The *Swift* Technical Handbook
Version 13.0

Swift Science Center

August 1, 2016

Revision History

The following is a list of the major changes in each version of the *Swift* Technical Handbook. Only major changes are listed. The current version is 13.0, which was created August 1, 2016.

- Version 13.0 — August 1, 2016
  - Updated for Cycle 13
- Version 12.0 — August 1, 2015
  - Updated for Cycle 12
  - Updated XRT sensitivity
  - Fixed broken links
  - Added section on Optical Loading
- Version 11.0 — August 15, 2014
  - Updated for Cycle 11
  - Refined the UVOT filters properties (Table 8)
  - Refined the UVOT coincidence loss corrections (Table 9)
- Version 10.0 — August 30, 2013
  - Updated for Cycle 10
  - Added study of pointing accuracy
- Version 9 — There is no Version 9
  - Version 9 has been skipped so that the version number will match the Swift GI Program Cycle number.
- Version 8.0 — July 20, 2011
  - Updated for Cycle 8
- Version 7.0 — July 28, 2010
  - Updated for Cycle 7
- Version 6.0 — June 16, 2009
  - Updated for Cycle 6
- Version 5 — There is no Version 5
  - Version 5 has been skipped so that the version number will match the Swift GI Program Cycle number.
- Version 4.1 — October 31, 2008

  - Update the UVOT AT sequence.
  - Refine the UVOT redshift table.
  - Corrected typos.
- Version 4.0 — July 18, 2008
  - Updated for Cycle 5
- Version 3.0 — May 17, 2007
  - Updated for Cycle 4
- Version 2.3 — November 20, 2006
  - Added coincidence loss table.
- Version 2.2 — May 11, 2006
  - Updated for Cycle 3
- Version 2.1 — March 25, 2005
  - Updated with post-launch information
- Version 2.0 — September 20, 2004
  - Updated for Cycle 2
- Version 1.1 — October 23, 2003
  - Updated XRT parameters and activity sequences.
  - Corrected Moon avoidance angle.
  - Updated XRT description.
  - Most UVOT information has been rewritten.
  - Information on the dark burst message has been added.
- Version 1.0 — August 29, 2003
  - First Public Release

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1 Overview

1.1 The Swift Technical Handbook

This document contains the information that is needed to write a *Swift* Guest Investigator[1] (GI) proposal. The purpose of the *Swift* Technical Handbook is to provide GIs with information about the *Swift* mission, the spacecraft's science instruments, the data processing and archiving, and simulating *Swift* data. Please see the Swift Data Analysis Web Page[2] links to more documentation about *Swift*, its instruments, and its data.

1.2 Mission Overview

Swift is a first-of-its-kind multi-wavelength observatory dedicated to the study of gamma-ray burst (GRB) science. Its three instruments work together to observe GRBs and their afterglows at gamma-ray, X-ray, ultraviolet (UV), and optical wavelengths. *Swift*, part of NASA's medium explorer (MIDEX) program, has been developed by an international collaboration of Italy, the United Kingdom, and the USA. It was launched into a low Earth orbit on a Delta II 7320 rocket on November 20, 2004. During the first ten years of operation *Swift* has observed approximately 900 bursts[3] with a sensitivity approximately three times fainter than the BATSE[4] detector aboard the Compton Gamma-Ray Observatory[5]. *Swift*'s Burst Alert Telescope can detect gamma-ray bursts and relay a position estimate that is accurate to within 1–3 arcminutes to the ground within approximately 15 s. After the initial burst detection, the spacecraft "swiftly" (approximately 20 to 75 seconds) and autonomously repoints itself to bring the burst location within the field of view of the sensitive narrow-field X-ray and UV/optical telescopes. *Swift* provides spectral energy distributions for the bursts and multi-wavelength light curves for the duration of the afterglow. *Swift* measurements have been of great interest to the astrophysical community. All data products are available to the public via the Internet as soon as they are processed. The *Swift* mission represents the most comprehensive study of GRB afterglows to date.

The main mission objectives for *Swift* are to:

- Determine the origin of GRBs.
- Classify GRBs and search for new types of cosmic explosions.
- Use GRBs to study the early universe.
- Perform a sensitive survey of the sky in the hard X-ray band.

[1] http://swift.gsfc.nasa.gov/proposals/swiftgi.html
[2] http://swift.gsfc.nasa.gov/analysis/
[3] http://swift.gsfc.nasa.gov/archive/grb_table/stats/
[4] http://www.batse.msfc.nasa.gov/batse/
[5] http://cossc.gsfc.nasa.gov/

- Multi-messenger time domain astronomy
- Supernova cosmology

Swift has a complement of three co-aligned instruments for studying GRBs and their afterglows: the Burst Alert Telescope (BAT)[6], the X-Ray Telescope (XRT)[7], and the Ultraviolet/Optical Telescope (UVOT)[8]. The largest instrument on board *Swift* is the BAT, which can view approximately one sixth of the sky at a time. It currently localizes approximately 90 GRBs per year. Within seconds of detecting a burst, the spacecraft "swiftly" and autonomously repoints itself to aim the XRT and UVOT at the burst to obtain high-precision X-ray and optical positions and spectra. *Swift* provides detailed multi-wavelength light curves for the duration of the afterglow. Key data taken by *Swift* are relayed to the ground in near-real time, allowing the Gamma-Ray Burst Coordinates Network (GCN)[9] to immediately distribute it to the world via the internet for follow-up observations and study. *Swift* also uses the BAT to perform an all-sky survey of hard X-rays that will be significantly more sensitive than any previous all-sky survey.

The *Swift* mission began with an activation phase lasting approximately 45 days. This was followed by a verification phase of approximately three months. On April 5, 2005 the verification phase was completed and regular observations began. All *Swift* data taken during the activation and verification phases have been made available to the astrophysical community. All data taken after April 5, 2005 are made public as soon as they are processed, usually about three hours after the observations were taken.

1.3 Instrument Overview

The *Swift* telescope payload consists of three instruments that work together to provide rapid identification and multiwavelength follow-up of GRB afterglows and other sources. When triggered by a GRB or another transient source, the spacecraft autonomously slews within 20 to 75 seconds since the trigger so that the fields of views (FoVs) of the three instruments overlap the location of the source. Monitoring continues as long as the observations provide a reasonable science return. Each target is re-evaluated on a daily basis to determine if observations should be continued. All *Swift* data are rapidly disseminated to the astrophysics community via a public archive.

The three instruments on board *Swift* are:

The Burst Alert Telescope (BAT) The BAT is a wide-field, coded-mask gamma-ray detector that is sensitive to energies of 15–150 keV. It detects GRBs and other gamma-ray transients, computes their positions to 1–3 arcminutes, and triggers autonomous slews of the spacecraft to point towards the bursts.

[6] http://swift.gsfc.nasa.gov/about_swift/bat_desc.html
[7] http://swift.gsfc.nasa.gov/about_swift/xrt_desc.html
[8] http://swift.gsfc.nasa.gov/about_swift/uvot_desc.html
[9] http://gcn.gsfc.nasa.gov/

The X-Ray Telescope (XRT) The XRT is a narrow-field *X*-ray telescope that localizes a GRB to approximately 3–5 arcseconds, and performs imaging and spectroscopy in the 0.2–10 keV band. With the aid of UVOT astrometric correction, the uncertainty in XRT localizations can be reduced to as little as 1.4 arcsec radius (90% confidence level).

Ultraviolet/Optical Telescope (UVOT) The UVOT is a narrow-field UV/optical telescope with a 30 cm aperture mirror that operates at wavelengths between 1600 Å and 6000 Å. It provides burst positions to 0.5 arcseconds, a finding chart, and performs broad-band imaging on GRB afterglows. The UVOT also has the ability to take grism spectra in the 1700-2900 Å range

The placement of the three instruments on the spacecraft is shown in Figure 1. The ability of *Swift* to zero in on the position of a transient source is illustrated in Figure 2.

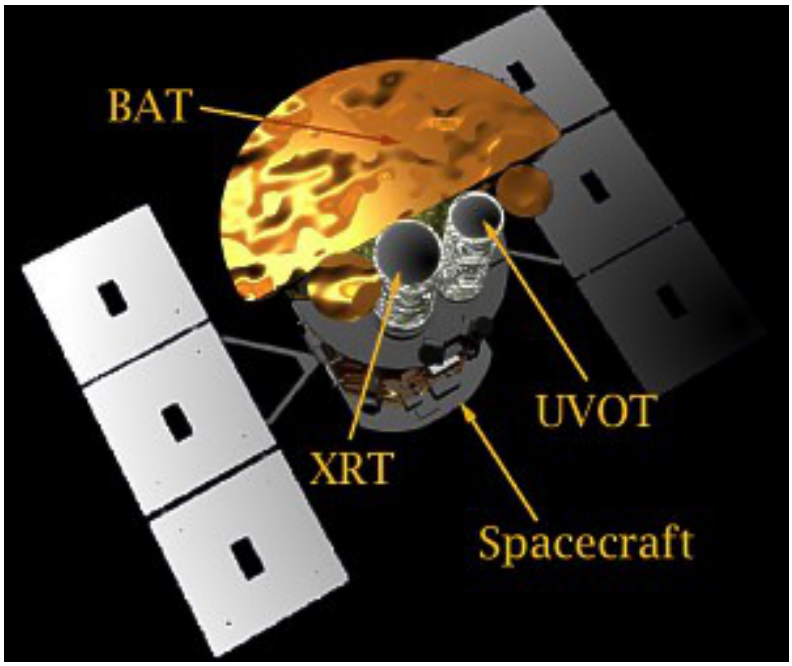

Figure 1: This figure shows the placement of the three telescopes on *Swift*.

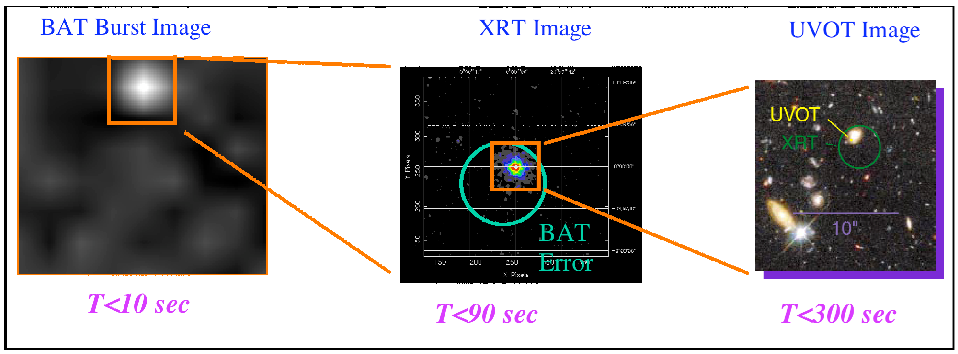

Figure 2: Rapid localization of GRBs with *Swift*.

2 Observatory Policy

2.1 Proprietary Data Rights

There are *no* proprietary rights to any of the data obtained with the *Swift* Observatory. All data will be released to the community, as described in §9, as soon as they have been processed by the Swift Data Center.

2.2 Guest Investigator Program

The *Swift* GI Program solicits proposals for basic research that is relevant to the *Swift* GRB mission. Cycle 12 of the *Swift* GI Program began in April 2016 and will last for 12 months. Cycle 13 will begin in April 2017 and last for 12 months.

The *Swift* GI Program is open to all principal investigators, *but funding is only available to scientists at U.S. institutions for proposals with a principal investigator at a U.S. institution.* U.S.-based co-investigators on non-U.S. led proposals do not qualify for funding.

The GI Program is intended to provide the following benefits to participating scientists.

- Provide funding for theoretical investigations that will advance *Swift* mission science return. Theory proposals are not restricted to GRB investigations and will be considered provided that they address the degree to which the investigations directly advance *Swift* science goals.
- Provide funding for correlative GRB observations that involve new or enhanced ground-based infrared capabilities for investigating high redshift bursts. Proposals to bring new or enhanced ground-based IR capabilities online may require funding substantially above the average award. Such budget requests will be considered provided they are strongly justified.
- Provide funding for other correlative observations that will support *Swift* observations. This category includes both correlative GRB observations and correlative non-GRB observations.
- Provide funding for new *Swift* (GRB and non-GRB) projects.
- Allow observations of non-GRB targets, target of opportunity observations of non-GRB sources, target of opportunity observations of GRB sources detected by other instruments, and fill-in targets.

It is anticipated that a total of five million seconds of observing time will be made available to the Cycle 13 GI program. *Swift* observations will be performed only as the result of an uploaded ground command through the normal science planning process. Proposers *may not* request autonomous slewing. GI observations will have a lower scheduling priority than GRBs and will be observed on a best-effort basis as time becomes available in the observing schedule.

This restriction means that successful proposers should be aware that they are not assured 100% of the time awarded will actually be available. Every effort will be made to observe 80% or more of an accepted program within scheduling constraints. A single observation is defined as one requested pointing at a target, but proposers should be aware that, due to *Swift*'s low orbit and scheduling priorities, any GI observation longer than approximately 20-30 min is likely to be split into multiple snapshots on different orbits.

Non-target-of-opportunity proposals are subject to the following limitations.

