software task operating on the Level 1 data. The steps in the BAT pipeline for burst data modes are:

1) Generate light curves from BAT raw mask tagged rate files using the ACS timeline and source location.
2) Perform PHA to PI conversion and mask convolution on raw event files using ACS, gain-offset maps and source location to produce processed Level 2 event files.
3) Bin events in Level 2 event files to produce burst counts spectra and burst light curves,
4) Generate Detector Plane Images (DPIs) from Level 2 event files,
5) Apply a GRB position aperture to generate burst sky images from DPIs.

Raw BAT Detector Plane Histograms are used to generate the BAT survey products. Some survey products are produced for a single DPH, and others result from summing all DPHs in a given pointing. The steps involved in the pipeline processing of BAT survey data are:

1) Generate rebinned DPHs from Level 1 files using the gain/offset information. Rebinning is done by energy.
2) Produce DPIs from DPHs.
3) Generate sky images from DPIs using ACS data, an aperture file and a quality map.
4) Generate light curves for survey sources applying a source detection algorithm, the mask pattern and a cleaning algorithm to eliminate confusing sources.

10.5.4.1 Dynamic Calibration Files

Some BAT calibration data changes on the timescale of an observation, and thus is not appropriately tracked in the slowly changing caldb system. In these cases, the data are organized in dynamic calibration files. The processing software then uses this information. Dynamic calibration files will be generated in the pipeline for each BAT snapshot and will track information about detector enablement, detectors ignored during imaging, general detector quality, gain/offset maps generated in flight, gain/offset quadratic correction maps generated by the BAT team, mask weight maps for each mask weight source, gain and offset calibration maps, and calibration source spectra. This information can then be used as screening criteria in generating Level 2 files.

10.5.4.2 BAT Level 2 Processing

The BAT processing pipeline produces Level 2 event files and Detector Plane Images (DPIs), needed to generate sky images. BAT Level 2 event files have their PI and MASK_WEIGHT columns filled by the pipeline. This information depends on spacecraft attitude, source location and the gain/offset information of the detector.

Detector Plane Images (.dpi files) are histogram images of calibrated events, and must be deconvolved with the mask to produce useable sky images. Since they do not have a defined projection onto the sky, WCS keywords cannot be defined for these images. Every sky image is derived from a DPI, so there is a one-to-one correspondence between the two types of data products, and the file naming convention used for both is similar.

For survey mode, DPHs are merged, summed and gain-corrected to produce Level 2 files.

10.5.4.3 BAT Level 3 Processing

Level 2 event files are rebinned to produce burst light curves and spectra. Photon spectra are derived by fitting count spectra to models such as the Band model (Band et al., 1993) and are corrected for the effects of partial coding and the reduced off-axis response. Detector response matrices are also calculated as Level 3 products.

For BAT survey data, count spectra and response matrices will be produced and archived for sources found in the survey. During burst mode, count spectra and response matrices are generated for bursts before, during and after the slew. Photon spectra before, during and after the slew are also produced during burst mode.

The pipeline will produce deconvolved sky images with valid WCS keywords as Level 3 files. A Perl script will produce “postage stamp” images for GRBs in the region around the burst. Images will contain data from an interval (typically 5 minutes), or are derived from the combined DPHs of an entire snapshot. Images will be generated that contain the bright sources and that have been cleaned of bright sources. Images will be available in 4 energy bands as well as a broadband image. Source detection algorithms are then run on these images searching for fast transients over the energy and time ranges available. Most of these pipeline-produced images will not be archived due to their large size and redundancy. Instead, only images from entire observations will be archived.

10.6 Multi-wavelength Analysis

Swift’s unique purpose of observing a GRB in progress and its afterglow across the spectrum demands that spectral data from the three instruments be analyzed together. With this goal in mind, UVOT spectra are prepared with the associated response matrices and calibration information to allow them to be input into XSPEC (as well as the more traditional UV-optical spectral analysis tools, such as IRAF). With a well-understood cross calibration of the instruments, this functionality allows users to fit various spectral models for bursts, search for the energy range of spectral breaks, and accurately measure the Lyman alpha cut-off (and hence the redshift) for the afterglow.

11.0 Calibration

The Swift instrument teams are responsible for calibrating their instruments, analyzing the results and delivering the results to the SSC. The SSC then delivers the calibration information to the calibration database (CALDB). The products of instrument calibration activities are delivered in the form of documents, software and calibration files. The SSC is responsible for obtaining the calibration products from the instrument teams and delivering them to the HEASARC via CALDB so that all Swift users have access to the information.

11.1 Documentation

In cooperation with the instrument teams and the OGIP CALDB team, the Swift SSC will provide a set of documents that describe Swift calibration. These documents will be public and available on-line in text, postscript and HTML formats. The document set will cover the following subjects:

- Description of ground and in-orbit calibration

The Swift SSC will assist the hardware teams in documenting their calibrations. This documentation will include, at the minimum, when and how the ground and in-orbit calibrations were/are conducted, and which parameters are determined. Illustrations making clear the configuration of the calibration experiments will be included.

- Description of the calibration files

The origins, formats, meanings, and usage of the calibration files stored in the CALDB will be explained.

- Algorithms for acquiring instrument-specific calibration products

The algorithms used to construct instrumental responses and perform other instrument specific corrections using the calibration files and software provided will be explained. For example, it will be documented how RMFs (define acronym) and ARFs are created from spectral files, and how exposure maps are made from event files and attitude files.

- Summary of important calibration parameters

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

- Calibration uncertainty

Unexplainable systematic uncertainties in the latest responses are described so that data analysts are informed. It is the instrument teams' responsibility to define such calibration uncertainties.

