# The Swift Target of Opportunity Program

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Abstract

The Swift Gamma-Ray Burst Explorer is a flexible, rapid-response multi-wavelength observatory designed to study Gamma-Ray Bursts. The observatory design is ideally suited to multiwavelength followup of Target of Opportunity (ToO) observations from MAXI and other missions.

Key words: missions: Swift

## 1. The Swift Mission

The *Swift* Gamma-Ray Burst Explorer (Gehrels et al. 2004) was launched into low Earth orbit on Nov. 20, 2004. Its Burst Alert Telescope (BAT; Barthelmy et al. 2005) detects transient events and monitors known and transient X-ray sources in the 15–150 keV band. An X-ray Telescope (XRT; Burrows et al. 2005) provides sensitive observations of X-ray sources to fluxes of order $10^{-14}$ cgs in the 0.3–10 keV band with a 24 arcminute diameter field of view and $< 2$ arcsecond position accuracy. An Ultraviolet-Optical Telescope (UVOT; Roming et al. 2005) has subarcsecond position accuracy and sensitivity of order $22^{nd}$ magnitude in the 170–650 nm band. In order to carry out its prime mission of the discovery and rapid follow-up of Gamma-Ray Bursts (GRBs), *Swift* was designed to be agile and autonomous. The characteristics that allow *Swift* to automatically slew to and observe GRBs within minutes of their occurence also allow it to perform rapid, autonomous observations of Targets of Opportunity (ToOs), and the operational design that facilitates flexible rescheduling of new GRBs also permits rapid incorporation of ToOs into our preplanned schedules.

## 2. Swift Science Operations

The Swift observatory is operated from a Mission Operations Center located at Penn State University. The *Swift* operations team consists of a Flight Operations Team responsible for the health and safety of the observatory, and a Science Operations Team (SOT; headed by Dr. Jamie Kennea) responsible for its scientific productivity and operation. The *Swift* SOT comprises a small group of scientists at the *Swift* Mission Operations Center who monitor the scientific performance of the observatory, plan and schedule observations (including GRB followup, GI targets, fill-in targets, and ToOs), and respond to GRBs discovered by *Swift*. One of the key roles within the SOT is that of Observatory Duty Scientist.

### 2.1. The Observatory Duty Scientist

An Observatory Duty Scientist (ODS) is available 24 hours/day, 7 days a week (on a rotating schedule) to respond to GRBs, ToO requests and spacecraft events that affect the scientific performance of the observatory.

Among the duties of the ODS is dealing with new ToO requests. The ODS and the *Swift* Principle Investigator (PI; Dr. Neil Gehrels) are notified automatically when a ToO request is submitted. Once the ToO request has been approved, the ODS will take one of the following actions, depending on the urgency of the target:

- Schedule a rapid satellite response by uploading the coordinates of the target to the spacecraft. This generally overrides other pre-planned targets during the ToO observation. Occasionally this is not possible for targets that happen to be in a part of the sky that warms the XRT detector.

- Add the target to our medium range planning schedule. In this case the target will be scheduled as part of our normal daily planning process, typically resulting in an observations 2-3 days later (unless the request is for an observation further in the future).

## 3. Swift Targets of Opportunity

### 3.1. Target of Opportunity submission

*Swift* ToO requests can be made at *http://www.swift.psu.edu/too.html*. The process involves filling out a simple Web form. In order to submit a ToO request, you must first register using the New User form located at this URL. You will then be allowed to submit ToO Requests using the ToO Request form at the same URL. The ToO Request form requires an RA and Dec for the source, an indication of the urgency of the observations, requested observing time and instrument modes, and several other relevant items. Once the form has been submitted, you should receive an email notifying you that we have received the request.

ToO observation observations require approval by the *Swift* PI. Observations normally take place between between 1 hour and several days later, depending on the urgency of the request and on the *Swift* observing schedule. Following approval (or rejection) of your ToO request, you will get a second email from the current ODS notifying you of the fact. You may receive additional email from the ODS if there are any questions about the implementation of your observing request. Please direct all queries about your observation to *swiftods@astro.psu.edu*, not to the individual ODS who contacted you, as this person may not still be on duty.

### 3.2. Swift ToO Response

Notification to the *Swift* team of the ToO request depends on its urgency and on the time of day in the eastern US. The highest urgency requests (objects that must be observed within 4 hours) page the *Swift* PI and the ODS immediately at any time of the day or night. High Urgency requests (requiring observation within 24 hours) will page the PI and ODS immediately between 8:00 AM and 10:00 PM in the eastern US, but overnight requests will be held until 8:00 AM the next morning before notifying the *Swift* team. Lower priority requests notify the team by email.

The *Swift* team response to ToO requests also depends on the urgency of the request. Targets in the High Urgency category will often be observed within a few hours of the ToO submission if this happens during working hours at the MOC. Medium or Low Urgency targets will typically be scheduled as pre-planned targets in the next planning sequence, which usually means several days after we receive the request.