- Requested time per observation will be limited to between 1000 s (minimum) and 40 000 s (maximum).
- Monitoring programs are defined as programs requiring two or more observations of the same object, each of which is considered to be a "visit".
- No more than 2000 visits will be permitted in Cycle 13. This is the total for all proposal categories, including both monitoring and non-monitoring observation requests.

Time constrained observations are subject to the following limitations.

- The length of the observing window must exceed three (3) hours.

There is no limit on the number of time-constrained observations.
ToO proposals are subject to the following constraints.

- Proposals must give exact, detailed trigger criteria and a realistic estimate of the probability of triggering during Cycle 13.
- Proposals must assign a priority to each ToO target based on the time criticality of the observation. For the time of the trigger the priorities are described as:
  - **Highest Urgency:** Observations should be performed within four (4) hours
  - **High Urgency:** Observations should be performed within 24 hours.
  - **Medium Urgency:** Observations can be performed within 1–7 days.
  - **Low Urgency:** Observations can be performed within weeks.
- There are no restrictions on the maximum number of highest- and high-urgency ToOs that will be performed.

Large proposals are defined as proposals that have more than 100 targets or more than 100 ks total exposure time. Due to *Swift*'s low Earth orbit, and scheduling priorities for other objects, any long observation exceeding a few ks will be broken up into several different visits on different orbits.

Fill-in targets are intended to provide a list of peer-reviewed targets that can be used to fill in gaps in *Swift*'s planned science observations timeline. Fill-in targets must not be ToOs, must have no observational constraints, and can not require multiple observations. The total requested integration time must be between 1000 s and 40 000 s. There is no guarantee that any fill-in target will be observed, or reobserved if observations are interrupted. There is *no* funding available for fill-in observations.

Key Projects are intended to greatly advance the *Swift* science program, enhance its breadth of impact, and represent an enduring legacy of *Swift* results. Proposals in this category may request support for new *Swift* projects, theoretical investigations, observations of non-GRB non-ToO targets, and observations of ToO targets. The proposed research plans can be carried out in one or two years. Key Projects proposals may also require funding in the range of $100,000 per year. Such budget requests will be considered, provided they are **strongly justified**. Proposals requesting fill-in targets or support for correlative observations cannot be submitted into this category.

Successful proposers do *not* get any proprietary rights to any *Swift* data. Table 1 lists the critical dates for Cycle 13 GI proposals. For more information please see the *Swift* Guest Investigator Program Web page[10].

Date	Action
Sep 23, 2016	Phase 1 Proposals Due at 4.30pm EDT
early Dec 2016	Proposal Review
Feb 2017	Phase 2 Budget Proposals Due
Apr 1, 2017	Cycle 13 Investigations Begin
Mar 31, 2018	Cycle 13 Investigations End

Table 1: Critical dates for the *Swift* Cycle 13 GI Program.

2.2.1 Joint Swift/XMM-Newton Program

Proposers interested in making use of *Swift* time as part of their XMM-Newton science investigation may submit a single proposal in response to the XMM-Newton Announcement of Opportunity. The award of *Swift* observing time will be made to highly ranked XMM-Newton proposals and will be subject to approval by the *Swift* Project. The awarded *Swift* time will last for 12 months, no multi-year awards are supported by the Swift GI program. Details about the Program elements will be posted on the XMM-Newton Science Operations Centre web site as soon as they become available. No funds will be provided from the *Swift* Project for such joint *Swift*/XMM-Newton investigations.

[10] http://swift.gsfc.nasa.gov/proposals/swiftgi.html

2.2.2 Joint Swift/Chandra Program

Proposers interested in making use of *Swift* time as part of their Chandra science investigation may submit a single proposal in response to the Chandra Call for Proposals. The award of *Swift* observing time will be made to highly ranked Chandra proposals and will be subject to approval by the *Swift* Project. Details about the Program elements will be posted on the Chandra web site as soon as they become available. No funds will be provided from the *Swift* Project for such joint Swift/Chandra investigations.

2.2.3 Joint Swift/INTEGRAL Program

Proposers interested in making use of *Swift* time as part of their INTEGRAL science investigation may submit a single proposal in response to the INTEGRAL Announcement of Opportunity. The award of *Swift* observing time will be made to highly ranked INTEGRAL proposals and will be subject to approval by the *Swift* Project. Details about the Program elements will be posted on the INTEGRAL web site as soon as they become available. No funds will be provided from the *Swift* Project for such joint Swift/INTEGRAL investigations.

2.2.4 Joint Swift/NRAO Program

Starting from Cycle 11, a joint Swift/NRAO observing program has been established, as detailed in a Memorandum of Understanding[11]. By this agreement, NRAO permits the *Swift* Program to award up to 5% of scientific observing time on NRAO's VLA, GBT and VLBA, or up to 200-300 hours per year on each telescope. The allocation of time on the Atacama Large Millimeter/Submillimeter Array (ALMA) is not covered by this agreement. The *Swift* Project will make funding available to successful U.S.-based investigators who request NRAO observing time through the Swift GI process. Only proposals falling in the NRAO Regular proposals and Triggered proposals categories are eligible for observing time through this joint opportunity. Radio data acquired through the Swift GI Program will be the property of the proposers for the standard NRAO 12-month proprietary period. The award of NRAO observing time will be made to highly ranked *Swift* GI proposals and will be subject to approval by NRAO.

Proposers interested in making use of *Swift* time as part of their NRAO science investigation may also submit a single proposal in response to the NRAO Call for Proposals. The award of *Swift* observing time will be made to highly ranked NRAO proposals and will be subject to approval by the *Swift* Project.

No funds will be provided from the *Swift* Project, however successful NRAO investigators may request financial support by applying to the the *Swift* GI Program through the correlative observations category.

[11] http://swift.gsfc.nasa.gov/proposals/nrao.html

3 Observing Strategy

3.1 Observing

One of the key features of *Swift* is its ability to rapidly respond to the detection of a new transient source. As soon as a new, unknown transient is detected by the BAT the BAT will localize it to within 1–3 arcminutes. This position is distributed by the GCN within approximately 20 seconds of the initial detection. If the on-board software (see §3.2) determines that follow-up observations should be made, the spacecraft will automatically slew so that the transient is within the FoVs of the XRT and UVOT.

Swift's low orbit and pointing constraints (see §3.6) prevent it from having a continuous viewing zone. To accommodate this *Swift* observing is broken into snapshots of 5 to 30 minutes each, or up to 45 minutes for a GRB or uploaded ToO target. Figure 3 shows an example of the overall observing strategy.

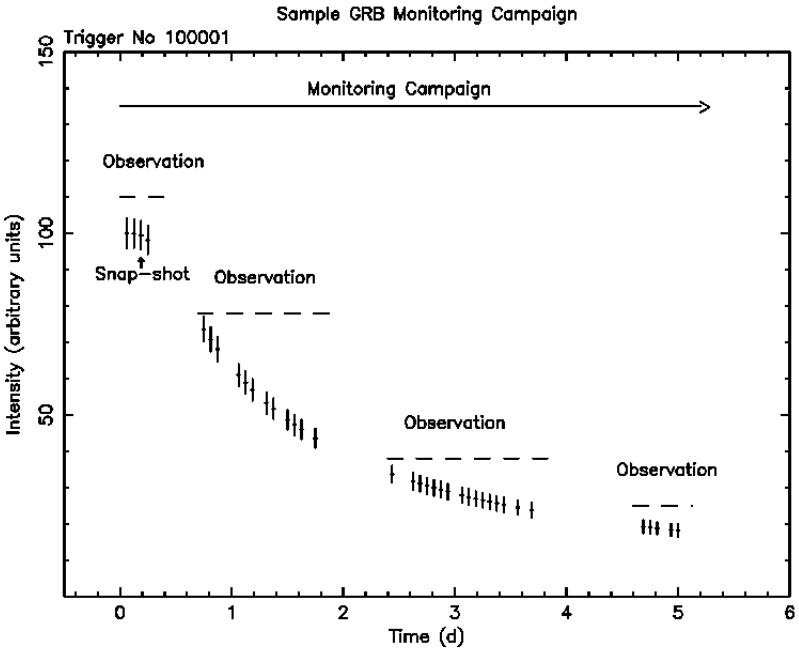

Figure 3: This figure shows an example of *Swift* observations of a GRB over a period of five days. Each observing segment (called a snapshot) is approximately 20–30 minutes long due to Earth occultation. A set of snapshots make up an observation segment. Observation segments for different transients will be interwoven to allow the monitoring of multiple sources.

The first observation segment will consist of an automated set of observations. The following observation segments are pre-planned and will be uploaded from the ground. *Swift* will observe each transient with all three of its telescopes and follow them until the automated observing sequence ends, another transient is detected, or a new observing sequence is uploaded from the ground.

Swift will slew to the location of an uncataloged transient source that is detected by the BAT as soon as possible after the initial detection. Automatic slewing to known sources is currently disabled (with a few exceptions for sources that are deemed to be unusually interesting). However, if a known source brightens above a certain threshold a message is sent to the ground and distributed through the Gamma-Ray Burst Coordinates Network (GCN). The slew time for *Swift* depends on the distance from the initial pointing to the final pointing, but the typical slew rate is approximately one degree per second. On-orbit experience has shown that XRT and UVOT observations with the narrow-field instruments begin during the prompt emission phase for some bursts. Table 2 shows an example sequence and approximate time scales for distributing alerts of transient sources detected by *Swift*. These times are approximate and depend on the details of *Swift*'s initial pointing relative to the transient, the slew time, ground communications, and other factors. Table 2 is intended to provide an overview of a typical detection sequence, assuming a slew time of 80 seconds.

The initial GRB position is normally determined by the BAT. However, if a burst is not detected by the BAT—because it occurred in a part of the sky where the BAT is not looking, or it falls below BAT's detection threshold—then the *Swift* Observatory Duty Scientist can initiate at Target of Opportunity observation by uploading a position from another satellite to *Swift*. In either case (a BAT-detected position or an uploaded position the spacecraft software plans and executes an autonomous slew to the new target. A "Figure of Merit" (FoM; §3.2) is calculated for each new burst based on information from the three instruments and the spacecraft. If the FoM is larger than that of the current observation then the current observation is interrupted and the spacecraft slews to the position of the new transient.

Each of the three *Swift* instruments (BAT, XRT, and UVOT) produces rapid alert messages after a GRB is detected (see Table 2). To ensure prompt delivery of transient detections to the ground these messages are sent through the Tracking and Data Relay Satellite System[12] (TDRSS) to the GCN for delivery to the astrophysics community. The entire delivery process takes approximately 20 seconds for the initial BAT positions (3 arcminute radius error circle) and approximately 70 seconds for XRT positions (5 arcsecond radius error circle).

When *Swift* is not engaged in prompt observations of GRBs it will follow a schedule uploaded from the ground. This schedule will provide for long-term follow-up observations of GRB afterglows, and for other science. A one- or two-day plan will be uploaded each working day, and at other times as needed. The MOC can generate a new schedule in less than two hours should the need arise.

[12] http://tdrs.gsfc.nasa.gov

Time	Activity
0 s	BAT detects transient
10 s	Slew begins
20 s	BAT localization distributed via GCN (20 s requirement)
90 s	XRT acquires GRB
90 s	UVOT begins observing
95 s	XRT image obtained
95 s	XRT localization
	BAT light curves distributed via GCN
100 s	XRT localization distributed via GCN
120 s	XRT spectrum obtained
135 s	XRT spectra distributed via GCN
250 s	UVOT finding chart obtained
300 s	Optical finding chart distributed via GCN
2 h	UVOT initial filter sequence complete
1.5–3 h	Ground station pass
	All burst data downloaded
	Return to pre-planned schedule

Table 2: This is the sequence and approximate time scale for *Swift*'s activity when a new transient source is detected, or when a known source exhibits a rebrightening. These times are approximate and are intended to provide an overview of a typical detection sequence, assuming a slew time of 80 seconds. This Table is *not* intended to be a detailed description of *Swift*'s activity for each detection.

3.2 The Figure of Merit

The Figure of Merit is the on-board instrument flight software module that is used to coordinate the observations of pre-planned and autonomous targets. When *Swift* is not observing a transient source it will perform pre-planned observations. During this time the BAT continually processes event data in order to detect transient sources. When a transient is detected the BAT determines its location and sends a notification to the MOC via the TDRSS link. Then the FoM evaluates the merit of this transient against the current observation to determine if the current observation should be interrupted in favor of observing the transient source. When the FoM decides that it is appropriate to slew to the new burst the FoM will request that the spacecraft slew to the new position and begin observations.

The design of the FoM is determined by the top-level science requirements of the *Swift* mission and is designed to maximize the amount of science data returned. The top-level FoM science requirements are listed below.

- Minimize the time delay to slew to a new burst (the design goal is less than 0.4 seconds for FoM processing).

- Not significantly degrade the observations of GRB afterglows by *Swift*. The predicted number of XRT afterglow photons shall be greater than 80% of the total predicted for an optimally efficient system.
- Multi-orbit automated observations of new BAT source locations to maximize the XRT and UVOT observing efficiency during the critical early phase of the afterglow.
- Maximize observing time for the uploaded program whenever a target is not being observed.
- Automated termination of automated observing of a target at completion of a pre-determined observing strategy.
- Pre-specified uploaded observations to override automated observations.
- Automated observations triggered by TDRSS commands.
- Allow the current automated target to override new GRBs based on input from the instruments.
- Allow the extension of automated observing time based on input from the XRT and UVOT.
- Allow for adjustment of the fraction of observing time allocated to the automated and uploaded programs for extended automated observations.
- Allow for termination of automated observing by command from the ground.
- Allow for a workable mechanism to implement new automated observations after launch.
- The capability to disable slew requests to the spacecraft by command.