11.2 Calibration Software

Calibration software is primarily written by the instrumental teams, and will be incorporated into the Swift package, simulation and/or response generators as appropriate.

When constructing instrumental responses or carrying out instrument specific corrections, it is important that general algorithms and instrument-specific parameters be separated as much as possible. The calibration software will be composed of general algorithms that produce calibration products by operating on instrument-specific calibration files. All instrumental parameters needed to generate the calibration products will be put in the calibration files. Consequently, when calibration information is improved, users need only update their calibration files (not necessarily the calibration software that generates the products).

11.3 Calibration Database (CALDB)

Swift calibration files shall be put in the HEASARC Calibration Database (CALDB). See http://heasarc.gsfc.nasa.gov/docs/heasarc/caldb/caldb_intro.html, which also contains calibration files for other high energy missions. All the calibration files in CALDB conform to the OGIP standard FITS format.

11.3.1 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 name of the mission. There are instrument directories (**data/mission/instrument)** for each instrument, and each directory contains three sub-directories, **pcf**, **bcf** and **cpf**, which stand for the *primary calibration files*, *basic calibration files* and *calibration product files*, respectively.

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 scientific data analysis are called calibration product files.

The Swift mission will archive ground calibration data in the **pcf** directory. The UVOT and XRT will store coordinate transformation information in *teldef files*, which carry important instrumental parameters such as dimensions, misalignments and positional gain variations of the sensors, and are examples of basic calibration files residing in the **bcf** directory. Calibration products that take bcf files as their input—for example, exposure maps that rely on bad pixel lists and attitude information—are calibration product files and are stored in the **cpf** directory.

11.3.2 Time-dependent Calibration Files

Some calibration files will be time-dependent. If the time scale of the variation is long enough (~ a couple of months) to include many observations, the time-variable calibration files will be put in CALDB to be used for the observations within the period. In other cases, such as some BAT gain tracking files, the time scale is as short as the length of a single observation. These calibration files will be created in the pipeline processing and archived with the data, for use only for that particular observation. These short time scale calibration files will not be put in CALDB.

11.3.3 Calibration File Name

Calibration files will be given unique names to indicate their contents and dates of the release. The file name and the physical file will have one-to-one correspondence; hence, symbolic links will not be used. The calibration files must have the mandatory CALDB keywords that describe the nature of the files and are referenced by CALDB software (see below).

Recommended naming convention for the Swift calibration files is the following, based on the convention adopted by the XRT:

swi<datatype>[<date>][<version>].ext

where

sw	indicates the file is associated with the Swift mission
i	indicates the instrument (x-XRT, u-UVOT, b-BAT)
<datatype>	a string that describes the type of calibration data
<date>	given as YYYYMMDD and is optional
<version>	is an integer given the file issue number, optional
ext	describes nature of the file (fits, rmf, etc.)

It will be necessary to have some exceptions to this convention. Currently the teldef files and the XRT .rmf file do not strictly conform to this convention but are nonetheless named uniquely and clearly.

To ensure that filenames are Y2K compliant, 4 digits are required to denote years. To enable files to be sorted in chronological order, the order of the date information is year, month and day number. **version** is the version, and **ext** is the file extension that can be **fits** or any other description of the nature of the file (e.g., **rmf** or **arf).** Note that periods ('.') may not be used anywhere except just before **ext**. For example, the XRT bad pixel map released on 2001 January 01 is named **swxbadpix20010101.fits**. Files may alternatively be named according to the "version" scheme, such as **swucol_transmission_v1-0.fits**. However, once files are named according to either the date or version scheme, the same naming convention will be followed for the same kind of files, so that names in the two schemes are not mixed.

11.3.4 Version Control

The SSC will receive calibration files from the instrument teams. For each calibration file, there shall be a contact person from the appropriate instrument team and another contact person in the SSC. The SSC will check that the required CALDB keywords appear in the files, and that applying the calibration file to data results in reasonable products. The SSC will then stage the calibration file at HEASARC for incorporation into the public CALDB.

A scheme has been established for CALDB 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. This information is taken from the mandatory CALDB keywords in each calibration file. Quality and validity flags for all of the calibration files, as determined by the Swift SSC and instrument teams, are included in the **caldb.indx file.** A package of the CALDB access software for choosing appropriate calibration files referencing **caldb.indx** is provided by the CALDB team.

The primary copy of the CALDB is maintained at GSFC. The ISAC and UKSSDC will mirror the GSFC caldb. Guest Observers can also obtain and install the entire CALDB on their sites, or they may access just the files necessary for their analysis.

11.4 Important Calibration Files

The important calibration files necessary for processing or analyzing Swift data are listed below.

11.4.1 General

• Telescope definition files (teldef 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 will be a separate teldef file for each instrument.

11.4.2 BAT

While many of the BAT calibration products will be dynamic, and apply only to a single observation, other BAT calibration information is static, and will be placed in CALDB. These files are needed in BAT processing. They include:

- **BAT aperture file**: The BAT coded aperture image file.
- **BAT ground summary**: summary file in TBD format containing distillation of ground calibration results. Used for deriving response matrices.
- **BAT ebounds files**: Two or more EBOUNDS files containing the standard BAT energy binning for surveys, triggers and rates.
- **BAT Master Catalog**: This catalog will include expected sources pre-launch, and will be updated with new sources seen by BAT in flight.