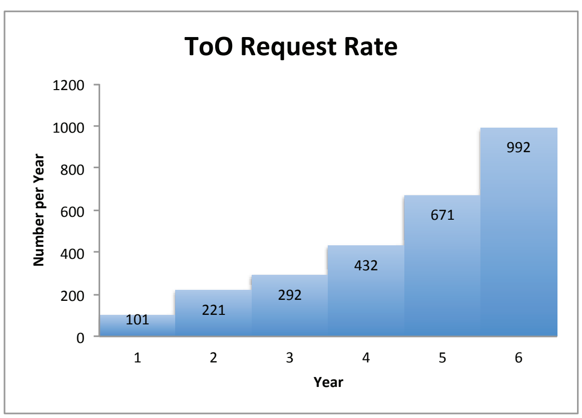


Fig. 1. Number of *Swift* Target of Opportunity requests per year from 2005–2010.

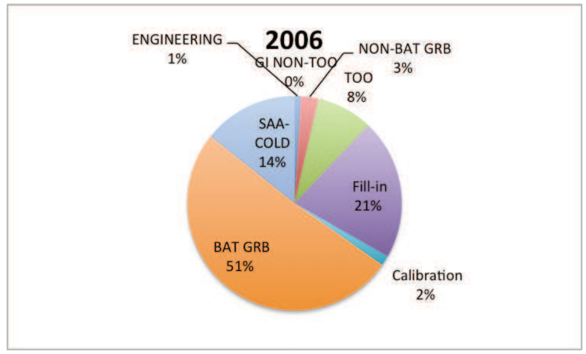


Fig. 2. Distribution of *Swift* observations in 2006. Early in the mission GRBs were taking more than half of the available time, followed by fill-in targets (low priority targets used to fill gaps in the observing schedule). ToO observations used only 8% of the observing time in 2006.

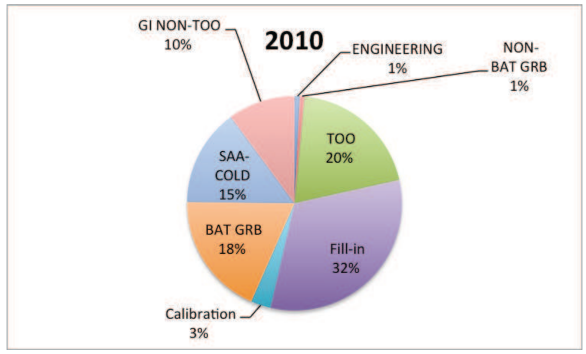


Fig. 3. Distribution of *Swift* observations in 2010. The fraction of time used for GRBs has dropped to 18%, while the time spent on ToOs has increased to 20%.

### 3.3. Swift ToO Statistics

The number of ToO requests submitted to Swift has increased dramatically over the past six years (Fig. 1). As a result of ToO pressure and changes in our strategy for GRB observations, the fraction of time spent observing ToOs has also increased dramatically, from about 8% in 2006 to $>$ 20% in 2010 (Figs. 2-3).

As an example of the typical range of targets and observation goals for *Swift* ToO requests, we show the distributions of ToO observations from September 2009. Fig. 4 shows the distribution by target types. ToO requests typically make use of Swift's multiwavelength capabilities, flexible scheduling, and rapid pointing capability to observe a variety of transient or variable objects, with AGN and X-ray transients dominating the target types.

The distribution of observing goals is shown in Fig. 5. Multiwavelength observations to determine spectral energy distributions (SEDs) account for nearly 40% of observations, followed by monitoring campaigns of variable

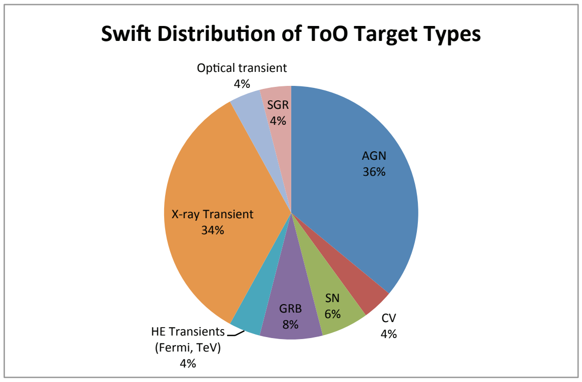


Fig. 4. Distribution of *Swift* ToO observations in Sept. 2009 by target types. Observations of AGN and X-ray transients dominated the ToO observing time.

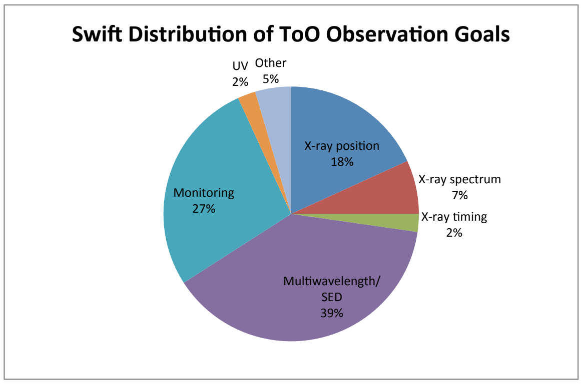


Fig. 5. Distribution of *Swift* ToO observations in Sept. 2009 by observation goal. The biggest fraction of the ToO exposure time is for multiwavelength/SED observations, followed by monitoring campaigns and X-ray target positions.

objects. The third-ranking observational goal is determination of an accurate source position, typically using the XRT.