The FoM software is provided by the science team and primarily affects the observing efficiency. The baseline observing strategy produced acceptable performance in the simulations, but we expect this strategy to be adjusted as we learn more about GRBs. The FoM can also accommodate more focused studies of specific GRB questions.

3.3 Orbital Information

Swift was launched on November 20, 2004 in a 584×601 km orbit with an inclination of 20.6 degrees and an orbital period of approximately 95 minutes. The spacecraft has passed its minimum scheduled life of two years, but the orbit is expected to remain stable until at least 2025. Detailed information about the spacecraft's attitude and orbital data will be maintained in housekeeping files at the Swift Data Center.

3.4 The South Atlantic Anomaly

Satellites launched into low Earth orbits with moderate inclinations will pass through the South Atlantic Anomaly (SAA). For *Swift* SAA passage occurs on approximately seven consecutive orbits per day. During passage through the SAA the high particle flux will affect *Swift*'s detectors. The orbital inclination (20.6 degrees) reduces the time that *Swift* will spend in the SAA but does not eliminate the problem. Therefore, the *Swift* instruments take several measures to protect themselves during SAA passage.

The BAT high voltage remains enabled during an SAA passage, but event collection and GRB triggering are disabled.

Simulations indicate that the XRT CCDs will not suffer damage from soft protons reflecting off the grazing incidence optics. The hard protons encountered in the SAA will slowly degrade the spectral resolution of the XRT instrument, an effect that is mitigated by features of the instrument's design. In order to avoid saturating the XRT telemetry with particle events during SAA passage the XRT's data collection is turned off during each SAA passage.

In order to protect the UVOT detectors the UVOT cathode voltage is set to zero and the MCP23 voltage is set to 70% of its nominal value during SAA passage. UVOT begins observing again after *Swift* has exited the SAA.

3.5 Slewing

The spacecraft will slew to a new target when directed to by the pre-programmed observing sequence. It will also slew to a new target whenever the BAT detects a new GRB with a FoM that is greater than that of the current observation.

The peak slew rate of the spacecraft is one degree per second, so XRT observations will typically begin approximately 90 seconds after the BAT trigger (median start time).

When a slew starts the XRT will end the current observation and start taking calibration frames. When these are complete, it will switch to Windowed Timing mode for the remainder of the slew. See §5.2 for a description of the XRT's modes.

The UVOT will not collect data during a slew. When the slew is complete the UVOT requires three seconds to settle. During this period the target is in the UVOT's field of view, at which time observations will begin. However, the target's location is only known to BAT accuracy (3 arcminutes). The UVOT finding chart is not produced until *after* the UVOT has settled. The UVOT cathode voltage will ramp up during this period of settling, so photometry on this data can not be calibrated in the standard manner.

3.5.1 Pointing Accuracy

The study of *Swift* pointing accuracy was updated in August 2013, and include all the observations carried out from October 1st, 2007 until August 22nd, 2013. The pointing accuracy was calculated by comparing the target positions in the

Pre-Planned Science Timeline (PPST) to the target positions in the As-Flown Science Timeline (AFST), which describes the observations that actually were performed.

Figure 4 reports the offset distribution between the pre-planned and the as-flown target positions. The median pointing accuracy is 1.2 arcmin, with a tail of the distribution extending to a few arcmin (<5.3 arcmin with 99% probability).

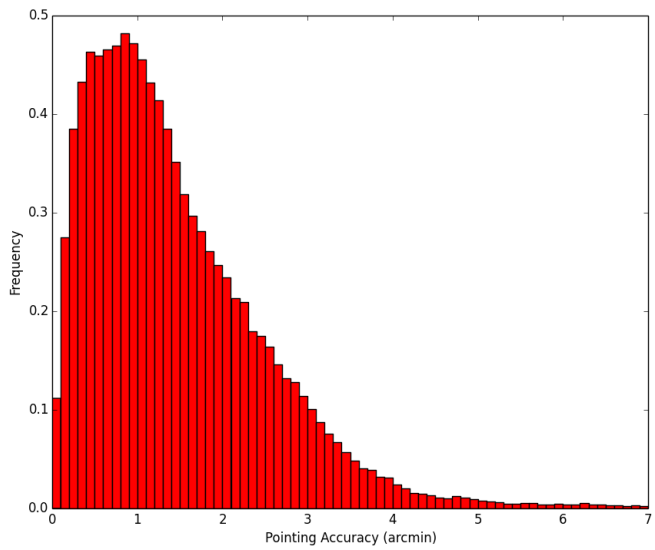

Figure 4: Histogram of the separation between the PPST and the AFST positions.

3.6 Pointing Constraints

There are several pointing constraints on the *Swift* spacecraft that proposers should be aware of. The spacecraft will not point any instrument within:

- 28 degrees of the Earth's limb (95 degrees from the center of the Earth),
- 46 degrees of the Sun, and
- 23 degrees of the Moon.

Targets near the declination of *Swift*'s orbital pole (+- 69 deg) could be unobservable for long periods of time as they violate its Earth constraint. An additional constraint is that the targets roll angle must keep the solar panels

pointed within 10 deg of the Sun. Proposers are encouraged to use the Roll Angle Calculator to estimate the allowed range of roll angles values for their target. Bright objects presents a hazard for the UVOT, and the instrument automatically sets its blocked filter when pointing close to them. The angular distance limits is 25 arcminutes for Venus, Mars, Jupiter, Saturn, and for stars between ?1.4 mag and 0.0 mag. No restrictions apply to Uranus, Neptune, and Pluto, while Mercury is too close to the Sun to be observed. Stars in the UVOT FoV are checked in the onboard star catalog for color and brightness, from which a predicted theoretical count rate is calculated. If a star would produce 200 000 counts per second or more the field is not observed. If the total counts received for any star during this pointing (up to approximately 45 minutes) reaches 1 000 000 the exposure is terminated and the next filter is tested.

If the total count rate on the whole UVOT detector is greater than about 200 000 counts then counts are lost in the electronics and a dark band will appear in the image. At 200 000 counts per second the magnitudes listed in Table 3 would be just observable, although coincidence loss would make measuring a reliable magnitude impossible.

Filter	Spectral Class	Magnitude
v	B1V	4.5
	A1V	5.1
	G2V	5.1
	M2V	5.0
uvw2	A1V	3.2
white	B1V	9.1
	A1V	7.6
	G2V	7.0
	M2V	7.0

Table 3: Approximate bright magnitude limits for UVOT observations of stars.

The UVOT detector has an autonomous onboard safety circuit that is designed to activate and turn off the detector when it senses that an observation is dangerous. The UVOT's safety circuit can trip during GRB chasing observations.

3.6.1 Optical Loading

Bright optical sources can also liberate significant charge in the XRT CCD, affecting the detection of X-rays at the location of the optical source. Above a certain level the X-ray event energy calibration and grade are affected, and for brighter objects it can cause X-ray events to be rejected or spurious events to be detected. Due to the wavelength-dependent response of the XRT CCD, the impact of optical loading[13] is a function of stellar type.

[13] http://www.swift.ac.uk/analysis/xrt/optical loading.php

Which level is relevant depends on the expected X-ray count-rate of the source in question, and the exposure time. e.g., if you are studying a source with an X-ray flux of 1 cts s^{-1}, then optical loading at a level of 10^{-2} cts s^{-1} may be acceptable; but if you are searching for faint sources in deep exposures, optical loading of 10^{-3} cts s^{-1} is likely to contaminate your results. The level of optical loading can be estimated using the web tool[14] provided by the UKSSDC.

[14] http://www.swift.ac.uk/analysis/xrt/optical tool.php

4 The Burst Alert Telescope

The Burst Alert Telescope (BAT; Barthelmy, et al. 2005, SSRv, 120 143) is a highly sensitive, large FoV instrument designed to provide critical gamma-ray triggers and 4-arcminute positions. It is a coded aperture imaging instrument with a 1.4 steradian field-of-view (half coded). Figure 5 shows the field of view of the BAT. The energy range is 15–150 keV for imaging with a non-coded response up to approximately 500 keV. Within approximately the first ten seconds of detecting a burst, the BAT will calculate an initial position, decide whether the burst merits a spacecraft slew and, if worthy, send the position to the spacecraft.

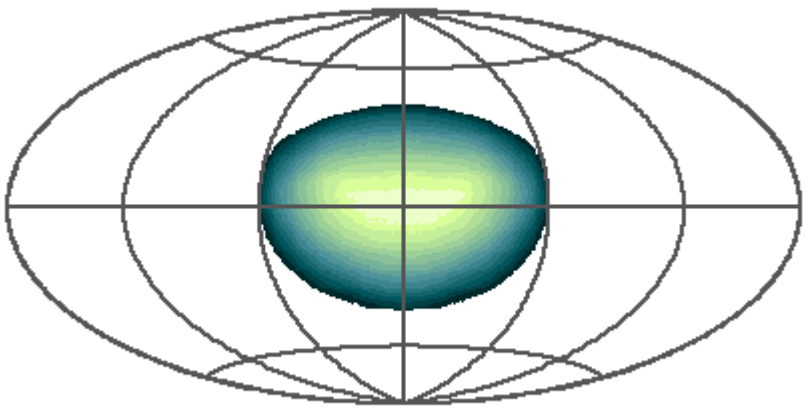

Figure 5: The FoV of the BAT superimposed onto an Aitoff projection of the sky. Color represents the coding fraction with white indicating fully coded and blue indicating partially coded.

In order to study bursts with a variety of intensities, durations, and temporal structures, the BAT has a 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 to detect a good fraction of bright bursts. Since the BAT coded aperture FoV always includes the XRT and UVOT FoVs, long duration gamma-ray emission from a burst can be studied simultaneously in the X-ray and UV/optical regimes. The data from the BAT will also produce a sensitive hard X-ray all-sky survey over the course of *Swift*'s mission. Table 4 lists the BAT's parameters.

BAT Parameter	Value
Energy Range	approximately 15–150 keV (imaging)
Energy Resolution	approximately 5 keV at 60 keV
Aperture	Coded mask, random pattern, 50% open
Effective Area	approximately 1400 cm^2 (see caption)
Detection Area	5240 cm^2
Detector Material	CdZnTe (CZT)
Detector Operation	Photon counting
Field of View	1.4 sr (half-coded)
Detector Elements	256 modules of 128 elements/module
Detector Element Size	$4 \times 4 \times 2$ mm
Coded Mask Cell Size	$5 \times 5 \times 1$ mm Pb tiles
Telescope PSF	22 arcminutes FWHM
Source Localization	1–3 arcminutes radius
15–150 keV Sensitivity (5σ)	$2 \times 10^{-8}\sqrt{(T/1\mathrm{s})}$ erg cm^{-2} s^{-1}
Number of Bursts Detected	approximately 100 localizations per year

Table 4: Characteristics of the BAT. The effective area listed above is the maximum on-axis effective area assuming that all 32 768 detectors are enabled.

4.1 BAT Technical Description

The BAT's 32 768 pieces of $4 \times 4 \times 2$ 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). 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 293 K, and its thermal gradients (temporal and spatial) will be kept to within one K. The typical bias voltage is -200 V, with a maximum of -300 V.

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

A graded-Z fringe shield, located both under the detector plane and surrounding the mask and and detector plane, reduces background from the isotropic

cosmic diffuse flux and the anisotropic Earth albedo flux by approximately 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 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. This is described in detail in the Figure of Merit section (§3.2) of the *Swift* Technical Handbook.

4.2 BAT Operations

The BAT runs in two modes: burst mode, which produces burst positions; and survey mode, which produces hard *X*-ray survey data. In the survey mode the instrument collects count-rate data in five-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.

4.2.1 Burst Detection

The rate 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-II* GRB observatory and upgraded based on *HETE-II* 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 continuously tracks hundreds of these criteria sets simultaneously. The criteria can be adjusted on orbit. The trigger threshold is commandable, ranging from 4- to 11-sigma above background noise with a typical value of 6.5-sigma. A key feature of the BAT instrument for burst detection is its imaging capability. Following a trigger the on-board software will check for and require that the trigger corresponds to a 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 0.1 milliseconds, which is the time stamp resolution. The absolute timing accuracy depends on the on-orbit accuracy of the spacecraft clock relative to UTC. The MOC maintains a log of the offset between the spacecraft clock and UTC. These data are used to reconstruct the absolute timing of of BAT events. The goal is to obtain an absolute timing accuracy of better than 0.2 milliseconds. When a burst is detected the sky its location and intensity is immediately sent to the ground and distributed to the community through the GCN.

4.2.2 Hard X-ray Survey

While searching for bursts the BAT performs an all-sky hard *X*-ray survey and monitor for hard *X*-ray transients. The BAT accumulates detector-plane maps every five minutes. These 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 two years. For regions where there are perpetually numerous strong sources in the BAT's FoV (i.e. the Galactic Plane), the limiting sensitivity is approximately 3 mCrab.