11.4.3 XRT

The XRT calibration plan includes the following deliverables:

- **TELDEF file:** As for the UVOT and BAT, this file is used to allow software to convert from raw to detector to sky coordinates. This is in mission-independent format, and used by coordinator, imagexform, etc.
- **Gain calibration files**: this file contains information about the detector gain as a function of time, one line for each new gain value. The format and content of this file is set for photon counting mode, and TBD for windowed timing and photodiode modes.
- **Bad Pixel Calibration file**: contains the locations on the detector of known bad pixels, when they were first determined to be bad, and the type of defect. Follows standard OGIP layout for bad pixel information.
- **Quantum Efficiency Calibration File:** Allows software to apply quantum efficiency effects to detected counts and energies.
- **Mirror Effective Area Calibration File:** Contains the on-axis telescope mirror effective area as a function of energy. Its dependence on the off-axis position is described in the vignetting calibration file. These effective area values come from a ray-tracing code and are expressed in units of cm^2. The energy step is 4.8 eV.
- **Filter Transmission Calibration File:** This will allow software to correct for the effects of the XRT filter transmission efficiencies.
- **Housekeeping Parameters Calibration File (TBD)**
- **Point Spread Function Calibration File:** The structure of this file is still under consideration. The PSF profile is radially symmetric and is well described by a King+Gaussian profile. This model has four free parameters plus normalization. The PSF profile changes as a function of the source position in the FOV (off-axis angle) and as a function of energy. The file will either store the PSF information using the coefficients of the analytical model that best describes the PSF as a function of energy and off-axis angle, or as a file containing tabulated encircled energy fractions for a grid of off-axis and energy values.

Vignetting Calibration File: this will describe the mirror effective area as a function of the position in the field of view (off-axis) and energy.

- **TAM reference positions (TBD):** Track the telescope alignment monitor reference positions.
- **Response Matrix:** For each available mode and grade selection, this CALDB file will include the appropriate response matrix. These matrices are built by an RMF generator tool that is not distributed with the XRT software, but is run at Leicester University.
- **Ancillary Response File:** The ARF is stored in the CALDB for on-axis, with TBD arcmin radius. The ARF generation tool is distributed with the software, allowing users to create a custom ARF to suit their needs.
- **Bias Calibration Files:** The detector bias is not subtracted in imaging data when they arrive on the ground. The bias may or may not be subtracted in the photodiode data depending on how XRT is operated. The ground software subtracts a single value of the bias appropriate for each mode. The files will be time-dependent and record all measured bias values, regardless of whether they change compared to previous measurements.

11.4.4 UVOT

The UVOT calibration plan includes the following deliverables:

- **TELDEF file:** As for the XRT and BAT, this file is used to allow software to convert from raw to detector to sky coordinates. This is in mission-independent format, and used by coordinator, imagexform, etc.
- **Bad Pixel Calibration file**: contains the locations on the detector of known bad pixels.
- **Color Transformation Coefficients:** contains the flux zero-points and color transformation coefficients.
- **Large-scale Flat Field file:** contains information about the large-scale variations in the instrument response.
- **Small-scale Flat Field file:** This file tracks the pixel-to-pixel variations in the instrument response.
- **Point Spread Function:** This calibration product contains the characterization of the mirror point spread function.
- **Grism Sensitivity vs. Wavelength**: This calibration product describes the sensitivity of the grisms as a function of wavelength. The projection of the grism spectrum onto the detector plane must also be specified. This product will be used to correct grism spectra to a true intensity scale.
- **Dead time and Coincidence Calibration file**: Swift will track the UVOT coincidence and dead time characteristics in one calibration file which will contain the parameters needed to estimate the effects of dead time and coincidence on the conversion from count rate to flux.

12.0 Swift Guest Investigator Program

In 2002 NASA HQ approved a GI program as an augmentation to the original Swift program. The study of gamma-ray bursts is inherently community-oriented, with follow-up observations performed by large and small telescopes across the electromagnetic spectrum. In addition, the three Swift instruments will offer rich data sets for a large number of non-GRB sources. The Swift GI program will offer financial support to the US scientific community for investigations involving the analysis of Swift data, correlative observations of GRBs with non-Swift instruments and observatories, and theoretical investigations. During the first year of operation, the GI program will not permit pointed observations with Swift; rather, the intent is to maximize the scientific output of the autonomous and pre-planned observing sequences which will be implemented during that cycle.

NASA HQ will administer the GI program with support from the Swift Project. The SSC will publicize the call for proposals, and provide detailed technical guidelines and mission information to proposers. The SSC will also receive the proposals electronically, make technical evaluations of the proposals, and organize and carry out the peer reviews. The Goddard/LHEA Office of Guest Investigator Support (OGIP) will manage the grants. Whenever feasible, the Swift GI program will leverage off existing HEASARC infrastructure. This includes utilization of Web tools for proposal submission (RPS), count rate simulation and feasibility studies (PIMMS, WebSpec, Viewing), etc.

12.1 On-line Service and Help

The Swift Science Center will use the SSC Web site (http://swift.gsfc.nasa.gov/) as the primary means of communicating with the US Swift user community. Since Swift data will be attractive to a variety of follow-up observers who are experts with analysis techniques that apply to observational data obtained at disparate wavelengths, the SSC must be ready to support scientists with a wide variety of exposure and comfort levels to Swift data and products. In addition, since all Swift data are immediately public within hours of the observation, the SSC must make every effort to ensure that the Swift user community is able to perform their scientific analysis and get their results rapidly.

With the above goals in mind, the SSC will create extensive Swift on-line documentation. Topics will include: how to access Swift data from the continuously populated SDC Quick-Look archive, how to browse the archived processed Swift data for complete observations through the HEASARC (and European archive centers), and detailed step-by-step recipes that describe the standard Swift data processing and analysis steps for the three onboard instruments.