## 4. Swift-MAXI coordination program

The *Swift* and MAXI teams have established a working group to coordinate *Swift* follow-up observations of MAXI targets. The working group met in February 2009 and again in Feb. 2010 to discuss status and objectives of the joint effort. As part of this work, a *Swift* GI proposal was submitted to perform XRT observations of new X-ray transients discovered by MAXI. This program was accepted and began on April 1, 2010. As of February 2011 this program has triggered on seven MAXI transients, three of which also triggered the *Swift* BAT instrument. Three new X-ray transients have been discovered through this program (Kennea et al. 2011).

### 4.1. Tiling of large error circles

The *Swift* XRT field of view is nearly circular with 23.6 arcminutes diameter. The UVOT field of view is 17 × 17 arcminutes. MAXI error circles are often larger than these fields of view and require special attention when searching for X-ray and optical counterparts of MAXI sources.

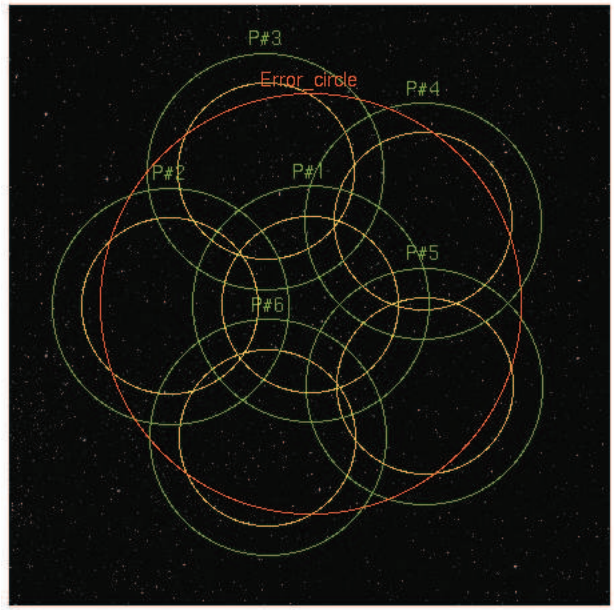


Fig. 6. Overlapping XRT fields designed to cover a 50 arcminute diameter error circle, which is shown in red. It is covered by six XRT pointings, labelled P#1 through P#6. For each of these pointings, the green circle shows the 23.6 arcminute XRT field of view, and the yellow circle shows the field with guaranteed coverage, taking into account slewing inaccuracies. The overlap of the fields is chosen to ensure that there will be no gaps near the center of the error circle, and to minimize gaps at the edges.

Observations of error boxes larger than the XRT/ UVOT fields of view can be accomplished by "tiling" the error box with multiple observations as shown in Fig. 6. Early in the *Swift* mission, this was a laborious procedure that involved setting up multiple manual commands to upload each individual pointing direction to the observatory. We have semi-automated the process, so that tiled observations can now be performed by the ODS using a single script that sets up all of the observations and uploads them automatically to the satellite. However, this still requires multiple ToO uploads to the observatory, with one observation commanded per ground pass. As a result, it takes at least six orbits (about 9 hours) to tile a single $\sim 1$ degree field like that shown in Fig. 6, and it can take substantially longer if the observations span one of the gaps in ground station passes. (These happen one or two times per day when the satellite orbit does not come within range of our ground stations for several orbits).

We expect that this situation will improve significantly in 2011 when we implement a new on-board tiling capability. Unlike the current technique, in which we observe one field per orbit, the new on-board tiling script will allow us to observe all six fields on each successive orbit until the total requested observing time for each field has been satisfied. This technique uploads a single command to the observatory, so the observations are not dependent on subsequent ground station passes and the tiled observations can occur even during our coverage gaps. Because each field is observed on every orbit, it maximizes the probability of finding the source rapidly, when it is still quite bright, and it will allow us to measure light curves with $\sim$ 95 minute sampling of all sources within the error circle, rather than obtaining a single data point on each source.

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## 5. Conclusions

Preliminary results from the *Swift*/MAXI transient source collaboration have been encouraging, and highlight the advantages of the *Swift* mission for performing rapid follow-up observations of newly discovered X-ray sources. We anticipate that *Swift* will continue to provide valuable benefits to the MAXI team through its flexible ToO program.

## 6. Acknowledgements

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## References

Barthelmy S. et al. 2005 SSR., 120, 143
Burrows D.N. et al. 2005 SSR., 120, 165
Kennea J.A. et al. 2011 this volume (*arXiv:1101.6055*)
Gehrels N. 2004 ApJ., 611, 1005
Roming P.W.A. et al. 2005 SSR., 120, 95