For on-board transient detection 5-minute detector-plane count-rate maps (5 minutes is the nominal exposure; in some cases the exposure may be greater or less) are accumulated in 80 energy bandpasses. 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 to be transients. Sources that do not match anything in the on-board catalog are considered to be GRBs. A subclass of long smooth GRBs that are not detected by the burst trigger algorithm may be detected with this process. Data on all of the hard X-ray transients that are detected are distributed to the astrophysical community through the GCN, just like the bursts are.

4.3 BAT Instrument Performance

A typical spectrum of the 60 keV gamma-ray line from an Am-241 radioactive source for an individual pixel is shown in Figure 6. It has a full-width-half maximum (FWHM) at 60 keV of 3.3 keV ($\Delta E/E = 5\%$), which is typical of CZT detectors. The typical FWHM resolution based on on-orbit performance is approximately 5 keV at 60 keV. The typical BAT background event rate in the full array above threshold is about 10 000 counts per second. The region around the SAA produces exceptionally high rates, and within the SAA itself BAT event processing is disabled. The background rate yields a GRB sensitivity of approximately (8 mCrab) $(T/20\text{ks})^{0.5}$ (15–150 keV) where 8 mCrab $= 2 \times 10^{-10}$ erg cm^{-2} s^{-1}. The burst sensitivity depends on burst duration. For example, the approximate observed 5-sigma sensitivities for bursts of duration 100 ms, 1 s, and 100 s are 9×10^{-8}, 2.8×10^{-8}, and 2.8×10^{-9} erg cm^{-2} s^{-1} respectively. These estimate are based on good observing conditions. If the particle background is high, or if there are nearby bright sources such as Sco X-1 or the Crab, the sensitivity will be degraded. More detailed sensitivity calculations can be done using the full BAT response matrix inPIMMS[15] (the Portable Interactive Multi-Mission Simulator).

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 22 arcminutes FWHM, yielding a conservative 3 arcminute centroiding capability for bursts and steady-state sources given an 8-sigma burst threshold.

The BAT team maintains a BAT Digest[16], which provides up-to-date information about issues that affect BAT observations and data analysis.

[15] http://heasarc.gsfc.nasa.gov/docs/software/tools/pimms.html
[16] http://swift.gsfc.nasa.gov/analysis/bat_digest.html

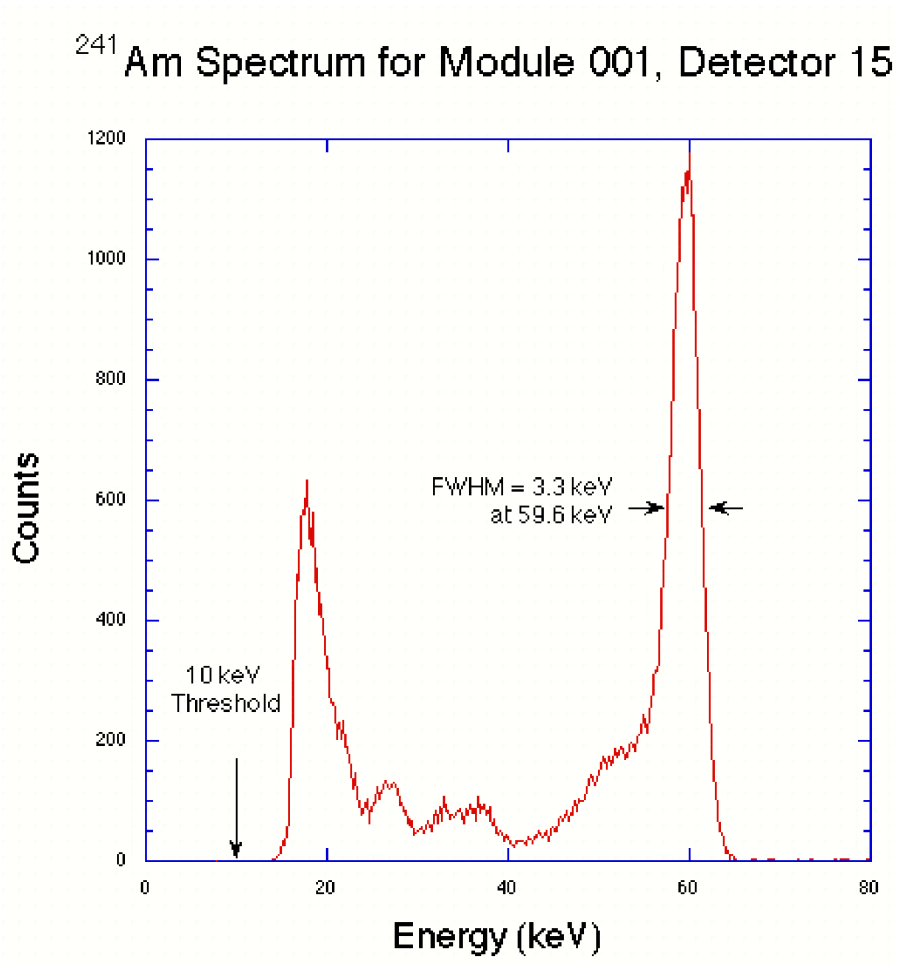

Figure 6: A typical BAT spectrum of Am-241 for a single CZT pixel.

5 The X-Ray Telescope

Swift's X-Ray Telescope (XRT; Burrows, et al. 2005, SSRv, 120, 165) is designed to measure the fluxes, spectra, and light curves of GRBs and their afterglows over a wide dynamic range covering more than seven orders of magnitude in flux. The XRT will pinpoint GRBs to 5-arcsecond accuracy within ten seconds of it target acquisition for a typical GRB, and will study the X-ray counterparts of GRBs beginning 60–80 seconds after the burst discovery and continuing for days to weeks. Table 5 summarizes the XRT parameters. More detail about the XRT can be found in Burrows et al. (2005, Sp. Sci. Rev., 120, 165).

XRT Parameter	Value
Energy Range	0.2–10 keV
Telescope	Wolter 1
Detector	E2V CCD-22
Effective Area	120 cm^2 at 1.5 keV
Detector Operation	Photon-counting, integrated imaging, and timing
Field of View	23.6×23.6 arcminutes
Detector Elements	600×602 pixels
Pixel Scale	2.36 arcseconds
Telescope PSF	18 arcseconds HPD at 1.5 keV
	22 arcseconds HPD at 8.1 keV
Sensitivity	4×10^{-14} erg cm^{-2} s^{-1} in 10 000 s

Table 5: Characteristics of the XRT.

5.1 XRT Technical Description

The XRT is a focusing X-ray telescope with a 120 cm^2 effective area, 23.6 arcminute FoV, 15 arcsecond resolution (half-power diameter, HPD) at 1.5 keV, and a 0.2–10 keV energy range. The XRT uses a grazing incidence Wolter 1 telescope to focus X-rays onto a 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 the FM3 units built, qualified and calibrated as flight spares for the JET-X instrument on the *Spectrum-X-Gamma* mission To prevent on-orbit degradation of the mirror module's performance, it is maintained at 293 ± 5 K with gradients of less than 1 K by an actively controlled thermal baffle. 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*[17] mission, is a three-phase frame-transfer device, using high resistivity silicon and an open-electrode structure to achieve a useful bandpass of 0.2–10 keV. The CCD consists of an image area with 600×602 pixels (40×40 μm) and a storage region of 600×602

[17] http://heasarc.gsfc.nasa.gov/docs/xmm/xmm.html

pixels (39×12 μm). At launch the FWHM energy resolution varied from 50 eV at 0.1 keV to 190 eV at 10 keV. Below 0.5 keV the effects of charge loss to surface states in the silicon 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 30–35 μm to give good QE at high energies. The detectors was intended to operate at approximately 173 K to ensure low dark current and to reduce the CCD's sensitivity to irradiation by protons (which can create electron traps which ultimately affect the detector's spectroscopy). During activation of the XRT the power supply for the thermo-electric cooler failed. XRT is currently passively cooled. Spacecraft pointings are monitored and in some cases restricted in order to keep XRT cooler than approximately 223 K.

5.2 XRT Operations

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 Imaging Mode produces an integrated image measuring the total energy deposited per pixel and does not permit spectroscopy.

Photodiode Mode This mode is used to obtain high timing accuracy for the rapidly varying flux from a bright source. Spectroscopy is possible in this mode. The timing resolution in photodiode mode is 0.14 ms. *This mode is currently not available.*

Windowed Timing Mode This mode is used to obtain high resolution timing (2.2 ms) with one-dimensional position information. Spectroscopy is possible for sources with fluxes less than 600 mCrab.

Photon-Counting Mode This 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 4×10^{-14} to 3×10^{-11} erg cm^{-2} s^{-1}. Pile-up becomes important for sources exceeding 0.5 ct s^{-1}.

The two timing modes (photodiode and windowed timing) sacrifice position information to achieve high time resolution and bright source spectroscopy through rapid CCD readouts.

5.3 XRT Instrument Performance

The mirror point-spread function (PSF) has an 18 arcsecond half-energy width. Given sufficient photons the centroid of a point source image can be determined to sub-arcsec accuracy in detector coordinates and to better than 5-arcsec on the sky. Figure 7 shows the XRT's PSF.

The XRT resolution at launch was approximately 140 eV at 6 keV, with spectra similar to that shown in Figure 8. The spectral resolution has degraded

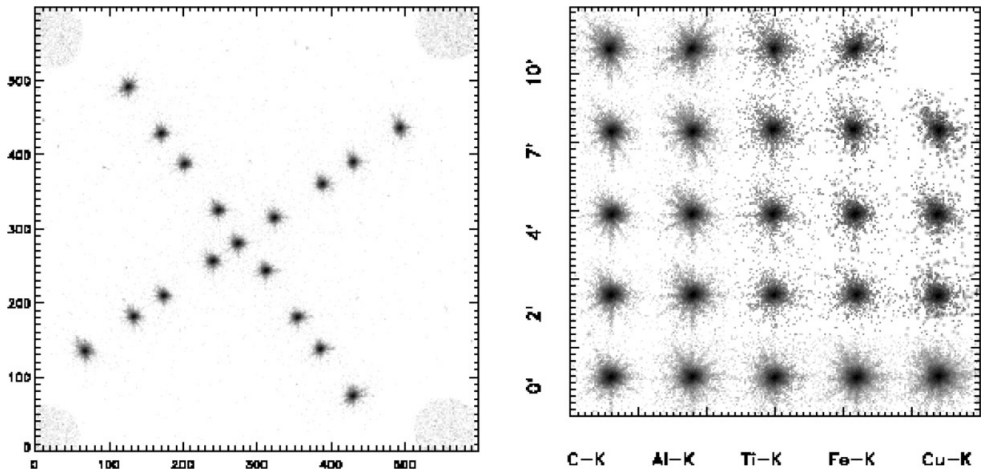

Figure 7: The left panel shows the XRT's PSF at different on- and off-axis positions. It was produced by summing different images taken at different times. The right panel shows a mosaic of images of PSFs for different energies and positions. The energies are 0.28 keV (C–K), 1.49 keV (Al–K), 4.51 keV (Ti–K), 6.40 keV (Fe–K), and 8.05 keV (Cu–K).

during the mission due to the development of charge traps in the detector. We have been measuring these traps and developing software corrections for the charge loss in these traps, which significantly improved the effective energy resolution. Photometric accuracy is good to 10% or better for source fluxes from the XRT's sensitivity limit of between approximately 4×10^{-14} erg cm^{-2} s^{-1} and 8×10^{-7} erg cm^{-2} s^{-1}. The evolution of the XRT spectral resolution is discussed in Pagani et al. 2011, A&A, 534, 20.

5.4 Automated XRT Analysis Tools

For GRBs, enhanced (improved-precision) positions, light curves, hardness ratios, and spectra are automatically produced from the XRT data and posted online[18] as soon as they have been created. These products are customizable, e.g. the light curve binning or temporal coverage of the spectra can be changed.

These products can also be produced on-demand for any point source detected by the XRT, via a Web page[19]. These products are of verified reliability and ready for scientific analysis, however users are advised to sanity-check the results before use. For example, low fractional-exposure light-curve bins, or light-curve bins with very few counts (implying a poorly chosen bin size) should often be discarded.

[18] http://www.swift.ac.uk/xrt_products
[19] http://www.swift.ac.uk/user_objects

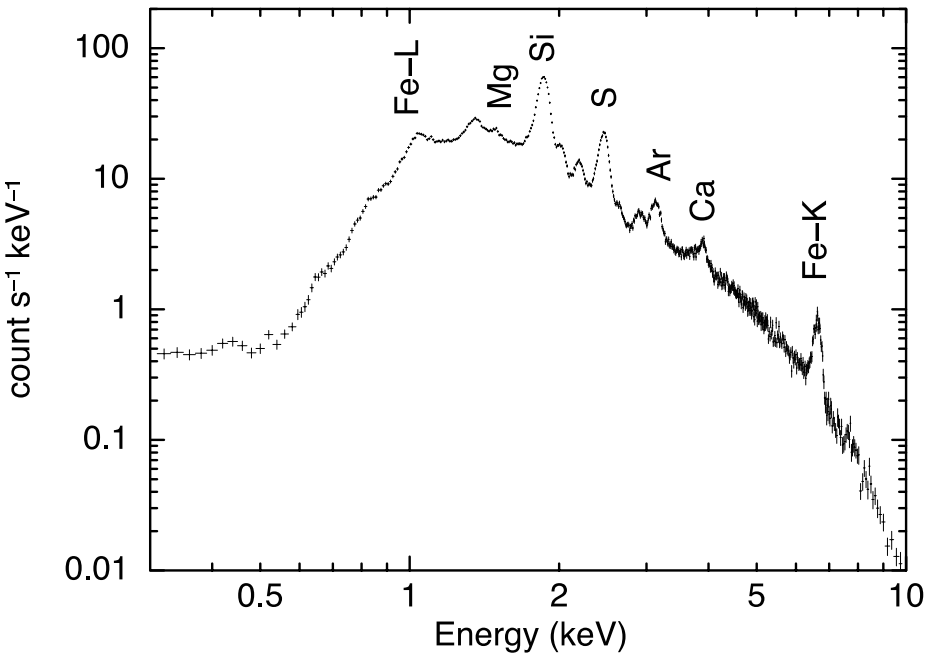

Figure 8: A 13.7 ks observation of the supernova remnant Cas A taken in February 2005 with the XRT.