In addition to educating users, the SSC is responsible for answering any questions they may have. The Swift user community will communicate with the SSC through our Web Feedback form, which is available from the SSC Website as well as the general HEASARC Website. Submitting a question or comment through this form triggers an email that is distributed to a list of recipients that will include all SSC staff as well as some members of the SDC, HEASARC, and FTOOLs teams. A designated SSC member will be responsible for making sure all questions are responded to, and the answers archived for future internal use. In addition, relevant questions and answers will be made public as part of a Swift "Frequently Asked Questions" document available at the SSC Web site.

The HEASARC will document the content of the Swift archive and how to use it. This information will be posted on web pages located on the SSC web site.

12.2 Proposal Support

NASA will officially release the Swift GI opportunity through the Research Opportunities in Space and Earth Science (ROSES) NASA Research Announcement (NRA). The SSC will be responsible for gathering any necessary input from the instrument teams to prepare detailed Swift technical appendices to include instrumental characteristics required for GIs to prepare proposals. The SSC will supply simulation tools and observation planning tools which are intended for use by GIs to estimate their expected count rates and justify their science goals when preparing proposals.

GO proposals will be submitted electronically through the Remote Proposal Submission system (RPS). RPS has been developed at OGIP and is used for the current GO programs of existing missions such as XMM and RXTE. Due to the nature of the Swift GI program, namely supporting the use of Swift data and correlative studies, the scientific justification and budget information will be solicited at the same time, and a single review will be organized to evaluate the proposals based on scientific merit and apportion GI funding accordingly. The format of the review will be based on the RXTE proposal review process, which is typically accomplished by four eight-person scientific review panels, each supported by a mission scientist and computer support, completed in about 2.5 days.

12.3 Observation Planning and Scheduling

There is no impact on observation planning and scheduling as the Swift GI program will not result in pointing the spacecraft to GI-selected targets during the baseline mission. Details of observation planning and scheduling will be coordinated by the MOC if the Swift project should transition to allowing preplanned target observations after the first two years of the mission.

12.4 Simulation Software

To aid Guest Investigators in proposal preparation, the SSC will make available to the community simulation software to determine when sources are visible to Swift, as well as the expected count rates and instrumental responses for each of the Swift instruments across a variety of source types. These simulation tools will be based on existing software used by current and planned OGIP missions. The tools include the Portable Interactive Multi-Mission Simulator (PIMMS), XSPEC/WebSpec, and Viewing.

12.4.1 Counting Rate Simulation -- PIMMS (XRT/BAT), and UVOTSIM

When proposing investigations using Swift data, investigators will typically need to estimate the expected counting rates in BAT, XRT and UVOT. For such a purpose, PIMMS (Portable, Interactive, Multi-Mission Simulator) has been developed at GSFC and is already widely used in the community. Modifications to PIMMS for the Swift instruments will allow users to estimate the expected counting rates for XRT and BAT. The user interface involves inputting the source flux and spectral model parameters. The source flux may be specified in physical units (ergs s^{-1} cm^{-2}) or expressed as a counting rate from another satellite/instrument.

PIMMS is described at http://heasarc.gsfc.nasa.gov/docs/software/tools/pimms.html. The WWW version of PIMMS, *W3PIMMS* is also developed, and in wide use in the high energy astrophysics community; it is available at http://heasarc.gsfc.nasa.gov/Tools/w3pimms.html.

For UVOT, existing software to estimate the expected count rates from the XMM-OM will be modified with the UVOT efficiencies to predict instrument performance for stars spanning a variety of spectral types. The SSC is working with the PIMMS developer to include UVOT, and with the developers of the UVOT count rate simulator at MSSL, to allow users to estimate count rates in each of the UVOT filters for GRBs of a specified redshift. Note that this functionality already exists within XSPEC, and will be incorporated into WebSpec in time to support GI simulations.

12.4.2 Spectral Simulation -- XSPEC

Interested BAT and XRT users will be able to use the existing XSPEC spectral fitting package to simulate instrument dependent pulse-height spectra for a given input photon spectrum. For each instrument, the effective area and efficiency (an ARF -- Ancillary Response File) and the detector response matrix (RMF -- Redistribution Matrix Files) can be used to simulate the expected observed spectrum. The WWW version of the XSPEC spectral simulation, *WebSpec*, is available at http://heasarc.gsfc.nasa.gov/webspec/webspec.html.

12.4.3 Viewing constraints

The Web-based tool *Viewing* (http://heasarc/Tools/Viewing.html) will be used to track when sources are accessible to the XRT and UVOT. This tool incorporates sun angle constraints and will return a range of dates for which Swift can view a given target. Modifications will be considered to incorporate the much larger, non-circular FOV of the BAT detector, in which some sources will be accessible even when Sun-angle constraints preclude the NFIs from observing them.

13.0 The Swift Archive

The Swift mission will be unprecedented in its rapid dissemination of data to the community. While there will be no proprietary period during normal Swift operations, there will be a 45 day check-out period and a 3-month verification phase during which Swift data will be made available only to the Swift team. After this initial phase, Swift data will typically be available to the community within hours of its receipt on the ground. Data from Swift reach the ground via two distinct paths. Short, informative TDRSS messages containing preliminary estimates of positions and burst characteristics are sent immediately after a GRB trigger is detected onboard are broadcast to the community via the GCN within minutes, and later archived as part of the final Swift Archive. The bulk of Swift telemetry is received at the Malindi ground station in Kenya, which will receive approximately 6-7 Swift data dumps per day. From Malindi, Swift data flow to the MOC at Penn State, and then to the Science Data Center at GSFC where the data are processed. The estimated data volume is 1 Gbyte per day.