Documentation and a usage policy[20] is provided online. For full details of how these tools work, and how their reliability was verified, see Evans et al. (2007 A&A, 469, 379), Evans et al. (2009, MNRAS, 397, 1177), and Goad et al. (2007, A&A, 476, 1401).

[20] http://www.swift.ac.uk/user_objects/docs.php

6 The Ultraviolet/Optical Telescope

6.1 Overview of UVOT

The UVOT (Roming, et al. 2005, SSRv, 120, 95) is a modified Ritchey–Chrétien telescope with a 30 cm aperture and an f-number of $f/12.72$. It operates in the wavelength range of 1600–6000 Å, although there is some low-level response in between 6000 Å and 8000 Å. It is mounted on the optical bench with the BAT and the XRT as shown in Figure 9 and co-aligned with the XRT. An 11-position filter wheel houses the UV and optical grisms, a 4-times magnifier, broadband UV and optical filters, a clear "white-light" filter, and blocking filter. Photons register on a micro-channel plate intensified charged-coupled device. These can operate in a photon counting mode and are capable of detecting very low light levels. When flown above the atmosphere the UVOT possesses the equivalent sensitivity of a 4 m ground-based telescope, capable of detecting a 22nd magnitude B star in 1000 seconds using the white-light filter. An outline of the UVOT's characteristics can be found in Table 6.

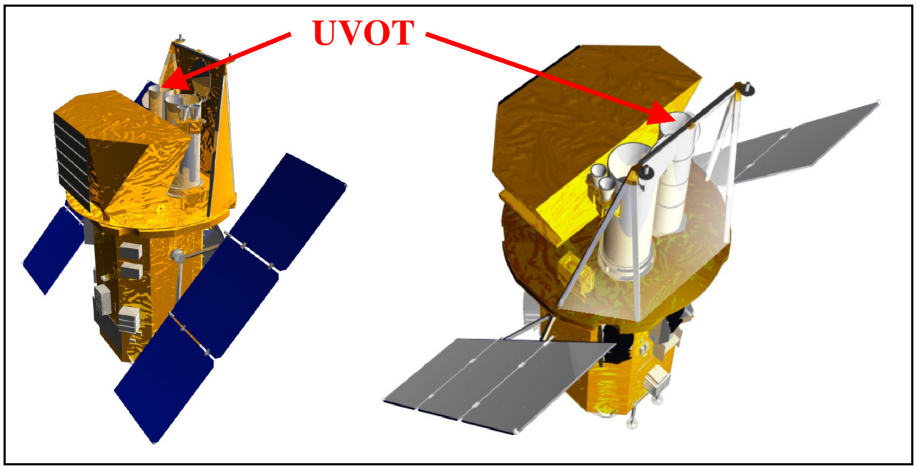

Figure 9: UVOT's placement on the *Swift* optical bench.

6.2 UVOT Description

The UVOT consists of five units (Figure 10): a Telescope Module containing a UV/optical telescope, a Beam Steering Mirror, two filter wheel mechanisms[21], two photon counting detectors, power supplies, and electronics; two Digital Electronics Modules, each one containing a Data Processing Unit, an Instrument Control Unit (ICU), and power supplies for the Data Processing Unit and ICU;

[21] In each case where two units are specified one unit is a "cold" redundant unit.

UVOT Parameter	Value
Telescope	Modified Ritchey–Chrétien
Aperture	30 cm diameter
f-Number	$f/12.72$
Detector	Intensified CCD
Detector Operation	Photon Counting
Field of View	17×17 arcminutes
Detection Elements	256×256 pixels
Sampling Elements	2048×2048 pixels after centroiding
Telescope PSF	approximately 2.5 arcseconds FWHM
Wavelength Range	1600–6000 Å
Filters	11
Sensitivity	$B = 22.3$ in white light in 1000 s
Virtual Pixel Scale	0.502 arcseconds
Timing Resolution	11.0329 ms
Gain	1.0 count ADU^{-1}
Readout Noise	0.0 count s^{-1} pixel^{-1}
Dark Current	7×10^{-5} count s^{-1} pixel^{-1}

Table 6: Characteristics of the UVOT.

and two Interconnecting Harness Units to connect the telescope module to the two Digital Electronics Modules.

6.2.1 Optics

The telescope tube contains a 30 cm primary and 7.2 cm secondary mirror which are both made from Zerodur. The optical train has a primary f-ratio of $f/2.0$ increasing to $f/12.72$ after the secondary. The primary mirror is mounted on a strong back for stability and the secondary mirror is mounted onto spider arms. To maintain focus the mirrors are separated by thermally stable INVAR metering rods. The boresight is near the center of each CCD.

For light rejection there are internal and external baffles. The external baffles are forward of the secondary mirrors and help prevent scattered light from reaching the detectors. The internal baffle lines the inner walls of the telescope tube between the primary and secondary mirrors. Secondary/primary baffles also surround the secondary mirror and the hole at the center of the primary. Behind the primary mirror is the Beam Steering Mirror which directs light to one of the two detectors.

Before the light enters the detector it passes through a filter housed in a filter wheel. Each filter wheel contains the following elements: a blocked position for detector safety, UV-grism, uvw2-filter, v-filter, uvm2-filter, optical-grism, uvw1-filter, u-filter, magnifier, b-filter, and white-light-filter. The characteristics of the UVOT lenticular filters can be found in Table 7. The lenticular

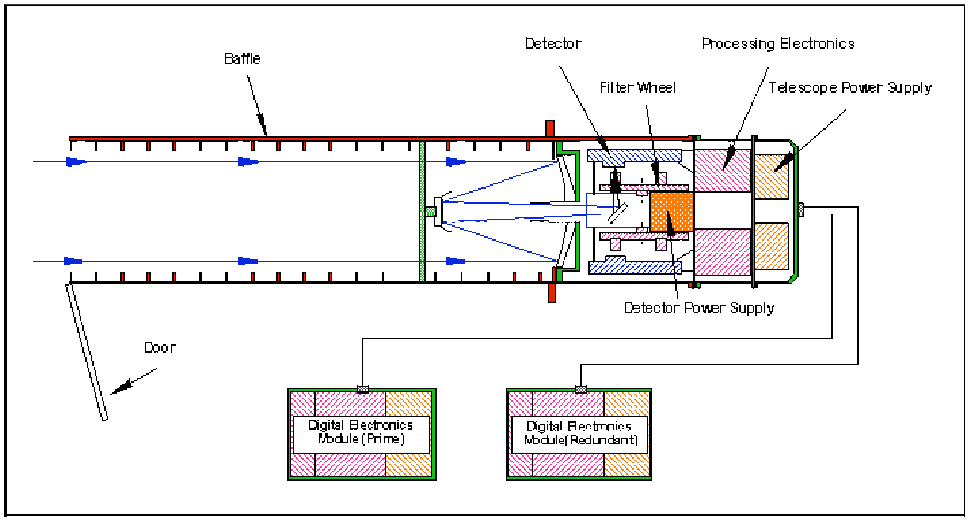

Figure 10: UVOT Schematic.

filter responses (Figure 11) are also provided. The grisms supply a low spectral resolution. The magnifier offers a 4-times increase in the image scale which increases the f-ratio to $f/54$ in the blue and provides diffraction-limited images. It does not operate in the UV because of transmission limitations in this part of the spectrum. Because the focal plane is curved, the filters are weakly figured and the surface of the detector window is concave. The UVOT PSF has an approximate FWHM of 2.5 arcsec, and there are small variations in the width of the PSF between the UVOT filters. The PSF has also been found to vary with temperature, so it can not be assumed to be constant with time. The time-dependent variation in the PSF and its effects on the UVOT photometry is discussed in section 2.2 of Breeveld et al., MNRAS, 406, 1687 (2010).

6.2.2 Detectors

Housed in the electronics tubes are the two detector assemblies. Each detector assembly consists of detector window, an S20 photocathode, three Micro-Channel Plates (MCPs), a phosphor screen, tapered fiber-optics, and a CCD (Figure 12). The CCD has 385×288 pixels, 256×256 of which are usable for science observations. Each pixel has a size of 4×4 arcseconds on the sky thus providing a 17×17 arcminute FoV. The first MCP has pore sizes of 8 micron with a distance of 10 micron between pore centers. The second and third MCPs have pore sizes of 10 micron with a distance of 12 micron between pore centers. The photocathode is optimized for the UV and blue.

Photons arriving from the Beam Steering Mirror enter the detector window and hit the photocathode. Electrons emitted from the photocathode are then

Filter	λ_0	FWHM	z
	(Å)	(Å)	
v	5402	769	4.5–5.6
b	4329	975	3.1–4.5
u	3501	785	2.4–3.3
uvw1	2634	693	1.2–2.8
uvm2	2231	498	1.0–3.0
uvw2	2030	687	0.8–2.3
white	3471	6400	0.8–7.2

Table 7: The effective wavelengths and full-widths at half-maximum (FWHMs) of the UVOT lenticular filter set for the A detector. The z column lists the redshifts where the Lyman limit (912 Å) corresponds to the approximate edges of the filter. This can be used to estimate the photometric redshift. These values are for first approximations only and should be used with caution. The red tails of the UV and White filters make the upper redshift cutoffs somewhat uncertain for these filters. The blue tail of the uvw1 filter makes the low redshift cutoff somewhat uncertain for this filter.

amplified by the three successive MCPs which in turn illuminate the phosphor screen. The photons from the phosphor screen are then sent through the fiber-optics to the CCD. This affords an amplification of 10^6 of the original signal. The detection of photons is accomplished by reading out the CCD at a high frame rate and determining the photon splash's position using a centroiding algorithm. The detector attains a large format through this centroiding algorithm by sub sampling each of the 256×256 CCD pixels into 8×8 virtual pixels, thus providing an array of 2048×2048 virtual pixels with a size of 0.502×0.502 arcseconds on the sky. Residuals of a pattern (referred to as mod-8) formed by creating the 8×8 virtual pixels can be removed by ground processing using the UVOTMODMAP software. At present this is not done for Quick-Look[22] data, but it is done for the "final" data that are sent to the *Swift* Data Archive (usually after about one week). Some of the data that were taken in IMAGE or IMAGE&EVENT mode were sent to the *Swift* Data Archive with the mod-8 noise already applied. Check the processing history in the FITS header for each exposure to determine if this correction has been applied. Unlike most UV/optical telescopes, because UVOT's CCD is read out at a high frame rate, the UVOT is operated in a photon-counting mode.

As with all photon-counting devices there is a maximum count rate limit, which depends on the rate at which the frame is read out. The frame rate of the UVOT detectors is 11.0329 ms for a full 17×17 arcminute frame; therefore, for count rates above approximately 10 counts per second (for point sources) a coincidence loss correction needs to be applied during the data processing. Details of this coincidence loss correction, as well as the dead time correction for

[22] http://swift.gsfc.nasa.gov/quicklook/

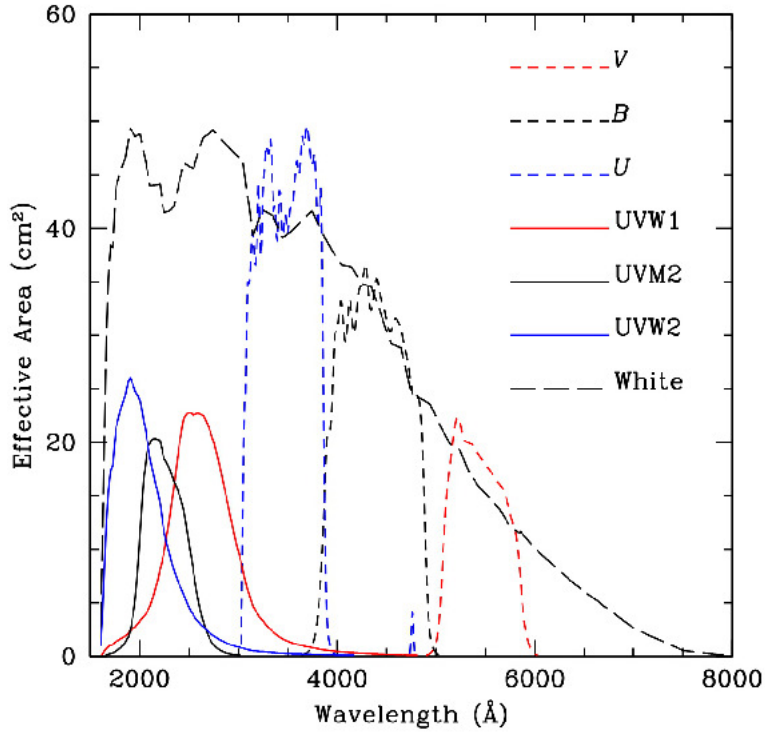

Figure 11: This figure shows the on-orbit UVOT lenticular filter responses.

the loss of exposure time while the frame is being read out, are provided in Poole, et al. (2008, MNRAS, 383, 627). Approximate coincidence loss corrections are given in Table 8. The UVOT photometry software corrects for coincidence lose. Care must be taken when observing bright sources as the local sensitivity of the photocathode is permanently depressed. Autonomous operations diminish the time spent on bright sources (see §6.2.3). The detector's dark noise is extremely low (a mean value of 7×10^{-5} counts s^{-1} $pixel^{-1}$) and can be ignored when compared to other sources of background noise.

6.2.3 Detector Safety

The *Swift* mission requires the UVOT to have autonomous functionality in order to protect itself against potentially damaging bright sources. This is accomplished through the use of a bright source catalog and a real time system for monitoring the raw pixel data from the camera and automatically reducing the detector gain when a signal above a programmable threshold is seen. The bright source limit is typically triggered by sources with a magnitude of $V = 5$–

6. A complicating factor is that brighter stars will suffer from high coincidence losses, making photometry very difficult.

6.2.4 Software

Both digital electronics units in the UVOT contain microprocessors running custom flight software. The ICU software is responsible for controlling and managing all aspects of the UVOT's operations, including:

- autonomous instrument safing in off-nominal observatory conditions,
- autonomous protection of the detector from fields containing bright stars, and
- interacting with the FoM computer to select and execute appropriate science observations.

Many ICU behaviors, most notably the exposure sequences used to observe targets, can be reconfigured via simple table uploads. ICU capabilities are implemented via a combination of compiled Ada code and a custom interpreted scripting language.

The Data Processing Unit software is responsible for reducing and packaging the detector event stream for transport to the ground. Data reduction tasks include spatial windowing of event data (to control telemetry volume), compression of event data, binning of event data into images, compression of images, transformation of engineering data streams into calibration products, and construction of a Finding Chart (which involves source detection). The Data Processing Unit contains significant data buffering capacity to accommodate variation in the science data and telemetry production rates.

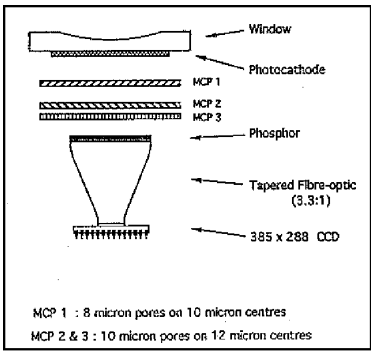

Figure 12: UVOT detector.

Magnitude	u	b	v	uvw1	uvm2	uvw2	white
11	Sat	Sat	1.98	1.55	1.05	1.49	Sat
12	1.46	Sat	1.08	0.77	0.47	0.73	Sat
13	0.71	1.25	0.49	0.33	0.20	0.32	Sat
14	0.31	0.59	0.21	0.14	0.08	0.13	1.41
15	0.13	0.25	0.08	0.06	0.03	0.05	0.68
16	0.05	0.10	0.03	0.02	0.01	0.02	0.29
17	0.02	0.04	0.01	0.01	0.01	0.01	0.12
18	0.01	0.02	0.01	0.00	0.00	0.00	0.05
19	0.00	0.01	0.00	0.00	0.00	0.00	0.02
20	0.00	0.00	0.00	0.00	0.00	0.00	0.01

Table 8: This Table provides approximate coincidence corrections for isolated point sources, designed to help with planning observations. The approximate corrections were calculated using a vega-type spectrum and do not include background; therefore they are lower limits. The values are the corrections, in magnitudes, that need to be subtracted from the uncorrected measured magnitudes in order to get the coincidence-corrected magnitudes. A value of "Sat" indicates that the measured count rate from the source is expected to exceed one count per frame. The actual value of a coincidence correction depends on the type of source and its brightness, the background rate, and neighbouring sources. See Poole, et al.. (2008, MNRAS, 383, 627) for details on computing coincidence corrections.

6.3 Observing Scenarios

There are six observing scenarios for the UVOT: slewing, settling, finding chart, automated targets, pre-planned targets, and safe pointing targets.

Slewing. As the spacecraft slews to a new target, the UVOT does not observe in order to protect itself from bright sources slewing across its FOV and damaging the detector.

Settling. Settling mode only applies to the automated GRB sequences. After notification from the spacecraft that the intended object is within ten arcminutes of the target the UVOT begins observing using the v filter. All photons in the entire 17×17 arcminute FoV are recorded in an event list. During this phase pointing errors are off-nominal, i.e. the target is moving rapidly across the FoV as the spacecraft settles. The positional accuracy is only known to a few arcmin based on the BAT's centroided position. However, positions with an astrometric accuracy of approximately 0.5 arcsec relative to other sources in the field can be reconstructed on the ground. The cathode voltage will ramp up from zero during the settling exposure, so photometry will be unreliable.

Finding Chart. If the intended target is a new GRB and the spacecraft is sufficiently settled, i.e. the pointing errors are small, the UVOT begins a 150 second exposure in the white filter to produce a finding chart. The finding chart is telemetered to the ground in order to assist ground based observers in pinpointing the burst. This is typically accomplished in less than 300 seconds while the afterglow is still bright. The positional accuracy of the finding chart is 0.42 arcsec (radius, 90% containment) for a bright afterglow. This error is dominated by the uncertainty in the star catalog used to aspect correct the image. It is anticipated that for most bursts the XRT will have reported a better than 5 arcsecond position for the target before the end of the finding chart observation (see Figure 2). After the first White finding chart is taken a u-band finding chart with an exposure time of 250 s is taken. A third finding chart will be taken several minutes later to obtain information about the variability of the source. The UVOT will use information from the BAT to make an educated guess as to whether the target is bright enough to allow grism observations to be taken. If the target passes this test, a 50 s UV grism exposure will be taken between the first (white) and second (u) finding charts.

Automated Targets (ATs). Once finding charts have been produced, a several thousand-second automated sequence of exposures, which uses a combination of filters, is executed. This sequence is based on the optical decay profile of the GRB afterglow and time since the initial burst. Most light curves are acquired by cycling through the six broadband filters and the white filter. Source variability during exposures is monitored by collecting data in event mode. New sequences are periodically added and existing ones modified as GRB afterglows become better understood. At present the UV grism is being used in the automated observations of GRB afterglows *if* the BAT properties of the burst suggest that this may be optically bright.

Pre-Planned Targets (PPTs). When there are no automated targets then observation of planned targets (which have been uploaded to the spacecraft) begin. Follow-up of previous automated targets, ToOs, and survey targets are included as planned targets. Because the UVOT filter wheels are limited-life items, many of the PPTs will only use one filter in a day in order to minimize the wear on the filter wheel motors. IMAGE mode data for PPTs are taken using 2×2 on-board binning to reduce telemetry. Scientific justification will need to be provided to the UVOT scientists in order to increase the number of filters used, or change the binning for a PPT observations.

Safe Pointing Targets. When observing constraints do not allow observations of automated or pre-planned targets the spacecraft points to predetermined locations on the sky that are observationally safe for the UVOT.

UVOT observations are taken in observing modes. Modes are sets of predefined observations with pre-specified filters and instrumental characteristics such as binning. In general only pre-defined observing modes will be used. There are several hundred modes available that allow observers to select almost any combination of filters and binning. The primary considerations, in priority order, for selecting a UVOT mode are instrument safety, the volume of telemetry generated, and the science return from the observations.

The commonly used UVOT modes[23] are:

0x30ed 6 filters (no white), 2×2 binning, UV weighting (4:3:2:1:1:1), full frame. This is the default mode for most supernova (SN) and AGN observations. This mode is not normally used for GRB observations

0x30c5 6 filters (no white), 2×2 binning, no weighting (1:1:1:1:1:1), full frame

0x2005 v-band filter, 2×2 binning, Earth limb protection (1:10:1), full frame

0x205d b- and v-band filters, 2×2 binning, no weighting (1:1), full frame

0x2227 white filter, 2×2 binning, Earth limb protection (1:10:1), full frame for first image and 8×8 arcminute hardware frame for the next two. This is the default for faint and faded GRBs that are less than 90 degrees from the Sun.

0x2019 white filter, 2×2 binning, Earth limb protection (1:10:1), full frame. This is the default mode for faint or faded GRBs in the anti-Sun direction.

0x308f The three UV filters, 2×2 binning, no weighting (1:1:1), full frame

0x20d1 The uvw1, u, b, and v filters, 2×2 binning, UV weighted (2:1:1:1), full frame

0x30d5 The uvw2, uvm2, uvw1, and u filters, 2×2 binning, UV weighted (4:3:2:1), full frame. This is the UV Survey mode.

To conserve telemetry and filter wheel rotations Filter of the Day modes are used for very late time GRB observations (after the afterglow has faded to below UVOT detectablity), Galactic Center observations, and many fill-in observations. The following Filter of the Day modes are used.

0x011e The uvw2 filter, 2×2 binning, full frame

0x015a The uvm2 filter, 2×2 binning, full frame

0x018e The uvw1 filter, 2×2 binning, full frame

0x01aa The u filter, 2×2 binning, full frame

[23] https://www.swift.psu.edu/operations/mode_lookup.php

A Hybrid Mode, which observes 1-2 ks in 0x30ed and the rest in Filter of the Day, is also available. The default grism modes are:

122f UV grism, clocked, uvw2

1230 V grism, clocked, uvw1

2243 UV grism, nominal, uvw2

2244 V grism, nominal, uvw1

In all four cases, the grism and UV observations are weighted 10:1. Grism observations are in 1x1, lenticular filters in 2x2. A lenticular observation before the grism is provided by the slew-in-place. The lenticular observations not only serve as Earth limb protection but can provide the anchor points for data analysis.

6.4 Data Products

The UVOT can produce seven types of data products: four science products and three engineering products. A description of the science produces is given below.

Event List. Each photon event is reported by its position on the detector and the associated CCD frame time-stamp. The accuracy of photon arrival time is dominated by the resolution of the CCD frame integration period (≈ 11 ms).

Image. Image data consist of a 2-D histogram (image) of the event stream taken over the specified integration period (generally 10–1000 s). Image pixels correspond to individual detector sub-pixels (1×1 binning) or binned detector sub-pixels (e.g., 2×2 or 4×4 binning). For large numbers of events, image data require much less telemetry than event data, at the expense of greatly reduced time resolution.

Finding Chart. Finding Chart data consist of a small subset of the pixels in an image, carefully chosen to lie under and near the brightest point sources. The number of pixels transmitted per source depends on the total number of sources above a threshold brightness. Pixels that are not in an $N \times N$ grid centered on the brightest pixel in a source are not transmitted to the ground. N is 1, 3, or 5 depending on the number of bright sources in the field. A "sparse" version of the full image can be constructed on the ground, providing a coarse representation of the detected point sources while consuming modest telemetry volume. Finding chart data are sent immediately via TDRSS to the GCN, whereas most other science data are stored for later downlinks via a ground station.

GRB Neighborhood Image (GeNIe). All of the data in the 324×324 Finding Chart pixels around the XRT position are sent to the ground. The purpose of the GeNIe, also called the dark burst image, is to transmit quickly to the ground more definitive information about the sources close to the XRT or BAT GRB position. Instead of transmitting a small number of pixels for each source, the GeNIe is a full image, with each pixel populated with the actual counts received by the detector. The GeNIe is sent immediately after the Finding Chart via TDRSS to the GCN.

6.5 Telemetry Volume

EVENT mode is very data intensive, so there are some limitations on how long UVOT can collect data in EVENT mode due to limitations in the spacecraft data storage capabilities, and the telemetry bandwidth between the UVOT-and-spacecraft and the spacecraft-and-ground station. Full frame event data can only be obtained for short periods of time. In general, the smaller the window size, the longer event data can be obtained.

Most UVOT IMAGE-mode observations will be taken with 2×2 binning in order to conserve telemetry. 1×1 binning can be requested if there is a strong scientific justification.

7 Operations

This section describes how data flows from the spacecraft to the ground and into the Swift Data Archive.

7.1 The Tracking and Data Relay Satellite System

The Tracking and Data Relay Satellite System[24] is a communication signal relay system which provides tracking and data acquisition services between spacecraft in low-Earth orbit and spacecraft control, or data processing, facilities.

The TDRSS space segment consists of seven on-orbit Tracking and Data Relay Satellites (TDRSs) located in geosynchronous orbit. The spacecraft constellation is distributed to provide global coverage.

The TDRSS ground segment is located near Las Cruces, New Mexico and consists of two functionally identical ground terminals collectively known as the White Sands Complex. Commands and data for *Swift* are uplinked from the MOC to the TDRSS and then from the TDRSS to *Swift*. Return data are downlinked from *Swift* via the TDRSS to the MOC at PSU.