13.1 The SDC Quick Look Facility

The SDC will process the telemetry files received from the MOC into time-sorted files with duplicate packets removed.These processed telemetry files will be archived at the SDC for the lifetime of the mission. Two types of processing are applied to the Malindi data. Quick Look data are produced after each Malindi dump. This will typically result in the same observation being reprocessed several times as new data arrive to fill in any gaps. After each Quick Look processing, the data are made publicly available (normally within 3-6 hours of receipt) on the Science Data Center's Quick Look Facility. In addition to this initial processing, the data are flowed through the processing pipeline a final time when the observation is complete, and is stored in the permanent archive. The final processing run uses the same pipeline and software as the Quick Look processing. One week after the observation is performed, the data are moved from the Quick Look Facility to the Swift archive centers at the HEASARC, ISAC, and UKSSDC and subsequently deleted from the Quick Look Facility.

13.1.1 Data Organization at the Quick Look Facility

Because the data are kept in the Quick Look Facility for only a week, the data volume will be small compared to that of the archive centers and a relatively simple user interface will be used. The data will be organized by sequence number, and all of the data and standard products for a particular sequence number will be assigned their own directory. The web site for the QLF will have a table listing all of the currently available sequence numbers and the corresponding target names, version numbers, and processing dates.

Clicking on an individual sequence number brings up a new page with tables listing all of the available files for that sequence number. The list includes calibration data, auxiliary data such as orbit information, as well as telemetry converted to FITS files. The tables provide the file name, file type (e.g., ASCII), file size, and a brief description of the contents. Users can specify individual files or groups of files (including all files) to download.

13.1.2 Transfer of Data from the Quick Look Facility to the Swift Permanent Archive

The Swift mission will use the Data Transfer System (DTS), originally developed for XMM with minor modifications for Swift, as the protocol to transfer data between the SDC Quick Look Facility and the three Swift data centers. The DTS system is described at http://legacy.gsfc.nasa.gov/dts/dts.html. The DTS system has proven capable of coping with multiple site data transfers and handling transfers of large files for XMM. Extra security capabilities will be added for use with Swift. When an observation is ready to be served to the Swift archive, the DTS system sends an alert email. The archive centers then pull the data from the SDC site by FTP. Once the transfer has been successfully completed, the archive centers send a return status email to the SDC, which then purges the data from the Quick Look Facility.

HEASARC has developed the Data Archive System (DAS) to move the data and associated tables from the staging area to the final archive location. DAS consists of Perl scripts initiated by DTS. DAS has the capability to move and replace data, and to make a copy of the data set on a back-up storage device. The DAS sends an e-mail message to the Swift archive operator to ingest databases, and produces and stores a log of the data in the archive.

HEASARC has also developed a set of scripts to ingest the database tables. It is consistent with the EXOSAT data base management system which is already in use at the other data center sites, and it contains specific ingest procedures to handle the Swift database tables.

13.2 Swift Archive Overview

The HEASARC is the U.S. archive for all the Swift data and related products. The HEASARC will contain all information, data and software needed to make analysis of Swift data by the community straightforward, well understood, and well supported. All of the data in the archive are in FITS format that conforms to OGIP standards. Other standard formats, such as HTML, are used for previewing products or recording a log of the processing. The SSC Web site, which is hosted by the HEASARC, will include documentation on the software, data files populating the Swift archive, details of the calibration and how it was arrived at, and information on the GI Program.

A summary of the data in the archive is provided in Tables 13.1 through 13.5.

Mode	**Data Content**
Event	1 event file containing the short events and the long events converted into short. This mode includes in the same file data taken during pointing and slew (Level 1 & 2)
	3 event files containing only the long events, short and long calibration events (Level 1)
	1 light curve file with 64-ms resolution FITS and GIF plot (Level 3)
	3 spectral files. Data taken during the pre-slew, slew and after-slew time periods (Level 3)
	1 GIF file containing the plot of the spectra from the above FITS files (Level 3 GIF)
	3 spectral response files associated with the pre-slew, slew and after-slew spectra (Level 3)
	4 sky and 4 detector images accumulated for the intervals pre-burst, burst, pre-slew and post-slew. Each file contains images in several energy bands (Level 3)
	1 GIF file. Montage of 4 time intervals of the sky region around the burst (Level 3).
Rate	4 light curve files. Two containing 1 sec & 64 ms in 4 energy band data from the entire array. Two containing 1.6 sec in 4 energy band & max

	count rates data per quadrant (Level 1)
	N light curves from mask tagged rate data one for each monitored source (Level 1 & 2)
Survey	M files (DPH), each for a given set of gains & offsets within an observation. (Level 1 & 2)
	1 file associated with the post-burst detection, e.g. starts after the events mode ended (Level 1,1a, &2)

Table 13.1 BAT Archive Data

Mode	**Data**
Event	N event files, each containing data for a specific mode, window and pointing (Level 1& 2)
	N-1 event files, one for each timing mode, window and pointing (Level 1a)
	3 light curves files for PC and WT modes & low rate PD with different binning, extracted from the possible afterglow region (Level 3 FITS).
	1 GIF containing the plot of the light curves from the above FITS file (Level 3 GIF)
	2 images for PC and WT modes (Level 3 FITS and GIF)
	3 spectra for PC, WT, low rate PD modes from the possible afterglow region (Level 3 FITS).
	1 GIF file containing the plot of the spectra from the above FITS file (Level 3)
	3 arf for PC, WT & low rate PD modes (Level 3)
Image	1 image file containing several image extensions (Level 1 & 2). The unit of the data in the file is Digital Number and not counts.
Image & Event	2 exposure files associated to sky images. One per PC and IM modes (Level 3)
	1 GIF file derived from the image (in charge units) & event mode (Level 3)

Table 13.2. XRT Archive Data

Mode	**Data**
Event	N event files, each containing data for a specific filter, binning & pointing (to distinguish data taken during settling, Level 1 & 2)
	2 event files, one for each grism containing events for the source (Level 3)
	1 light curve file with several extensions each containing binned events for each filter for the afterglow (Level 3).
Image	M image files, one per filter, each with several image extensions (Level 1 & 2)
	2 image files containing grism images in detector coordinates (Level 1a)
	M exposure files each containing exposures for each image file (Level 2)
	1 image file & 1 exposure file with several extensions, each containing the

	sum of all images or all exposure for a given filter (Level 3).
	2 spectral files, one for each grism, obtained with the coarsest binning (in imaging). First extension image, 2 extension spectrum (Level 3)
	2 GIF files, spectral plot & montage of the sum of all images (Level 3)
	1 Catalog file containing the detected sources in FITS (Level 3)
Image & Event	1 GIF file containing light curve plot of all filters. Event and image data are plotted together

Table 13.3. UVOT Archive Data

Type	**Data**
Housekeeping	HK data either from a specific APID or enmeshed in science data.
	HK headers and or trailers of the science data packets
BAT Trend	Am^{241} spectra monitoring per block & 3-D array
	Scaled map
	Calibration map gain and offset; Detection plane flags: Segment/strip
	Tables dumps: commandable & commanded, On board source catalog
	Tables: Veto; Long, Short, Rate, Image trigger; Rate diagnostic Running sum
XRT Trend	raw data mode images
	bias map taken typically during the slew
	TAM images monitoring the change in pointing for the star tracker and detector
XRT Monitoring	Calibration source energy, width and normalization
	Event grade histogram per observation and mode
	Detector background in PC mode
	Mean corner pixel values for single pixel events
	Standard deviation of pixel values for single pixel events
	Bias map mean and width
	TAM centroid and sigma
Ancillary	Ephemeris
	Time corrections

Table 13.4 Housekeeping, Trend, & Monitoring Data

Instrument	**Data Description**
XRT	Data taken at the Panter facilities and exercise the different modes with different calibration source. Used to derive high-level calibration products.
UVOT	Data taken at Goddard during the calibration run and exercise different mode and filter. Used to derive high-level calibration products.

Table 13.5. Calibration Data.

13.2.1 Archive Structure

The Swift archive is divided into 6 separate areas to provide more convenient access for users. Each area is discussed in turn in the following sections.

13.2.1.1 TDRSS messages

Software on the BAT instrument examines the many rates produced by the instrument and "triggers" whenever the analysis indicates that a GRB has been detected. Each such trigger is assigned a unique number. Each trigger generates a series of messages quickly sent to the ground using TDRSS. The number of messages for a particular trigger depends on whether the trigger is confirmed with the image processor and whether the observatory maneuvers so that the GRB is observed with the XRT and UVOT. The format and content of these messages is described in Appendix B of the "Onboard Operational Message Interface Document" (410.4-ICD-0006). In general, the trigger number assigned by BAT also serves as the target ID for ground processing and further observations. All the TDRSS messages will be stored together in one section of the archive. All of the messages for a particular trigger will be stored in its own directory whose name identifies the trigger number.

13.2.1.2 Production Data

All Level 1, Level II and Level III FITS files generated during the final pipeline processing on the data will be stored in one section of the archive. The data will be organized by sequence number – all the data for a particular sequence number will be stored in its own directory. The Level 1 data are the telemetry converted to FITS format with a limited amount of processing. The amount of processing varies for the several instruments, but includes adding the RA, Dec, and energy for the XRT event lists. The telemetry files themselves are maintained separately at the MOC and SDC for the duration of the mission in case they are needed for reprocessing.

The Level II data copy the Level 1 data for the scientifically useful observing times and in some cases add calibrated energy, position, and timing information.

The Level III data are the results of standard analysis routines carried out on the Level II data. These results provide a quick overview of each observation segment. The standard products include:

- Light curves in several energy bands (BAT)
- Energy Spectrum (BAT)
- Integrated image in several energy bands (XRT)
- Light curve for afterglow (XRT)
- Integrated image in each available color (UVOT)

13.2.1.3 Monitoring Data

Monitoring data will be stored in one section of the archive. These data are most useful when ordered by time rather than split into different observations. An example is the ephemeris data giving the position of the satellite as a function of time. These data will be organized by the type of data and then by time.

13.2.1.4 Calibration Data

Calibration data are also archived, and served via the CALDB.

13.2.1.5 GRB Summary Products

A typical GRB will be followed-up over the course of several observations, depending on the brightness of the afterglow in optical through X-ray. The HEASARC will produce GRB summary data products generated using all the observations relevant to a specific GRB. They are intended to give a standard overview of each GRB and its afterglow evolution. Data from all instruments will be used to document the characteristics of each burst. For a given GRB, the summary data products will be generated after the afterglow has faded away (~3-4 weeks after the data are received in the HEASARC).

These GRB summary products will be further organized into the overall Swift mission GRB catalog containing the main burst characteristics. Data in the catalog will be organized by GRB name. Since summary products will be generated after the last Swift observation of a particular GRB, these products will begin to populate the archive on a routine basis approximately five months after launch.