- TDRSS is used to track the spacecraft and to transmit State of Health telemetry for the spacecraft and its instruments from *Swift* to the ground.
- TDRSS is used to send burst alert messages to the ground. *Swift* will be in nearly-constant contact with the TDRSS so that burst alerts can be received when *Swift* is not in contact with its ground stations. The TDRSS link is used to download BAT localizations of transient sources approximately 12 seconds after initial detection by the BAT, XRT localizations (approximately 90 seconds after the initial detection), and an optical finding chart (approximately 300 seconds after the initial detection).
- TDRSS can also be used to upload commands that allow *Swift* to observe ToOs. This capability is intended to allow *Swift* to rapidly observe transients that occur outside the field of view of the BAT, but are detected by other satellites.

7.2 Ground Stations

The primary ground station for the *Swift* spacecraft is the Malindi Ground Station, which is located in Kenya at 40.1945 degrees east longitude and 2.9956 degrees south latitude. *Swift* also uses ground stations of NASA's Near Earth Network, and a ground station in Singapore. Each ground station uplinks spacecraft commands received from the MOC. It also receives spacecraft real-time housekeeping data and forwards it to the MOC in real-time. Ground stations also receive and record high rate spacecraft data, then forward it to the MOC after each contact.

[24] http://tdrs.gsfc.nasa.gov

7.3 The Mission Operations Center

The Mission Operations Center is located at Pennsylvania State University in State College, PA. It operates the *Swift* satellite and its instruments. The MOC supports pre-launch, launch, early orbit activation, as well as normal and contingency operations. The MOC performs all spacecraft and instrument mission planning, commanding, and monitoring.

Telemetry (Level 0) data from a ground-station contact are sent to the MOC. The MOC processes these data into packets, which are grouped by data type and sorted by time, and then makes them available to the *Swift* Data Center.

The MOC also has the ability to upload rapid response instructions to *Swift*. These allow follow-up observations of new GRBs detected by the on-board FoM software, and ToO inputs from the science team or the science community.

7.4 The Swift Data Center

The *Swift* Data Center is located at NASA's Goddard Space Flight Center[25] (GSFC) in Greenbelt, MD, USA. The *Swift* Data Center converts *Swift* Level 0 data products (telemetry) received from the MOC into Flexible Image Transport System[26] (FITS) files and standard data products using a semi-automatic processing pipeline. The format of the FITS files is consistent with Office of Guest Investigator Programs[27] (OGIP) standards. The Swift Data Center generates level 1, 2, and 3 data products. The data sets are organized by target to facilitate later scientific analysis. Quick-Look[28] data products are made on a shorter time scale using less complete telemetry and the same processing pipeline. Quick-Look data are made available in the Quick-Look area as soon as they are produced. The data in the Quick-Look will change as new data become available from the MOC. Finished data products are permanently stored in the *Swift* Data Archive. Quick-Look data will be removed after the data have been put into the permanent Data Archive[29]. The Swift Data Center receives new data from the MOC once per ground station contact, so the Quick-Look area will be updated on this time-scale. Figure 13 shows the flow of data through the *Swift* Data Center into the Data Archive. The Data Archive is described in detail in §9.2 of the *Swift* Technical Handbook.

7.5 The Swift Science Center

The Swift Science Center[30] is located at NASA's GSFC. The SSC is responsible for providing the astrophysics community with tools and support for analyzing *Swift* data. The SSC is responsible for testing *Swift* software packages, maintaining instrument calibration data for all three telescopes, and for maintaining

[25] http://www.nasa.gov/centers/goddard/home/index.html
[26] http://heasarc.gsfc.nasa.gov/docs/heasarc/fits.html
[27] http://universe.gsfc.nasa.gov/ogip/
[28] http://swift.gsfc.nasa.gov/quicklook/
[29] http://swift.gsfc.nasa.gov/archive/
[30] http://swift.gsfc.nasa.gov/

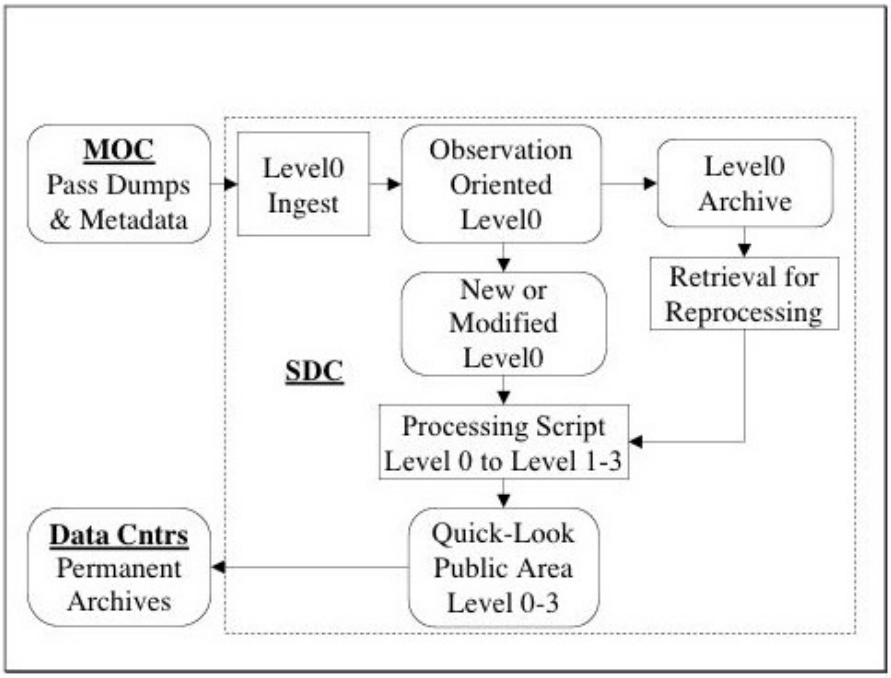

Figure 13: The flow of data through the Swift Data Center.

documentation for the data sets and analysis software. In addition the SSC manages the help center that provides the astrophysics community with advice on analyzing *Swift* data.

The SSC also assists with the Guest Investigator program reviews.

The SSC is based on similar efforts to support the users of *ROSAT*[31], *ASCA*[32], and *RXTE*.

[31] http://heasarc.gsfc.nasa.gov/docs/rosat/
[32] http://heasarc.gsfc.nasa.gov/docs/asca/

8 Data

8.1 Data Organization

Snapshot A snapshot is the time spent contiguously observing a target. This time is shorter than a single orbit due to interruptions from other targets, Earth occultation, and other observing constraints.

Observation This term is used to organize data in the *Swift* Data Archive. An observation is a collection of snapshots on a single target where the roll angle remains more or less constant across the separate snapshots.

Exposure This term is used only to organize the UVOT data into FITS files by mode (image or event) and filter. An exposure is defined as the time UVOT spends in the same general state for all parameters: mode, window size and filter.

8.2 HEASARC Data Levels

Swift data conforms to the HEASARC[33] standards. There are three levels of data that are archived.

Level 1—Raw Data Level 1 data are telemetry (also known as Level 0 data) that have been converted to FITS format files. No data processing is done in the conversion from telemetry format to FITS format. Examples of Level 1 data are the raw images, uncalibrated event lists, and detector plane histograms.

Scientists generally need to start their analysis from Level 1 products only if there have been improvements in the telescope calibration since the most recent data reprocessing, or if non-standard data screening is intended. Images are stored in raw detector coordinates. Event data are unscreened and recorded in raw detector coordinates. Level 1 data are merely the telemetry and TDRSS data after it has been converted to FITS format files.

Level 2—Reduced Data Level 2 data have been calibrated and have had some data processing done on it. Examples of Level 2 data are detector and sky images, and calibrated event lists.

It is envisaged that most scientists will start their analysis from the Level 2 products. The data reduction pipeline has been performed on images and event tables. Images are stored in J2000 sky coordinates (RA,Dec), although grism data are also stored in corrected detector coordinates. Exposure maps for each individual image are available. Columns containing corrected detector and sky coordinates have been populated. Event data have been screened for standard bad times, e.g. SAA passage and Earth limb avoidance.

[33] http://heasarc.gsfc.nasa.gov/

Level 3—High-Level Data Products Level 3 data are source level products. They are science data that can be used by the community. Examples of Level 3 data are source catalogs, calibrated spectra, and light curves.

Level 3 data products are intended to be quick-and-dirty representations of many of the products that the scientist would routinely create during their analysis; e.g. time-averaged images, light curves, spectra, etc. Since they are created non-interactively they are not intended as publishable products but as useful guides to the scientist. The number and type of Level 3 products in the archive will be determined by the confidence in any non-interactive burst detection and/or the time since the burst. More Level 3 products will populate the archive at an early stage if the burst has been identified during standard pipeline processing. Products will take longer to arrive if interactive analysis is required to identify the burst.

8.3 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 HEASARC calibration database[34] (CALDB). The CALDB system stores and indexes datasets associated with the calibration of high energy astrophysical instrumentation. The system can be accessed by users and software alike to determine which calibration datasets are available, and which should be used for data reduction and analysis.

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.

Swift calibration files are available from the CALDB. Details of the *Swift* calibrations, including documentation and the current calibration data files, are available at the Swift Calibration Files[35] Web site. All the calibration files in CALDB will conform to the OGIP standard FITS format.

Questions about the calibration of an instrument should be addressed to the Swift Help Desk.

[34] http://heasarc.gsfc.nasa.gov/docs/heasarc/caldb/caldb_intro.html
[35] http://swift.gsfc.nasa.gov/docs/heasarc/caldb/swift/

9 Quick-Look and Data Archive

9.1 Quick-Look Data

The *Swift* Data Center maintains an archive of time-sorted raw telemetry, with duplicates removed, from *Swift* for the lifetime of the mission. Two types of processing occur on the data. First, Quick-Look data are produced after download from the MOC. Quick-Look will be updated and replaced as new data become available. 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 on the Science Data Center's Quick-Look Facility.

In addition to this processing a final pass of the data through the processing pipeline is done when the observation is complete and all the data are at the *Swift* Data Center. This run through the pipeline produces the data that are stored in the permanent archive. The final processing run uses the same pipeline and software as the Quick-Look processing does. About one week after the end of an observation, the data are moved from the Quick-Look Facility to the Swift Archive at HEASARC[36] and then removed from the Quick-Look Facility.

The Quick-Look data products are usually available within two hours of the telemetry data arriving at the Swift Data Center. Quick-Look data is provided so that the scientific community has rapid access to *preliminary* data from the *Swift* mission. The Quick-Look data products may not be complete and will be reprocessed as new data arrives.

9.2 The Swift Data Archive

The HEASARC contains all the information, data, and software needed to make analysis of *Swift* data by the community straightforward, well-understood, and well-supported. In addition to housing the Swift Archive, all *Swift* data analysis software (*Swift* tools in HEADAS) is distributed by the HEASARC. The HEASARC also provides the Web server hosting the SSC Web site[37]. The SSC Web site includes 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.

For each observation, the Swift Archive will include the TDRSS messages (organized by their unique trigger number) and all Level 1, Level 2 and Level 3 FITS files (organized by observation) generated during the final pipeline processing on the data. Calibration data and files are also archived, and served via the CALDB. All archived *Swift* data will be in FITS format and comply with OGIP standards. GIF and HTML files will also be included for the purposes of previewing data before downloading, or to provide a record of the data processing.

[36] http://heasarc.gsfc.nasa.gov/
[37] http://swift.gsfc.nasa.gov/

In addition to observations of GRBs and their afterglows each *Swift* instrument will conduct a sky survey in its wavelength region. The instrument teams are responsible for planning the survey, analyzing the data, and delivering survey data and products to the Swift Archive. The Swift survey data will be organized in the archive according to observation time. The XRT survey is being conducted by Italian *Swift* Archive Center[38] (ISAC), the BAT survey by the BAT team at GSFC and Los Alamos National Laboratory[39] (LANL), and the UVOT survey by the UVOT team members at Mullard Space Science Laboratory[40] (MSSL).

BAT Survey The BAT Survey (Baumgartner, et al. 2013, ApJS, 207, 19) will produce the following products.

- A catalog and data products associated with sources found in the BAT field of view.
- Data are analyzed on four time scales:
  1. by orbit,
  2. by multiple orbits with the same attitude (approximately one day),
  3. by all-sky accumulation every six months, and
  4. by all-sky accumulation over the entire mission.

XRT Survey The XRT Survey (D'Elia, et al. 2013, A&A, 551, A142; Evans, et al., 2014, ApJS, 210, 8) will produce the following products.

- Catalog and data products associated with sources found in the XRT field of view.
- Summed data from similar pointings collected over approximately three weeks.

UVOT Survey The UVOT Survey will produce the following products.

- Catalog and data products associated with sources found in the UVOT field of view.

9.3 Other Archives

In addition to the HEASARC, *Swift* archival data will also be served to the community via mirror sites at the ISAC[41] and the UKSSDC[42] at the University of Leicester[43] in the United Kingdom.

[38] http://swift.asdc.asi.it/
[39] http://www.lanl.gov/
[40] http://www.mssl.ucl.ac.uk/pages/
[41] http://swift.asdc.asi.it/
[42] http://www.swift.le.ac.uk/
[43] http://www.le.ac.uk

10 Software Tools

10.1 Data Processing and Analysis Support

The SSC maintains software for processing and analyzing *Swift* data. Details about this software is available on the Swift Data Analysis Web page[44].

10.2 Swift Software

A set of software tools for reducing and analyzing *Swift* data has been developed. These tools are incorporated into the FTOOLS[45] software. FTOOLS is a general package of software to manipulate FITS files. A list of the *Swift* software tools can be obtained using the FTOOLS `fhelp swift` command.

The *Swift* software is publicly available from HEASARC's HEAsoft Web page[46]. Any questions or bug reports should be sent to the Swift Help Desk.

10.3 Simulation Tools

The HEASARC makes available several tool for simulating *Swift* data and planning observations. These can be used to estimate the measured count rates, determine the observed spectrum based on an input model source, compute expected signal-to-noise ratios, and perform other tasks to assist in preparing proposals. Proposers are encouraged to use the *Swift* Planning Tools[47] and to justify their use of *Swift* by simulating observations of the sources that they are interested in studying.

This Section contains an overview of the simulation tools that are available for performing *Swift* BAT, XRT and UVOT simulations.

10.3.1 XSpec

XSpec[48] is a command-driven, interactive, *X*-ray spectral-fitting program, designed to be completely detector-independent so that it can be used for any spectrometer. All of *Swift*'s spectral data can be used in XSpec. XSpec is distributed as part of the HEAsoft[49] software package. Extensive help with XSpec is available simply by typing `help` at the XSpec prompt and following the instructions.

WebSpec is a Web tool based on XSpec. WebSpec implements a subset of the functionalities of XSpec. It allow easy access and use without the need to install software, but WebSpec does not have all the functionality of XSpec. An example of using using XSpec to simulate GRB spectra, and using UVOT data in XSpec, is available at the SSC proposers Web page[50]. Please note that the

[44] http://swift.gsfc.nasa.gov/analysis/
[45] http://heasarc.gsfc.nasa.gov/docs/software/ftools/ftools_menu.html
[46] http://heasarc.gsfc.nasa.gov/lheasoft/
[47] http://swift.gsfc.nasa.gov/proposals/#tools
[48] http://heasarc.gsfc.nasa.gov/docs/xanadu/xspec/index.html
[49] http://heasarc.gsfc.nasa.gov/lheasoft/
[50] http://swift.gsfc.nasa.gov/proposals/swift_xspec_sim.html

response matrices provided there may not be the most up-to-date versions and care should be taken when using them to simulate spectra. The most up-to-date response matrices can be obtained from the *Swift* CALDB.

10.3.2 Simulating Swift Data Using WebSpec

WebSpec provides a Web-based facility for simulating spectra for a variety of combinations of missions and instrument using several different physical models. It utilizes XSpec and thus has similar inputs and produces similar results as an XSpec fit does.

There are currently two ways to run WebSpec. First, there is the initial WebSpec page, which provides a straightforward means for specifying the desired model. The more experienced XSpec user may wish to use the more advanced WebSpec interface[51].

Users who wish to simulate BAT spectra should also see the help file for the batphasimerr task in the current *Swift* software release.

[51] http://heasarc.gsfc.nasa.gov/webspec/webspec_advanced.html

10.3.3 WebPIMMS

WebPIMMS[52] is a Web tool based on PIMMS (the Portable Interactive Multi-Mission Simulator) created by Koji Mukai. WebPIMMS implements a subset of the functionalities of the command line PIMMS. It allows easy access and use without the need to install the software, but WebPIMMS does not have all the functionality of the command line version.

An example is comparing what *Swift* will see from a GRB similar to one that was observed by *BeppoSAX*[53]. Take a GRB with a peak count rate in the SAX/MECS detector of 65 counts/s, that is in its early phase, and was measured to be well-described by a power law with a photon index 1.2. What would *Swift* observe?

To perform this comparison using WebPIMMS do the following.

1. Choose `SAX/MECS Count Rate 2 MECS` for **Convert From** using the pull-down menu.

2. Choose `SWIFT` for **Into** from the pull-down menu. You may use the default values for the energy range of the input detector. If the count rate you have is over a smaller range of energy change the default energy range in the next box.

3. Input `65` in the **Source: Flux/Count Rate** box. WebPIMMS will automatically chose the units of counts/s due to your choice of input above.

4. Choose a value of the Galactic hydrogen column density, nH, and a redshift. For this example choose `1e19` cm^2 for nH, and a redshift of `0.65`.

5. Choose a source model. For this example select a power law with a photon index of `1.2`.

6. Click the **Estimate Count Rate** button to perform the calculation.

The WebPIMMS output screen (see below) summarizes the input parameters and displays estimated count rates for the XRT, BAT and UVOT. More information about the response matrices used can be found on the SSC Web site.

[52] http://heasarc.gsfc.nasa.gov/Tools/w3pimms.html
[53] http://www.asdc.asi.it/bepposax/

```
                         Output from PIMMS


Input Parameters:

Model #1: Power Law Model #2: Model #3: Model #4:

P_l/keV: 1.2 P_l/kev: P_l/keV #3:

Galactic nH: 1e19 cm-2
Intrinsic nH: 0.0 //cm-2

Redshift: 0.65
From: sax mecs
Output Flux energy range: keV;
Count Rate: 65 cps
Internal model normalization = 1.174E+00
Redshifted with z= 0.6500 and a Galactic Hh= 1.000E+19



Useful mission related information may be found at:
http://swiftsc.gsfc.nasa.gov/
http://heasarc.gsfc.nasa.gov/docs/sax/inst_papers.html



                              SWIFT XRT


PIMMS predicts 1.429E+02 cps with SWIFT XRT PC
(Grade 0-12 on-axis count rate for an infinite extraction region)
or 1.117E+03 cps in Grade 0


                              SWIFT XRT


PIMMS predicts 1.521E+02 cps with SWIFT XRT WT
(Grade 0-12 on-axis count rate for an infinite extraction region)
or 1.401E+02 cps in Grade 0


                              SWIFT XRT
```

```
PIMMS predicts 1.632E+02 cps with SWIFT XRT PD
(Grade 0-12 on-axis count rate for an infinite extraction region)
or 1.591E+02 cps in Grade 0


                              SWIFT BAT

PIMMS predicts 9.052E-02 cps with SWIFT BAT SINGLE
(Channel 3-78 count rate per fully illuminated detector)
With 0.2620 background cps, it can be detected at S/N=5.0 in 0.204 s

Results in the 4 standard Swift/BAT survey bands are:


    Channel / Energy     Source     BGD    Detection


   3-7 /  14-24 keV         0.020  0.0766      1.127 s


   8-19/  24-48.9 keV       0.033  0.0835      0.510 s


  20-41/48.9-98.8 keV       0.030  0.0646      0.496 s


  42-78/98.8-194.9 keV  7.828E-03  0.0373      3.662 s


Note PIMMS is primarily an X-ray tool, and extrapolation to the UV
regime introduces additional uncertainties. In particular, PIMMS
assumes E(B-V) = N_H / 4.8E+21 and an average Milky Way extinction law.


                              SWIFT UVOT


PIMMS predicts 1.305E+01 cps with SWIFT UVOT UVW1


                              SWIFT UVOT


PIMMS predicts 8.418E+00 cps with SWIFT UVOT UVM2
```

```
                              SWIFT UVOT

PIMMS predicts 1.982E+01 cps with SWIFT UVOT U

                              SWIFT UVOT

PIMMS predicts 1.481E+01 cps with SWIFT UVOT B

                              SWIFT UVOT

PIMMS predicts 5.610E+00 cps with SWIFT UVOT V

                              SWIFT UVOT

Note: Grisms still use pre-flight effective area files
PIMMS predicts 9.199E+01 cps with SWIFT UVOT UGRISM

                              SWIFT UVOT

Note: Grisms still use pre-flight effective area files
PIMMS predicts 8.686E+01 cps with SWIFT UVOT VGRISM

                              SWIFT UVOT

PIMMS predicts 9.497E+01 cps with SWIFT UVOT WHITE
```

10.3.4 XRT Data Simulator

The ASI Science Data Center[54] in Italy provides a Web-based XRT Data Simulation tool[55]. This tool creates science-like event FITS[56] files from simulated or real sky fields.

10.3.5 UVOT Signal-to-Noise Calculator

The UVOT[57] instrument team at MSSL have developed a Web-based tool for calculating signal-to-noise ratios, background levels, and sensitivity limits for UVOT[58] observations

10.3.6 Viewing

VIEWING[59] is a Web tool which determines when, or if, an astronomical position can be viewed by a given space telescope.

An example is determining when Cyg X-1 will be visible with *Swift*.

Use the VIEWING Web form[60].

1. Select `Swift` from the list of space telescopes.
2. Enter `Cyg X-1` in the **Object Name or Coordinates** box.
3. Select a **Name Resolver**. The default is usually good.
4. Select the `J2000` **Coordinate System** from the pull-down menu.
5. Click the **Submit** button to perform the calculation.

The VIEWING output screen (see below) summarizes the input parameters and time when the object is visible from *Swift*.

[54] http://www.asdc.asi.it/
[55] http://www.asdc.asi.it/simulator/swift/
[56] http://heasarc.gsfc.nasa.gov/docs/heasarc/fits.html
[57] http://swift.gsfc.nasa.gov/about_swift/uvot_desc.html
[58] http://swift.gsfc.nasa.gov/about_swift/uvot_desc.html
[59] http://heasarc.gsfc.nasa.gov/Tools/Viewing.html
[60] http://heasarc.gsfc.nasa.gov/Tools/Viewing.html

```
                Viewing Results

  +-------------------------------------------------+
  | Input equatorial coordinates:                   |
  |   Cyg X-1, resolved by SIMBAD (local cache) to |
  |   [299.5903, 35.2016], equinox J2000.0          |
  +-------------------------------------------------+

                     Swift

   Double-check the latest TOO evaluation criteria
                at the Swift MOC.

   *** VIEWING Version 3.2  run on 2011 Jul 20 ***
        for the period 2011 Jul 20 to 2013 Jul 20

   For Follow-up with Swift (Sun angle range =  46.0-180.0):
                (and Moon avoidance limit of  23.0 degrees)
     Observable throughout the specified period
       and is always far enough away from the Moon

   For preferred TOO observations with Swift (Sun angle range =  46.0-180.0):
                                 (and RA difference > 9.00 hours):
                                 (and Moon avoidance limit of  21.0 degrees)
     Observable between 2011 Jul 20 or before and 2011 Sep 06
       and is always far enough away from the Moon
     Observable between 2012 Jun 06           and 2012 Sep 05
       and is always far enough away from the Moon
     Observable between 2013 Jun 06           and 2013 Jul 20 or later
       and is always far enough away from the Moon
```

Appendices

A Swift Help Desk

All questions regarding the *Swift* Guest Investigator Program, as well as *Swift* observations and data should be directed to the Swift Help Desk. The *Swift* Help Desk can be reached at
`http://swift.gsfc.nasa.gov/helpdesk.html`.

B Frequently Asked Questions

The following is a list of frequently asked questions (FAQs) that are relevant to the *Swift* mission. Please consult these FAQs before contacting a help line.

- The Swift FAQ

  `http://swift.gsfc.nasa.gov/help/swiftfaq.html`

- The HEASARC FAQ

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

- The FTOOLS FAQ

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

C Abbreviations and Acronyms

This appendix contains a list of the abbreviations and acronyms used in *Swift* Technical Handbook.

AGN	Active Galactic Nucleus
ASIC	Application Specific Integrated Circuit
BAT	Burst Alert Telescope
BATSE	Burst and Transient Source Experiment
CALDB	Calibration Database
CCD	Charge-Couple Device
CZT	Cadmium-Zinc-Telluride
Dec	Declination
ESA	European Space Agency
FITS	Flexible Image Transport System
FoM	Figure of Merit
FoV	Field of View
FWHM	Full-Width at Half-Maximum
GCN	Gamma-Ray Burst Coordinates Network
GI	Guest Investigator
GIF	Graphics Interchange Format
GRB	Gamma-Ray Burst
GSFC	Goddard Space Flight Center
HEASARC	High Energy Astrophysics Science Archive Research Center
HPD	Half-Power Diameter
HTML	Hypertext Mark-Up Language
ICU	Instrument Control Unit
INTEGRAL	International Gamma-Ray Astrophysics Laboratory
IRAF	Image Reduction and Analysis Facility
ISAC	Italian *Swift* Archive Center
JET	Joint European Telescope
LANL	Los Alamos National Laboratory
MOC	Mission Operations Center
MSSL	Mullard Space Science Laboratory
NASA	National Aeronautics and Space Administration
OGIP	Office of Guest Investigator Programs
OM	Optical Monitor
PIMMS	Portable, Interactive Multi-Mission Simulator
PSF	Point-Spread Function
PSU	Pennsylvania State University
QE	Quantum Efficiency
RA	Right Ascension
RXTE	*Rossi* X-*Ray Timing Explorer*
SAA	South Atlantic Anomaly
SN	Supernova
SSC	*Swift* Science Center

ToO	Target of Opportunity
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
UKSSDC	United Kingdom *Swift* Science Data Center
USNO	United States Naval Observatory
UTC	Coordinated Universal Time
UV	Ultraviolet
UVOT	Ultraviolet/Optical Telescope
WCS	World Coordinate System
XMM	*X*-Ray Multi-Mirror Mission
XRT	*X*-Ray Telescope
ZP	Zero Point