13.2.1.6 Swift Survey Archive

In addition to observations of GRBs and their afterglows, each instrument will conduct a sky survey in their wavelength band. The instrument teams are responsible for planning the survey, analyzing the data, and delivering survey data and products to the Swift archive. The Swift archive will begin to be populated with survey data no later than one year into normal mission operations, with updates expected to occur every three months. The Swift survey data will be organized in the archive according to observation time. The XRT survey is being conducted by ISAC, the BAT survey by the BAT team at GSFC and LANL, and the UVOT survey by the UVOT team members at MSSL. The survey results will be archived at the HEASARC.

13.2.1.6.1 XRT Survey

The XRT will image serendipitous sources outside the central region of the XRT field-of-view that contains the GRB afterglow. The XRT survey is the collection of positions, intensities and data products of these serendipitous sources. It is expected that the survey will reach a limiting sensitivity of a few 10^{-15} erg cm^{-2} s^{-1}.

The X-ray positions and fluxes are obtained using a wavelet algorithm and parameters are derived for each detected source both from the serendipitous pipeline and from a cross-correlation with other catalogs. The collection of these parameters forms the XRT survey catalog. The catalog consists of two tables. One table contains the results of the analysis of the X-ray images, and the other table contains results obtained from cross-correlating the positions with other catalogs. The tables are ASCII files containing a header and the data in a tdat format, which is a standard HEASARC format (http://heasarc.gsfc.nasa.gov/docs/software/dbdocs/tdat.html).

The survey also contains additional data products that are divided into two categories: a) products associated with the entire field, b) products associated with each source. The format of the data products is FITS, following the OGIP standards. When appropriate, a view of the product is provided as a GIF image.

Details of XRT survey data, file names, and directory structure are documented in the HEASARC ISAC ICD (410.4-ICD-0013).

13.2.1.6.2 UVOT Survey

Besides imaging the GRB afterglow position at the center of the FOV, the UVOT will image serendipitous sources in the remaining area. The UVOT survey is the collection of the positions and intensities of these serendipitous sources as well as the images from which these values were derived. An integrated image will be produced from all the snapshots of a specific target. Separate images will be produced for each of the UVW2, V, UVM2, UVW1, U, B, and white filters.

The UVOT positions and fluxes are obtained using a detection algorithm and for each source detected parameters are derived from the UVOT data and from the cross-correlation with other catalogs. The collection of these parameters forms the UVOT survey catalog. The catalog consists of two tables. The first contains the results of the analysis of the UVOT images, and the other contains results obtained from cross-correlating the positions with other catalogs. The tables are ASCII files containing a header and the data in a tdat format.

Data products associated with the catalog are the integrated images used to run the detection algorithm. The images are provided in FITS format, following the OGIP standards. A view of the image is also provided in GIF format.

Details of the UVOT survey data, file names, and directory structure are documented in the HEASARC UVOT ICD (410.4-ICD-0024).

13.2.1.6.3 BAT Survey

While waiting to catch a new GRB, the BAT instrument observes a large part of the sky, imaging and monitoring hard X-ray sources. The hard X-ray survey is a collection of positions, intensities, and data products of these serendipitous sources.

The hard x-ray survey is created by analyzing the data on four different time scales. These are:

- Survey results from an individual orbit. These results are typically obtained using a single snapshot of ~30-minute duration. Data are analyzed on 5-minute time-scales and over the entire interval. This data set is named “orbit survey”.
- Survey results from multiple orbits obtained with the same spacecraft attitude. These results are obtained by summing several snapshots all having the same spacecraft attitude on a time interval of ~1 day. The data are expected not to be contiguous in time. This data set is named the multi-orbits (MO) survey.
- Survey results every 6 months. These results are obtained by summing data from all of the sky in sequential, non-overlapping intervals of six months. This data set is named the 6-months survey.
- Cumulative survey results from all of the sky over the whole mission. These results are obtained by summing data from all of the sky into an integrated all-sky map for the entire lifetime of the mission. The cumulative map is updated every TDB months. The final all-sky map contains data from the entire mission. This data set is named the cumulative survey.

The catalog for the BAT Hard X-ray survey is a composite of two types of tables related via a common parameter. The first table is a master list of sources detected by the BAT. This list contains as many entries as there are unique sources detected in the BAT. A unique identifier will be associated with each source. The second table contains more detailed source information derived from the analysis of the BAT survey data on the different time scales. The data products associated with the short time scale surveys (orbit and multi-orbit) include the 80-channel spectra for each of the detected sources, source light curves with different time scale integration, FOV images in 5 energy bands with the bright sources removed, and images with the sources added. The data products for the 6-months and cumulative surveys are flux all-sky images in 5 energy bands with the bright sources removed and images with the bright sources added, exposure maps and noise map integrated over 6-months or over a cumulative time into the mission.

The cumulative data volume estimated for the hard X-ray survey is larger than the rest of the Swift archive. The baseline list for data products given above is being reviewed with a goal of reducing the storage requirements while retaining the most useful data products.

Details of BAT survey data, file names, and directory structure are documented in the HEASARC BAT ICD (410.4-ICD-0014).

13.2.1.7 The Swift Follow-up Archive

The Swift follow-up team will collect data from a large variety of ground-based observatories at various wavelengths in response to a GRB alert from Swift. HEASARC will provide a facility for the members of the follow-up team to archive their observations on a voluntary basis. It will maintain a record of these follow-up data, and provide a mechanism to obtain follow-up data, as part of the permanent Swift archive. Collecting this information and maintaining a permanent, accessible record will allow users to track, for a given GRB, which observatories have performed observations and at which energy ranges. This information will be useful for planning further Swift observations of GRBs. It will also allow for a comprehensive catalog of results on the GRBs observed by Swift.

Follow-up data will be submitted to the Swift archive using a Web form based on the Remote Proposal System (RPS) in use for OGIP-supported missions within the HEASARC. Modifications of RPS for the Swift follow-up archive will allow the observer to generate a cover page with team member information, and an observation form for the upload of the observational data as well as summary results. The observation form will accept as input: results in pre-allocated spaces; data files; a link (URL) to a site or to the data; and any notes the user feels should accompany the uploaded data.

When a user submits the form, it will be verified for completeness of required fields, and uploaded to the Follow-up archive. An email will be sent to the user with all recorded input information for the follow-up observation. The input information is ingested in a database system, which tags the data by GRB name, team member information and observatory name. This format will allow the archive to be searched for GRB name or time using HEASARC Browse. On subsequent visits to the Swift follow-up site, users will have the ability to clone or add/delete their previous input results.

13.2.2 Accessing the Swift Archive

Access to the Swift archive will be available through the HEASARC Browse Web facility as well as a dedicated Swift archive page. The Swift archive page will be a front-end page to Browse, with some Swift archive-specific additions. The Swift archive page will also be used to post news on the Swift archive, to provide up-front common Swift parameters for searches (besides position & time), and to link the other data archive centers related to Swift and the GCN. Query outputs from Browse and the Swift archive page will be identical, as they will use the same underlying software.

13.2.3 Swift Database Tables

Each Swift data set will have at least one associated database table. Database tables organize the data from Swift observations by categories that allow users to select and retrieve data according to their particular needs. The main Swift database table will contain the standard high-level information related to a particular data set (such as sky position, time and other observation parameters). Additional tables associated with the production data will include: the as-flown timeline (which logs the times of specific events), and the instrument configuration tables (which log modes used by each of the instruments during an observation).

All tables associated with the production data contain keys (such as the sequence number) to relate individual table entries with their associated data files, as well as correlate entries from the same GRB that may appear in different tables (for example target ID). Updated tables will be delivered by the SDC to the HEASARC with the production data. Updated tables associated with the surveys and GRB products will be delivered on the same schedule as for the production data.

APPENDIX A – ACRONYM LIST

APID	Application Process Identifier
ARF	Ancillary Response File
ASDC	ASI Science Data Center
ASI	Italian Space Agency
ASINET	ASI Network
AZ	Arizona
BAT	Burst Alert Telescope
CCB	Configuration Control Board
CCR	Configuration Change Request
CCSDS	Consultative Committee for Space Data Systems
CDR	Critical Design Review
CDRL	Contract Deliverable Requirements List
CMS	Configuration Management System
COP-1	Command Operation Procedure-1
CSOC	Consolidated Spacecraft Operations Contract
DAS	Demand Access System
DRB	Discrepancy Review Board
F&PR	Functional and Performance Requirements
FITS	Flexible Image Transport System
FoM	Figure of Merit
FOT	Flight Operations Team
FOV	Field of View
GCN	GRB Coordinates Network
GNEST	Ground Network for Swift
GRB	Gamma-Ray Burst
GSFC	Goddard Space Flight Center
GUI	Graphical User Interface
HEASARC	High Energy Astrophysics Science Archive Research Center
I&T	Integration & Test
IONET	Internet Protocol Operational Network
IOWG	Instrument Operations Working Group
ISAC	Italian Swift Archive Center
ISC	Information Systems Center
IT	Instrument Team
ITOS	Integrated Test and Operations System
JET-X	Joint European X-ray Telescope
JSC	Johnson Space Center
KSC	Kennedy Space Center
L&EO	Launch & Early Orbit
LD	L&EO Director
MGS	Malindi Ground Station
MIDEX	Medium-class Explorer
MMFD	Multi-Mission Flight Dynamics
MOC	Mission Operations Center
MOM	Mission Operations Manager

MOT	Mission Operations Team
MRTT	Mission Readiness Test Team
MSSL	Mullard Space Science Laboratory
NASA	National Aeronautics and Space Administration
NCC	Network Control Center
NFI	Narrow Field Instrument
NISN	NASA Integrated Services Network
NORAD	North American Air Defense Command
OAB	Brera Astronomical Observatory
ORR	Operations Readiness Review
PA	Pennsylvania
PDR	Preliminary Design Review
PI	Principal Investigator
PPT	Pre-planned Target
PSLA	Project Service Level Agreement
PSU	Pennsylvania State University
QR	Quality Record
QRL	Quality Record List
RFA	Request for Action
RT	Real-Time
RXTE	Rossi X-ray Timing Explorer
S/C	Spacecraft
SDC	Swift Data Center
SGP4	Simplified General Perturbations No. 4
SN	Space Network
SOC	Simulations Ops Center
SOMO	Space Operations Management Office
SOT	Science Operations Team
SRD	System Requirements Document
SRR	System Requirements Review
SSC	Swift Science Center
SSR	Solid State Recorder
STDN	Spacecraft Tracking and Data Network
T&C	Telemetry and Command
TBD	To Be Determined
TCS	Thermal Control System
tdat	Transportable Database Aggregate Table
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
TLM	Telemetry
ToO	Target of Opportunity
U.S.	United States
USN	Universal Space Network
UVOT	Ultra-Violet Optical Telescope
VC	Virtual Channel
WSC	White Sands Complex
WWW	World Wide Web
XMM	X-Ray Multi-Mirror Mission

XRT X-Ray Telescope

APPENDIX B – INDEX