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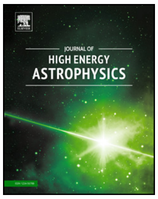

Review

# The Galactic transient sky with *Swift*

Jamie A. Kennea

*The Pennsylvania State University, 525 Davey Lab, University Park, PA 16802, USA*

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ABSTRACT

The unique capabilities of *Swift* that make it ideal for discovery and follow-up of Gamma-Ray bursts also make it the ideal mission for discovery and monitoring of X-ray Transients in the Milky Way and the Large and Small Magellanic Clouds. The Burst Alert Telescope allows for detection of new transient outbursts, the automated follow-up capabilities of *Swift* allow for rapid observation and localization of the new transient in X-rays and optical/UV bands, and *Swift*'s rapid slewing capabilities allow for low-overhead short observations to be obtained, opening up the possibility of regular, sensitive, long term monitoring of transient outbursts that are not possible with other currently operational X-ray missions. In this paper I describe the methods of discovery of X-ray transients utilizing *Swift*'s BAT and also collaboration with the MAXI telescope. I also detail two examples of X-ray transient science enabled by *Swift*: *Swift* discovery and monitoring observations of MAXI J1659-152, a Black Hole candidate Low Mass X-ray Binary in the Galactic Halo, which has the shortest known orbital period of any such system; and *Swift* monitoring of IGR J00569-7226, an edge on Be/X-ray binary that displayed an outburst in 2013 and 2014, and which monitoring by *Swift* allowed for detection of dips, eclipses and the determination of the orbital parameters, utilizing a measurement of Doppler shifts in the pulsar period.

## 1. Introduction

The flare-up of an X-ray transient typically signals a rapid increase in the rate of accretion onto a compact object, a white dwarf (WD), neutron star (NS) or black hole (BH), and provides an ideal laboratory for studying astrophysics in a relativistic regime. Even though transients have been studied for many years, our understanding of the processes behind extreme accretion events remains relatively poor. The term X-ray transients covers a wide range of different system phenomenology, but is typically used to mean Low Mass X-ray Binary (LMXB) and High Mass X-ray Binary (HMXB) systems containing BH and NS secondaries. However, it may also refer to a wide range of transient X-ray phenomena including millisecond pulsars (e.g. Campana et al., 2008), magnetar outbursts (e.g. Kennea et al., 2013), Stellar Flares (e.g. Drake et al., 2014) and many others.

The process of accretion that drives most X-ray astrophysical phenomena can often be dramatic and short lived, with increase in accretion rates causing X-ray flux rises of up to 6 orders of magnitude, in the case of Supergiant Fast X-ray Transients (Romano et al., 2014 and the references therein), from quiescent levels. In many cases these events lead to the discovery of previously unknown systems, or systems that were previously considered uninteresting. These transient events are rare and often short lived, making detection and detailed study difficult. Other transient outbursts may be from sources that were previously known outbursts, but have not been seen for many years, for example BH transient outbursts are known to be recurrent, but the time between outbursts has been reported to be as long as 60 years (Eachus et al., 1976). To obtain a good rate of detection of transient outbursts, X-ray instruments that cover very large areas of the sky are required.

However, wide field and all-sky instruments, such as *Fermi* GBM (Meegan et al., 2009), *MAXI* (Matsuoka et al., 2009), *INTEGRAL* ISGRI (Lebrun et al., 2003) and *RXTE* ASM (Bradt et al., 1993), typically lack the spatial resolution required to provide accurate localizations necessary for further optical and IR observations, and typically do not have enough sensitivity for a detailed analysis of the characteristics of the outburst.

NASA's *Swift* mission (Gehrels et al., 2004) was designed to localize bright X-ray transient events, in this case Gamma-Ray Bursts (GRBs). Its three instruments, the Burst Alert Telescope (BAT; Barthelmy et al., 2005), the X-ray Telescope (XRT; Burrows et al., 2005) and UV/Optical Telescope (UVOT; Roming et al., 2005), provide a unique complement of instruments to discover and follow-up Gamma-Ray bursts. This combined with a spacecraft that provides very rapid and accurate slewing to a target, allows for reporting of Gamma-Ray burst positions within minutes of them being detected.

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*E-mail address:* kennea@swift.psu.edu.

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The same capabilities that make *Swift* so successful at finding GRBs, are equally as well tuned for discovery and localization of bright X-ray Transients. In addition the rapid slewing capabilities of *Swift* allow for low-overhead short ($\sim$ 1–2 ks) observations to be taken, allowing for long-term sensitive monitoring of outbursts to be performed. No other operating mission is capable of high cadence monitoring outbursts in this manner.

In this paper I will explore *Swift*'s ability to detect, localize and follow-up X-ray transients in the Milky Way and the Large and Small Magellanic Clouds, as both a stand-alone telescope and in concert with other X-ray/Gamma-Ray wide field detectors utilizing the *Swift* Target of Opportunity (ToO) program.

## 2. *Swift* discovery and localization of X-ray transients

*Swift* performs observations of new X-ray transients utilizing triggers from both the BAT and from other wide field X-ray and Gamma-ray observatories. In this section I will describe the various methods of detection and follow-up that are commonly used to enable X-ray Transient science with *Swift*.

### 2.1. *BAT triggered X-ray transients*

The BAT covers approximately 1.4 steradian of the sky at any time, and due to *Swift*'s diverse observing strategy, both caused by the large number of targets observed in a typical day, and by the need to observe at least 3 targets per 96 min orbit in order to avoid looking too close to the Earth, BAT on average covers 80–90% of the sky daily (Krimm et al., 2013). Such near all-sky coverage means that it is excellent at detecting new X-ray transients that emit in the 15–150 keV BAT energy range.

When BAT detects a bright unknown transient, it triggers the *Swift* "automated target" (AT) response, which is the same response for GRBs: The BAT localization of the transient, with an error of typically $\sim$3 arcmin, is telemetered to the ground through the Tracking and Data Relay Satellite System (TDRSS), and if possible *Swift* will slew to the coordinates of the transient, and begin follow-up observations with the UVOT and XRT instruments. All *Swift* TDRSS telemetered products are distributed through the Gamma-ray Coordinates Network (GCN; Barthelmy et al., 1995), enabling community follow-up of newly discovered transients.

When observations begin, the XRT takes a series of short images of the field (0.1 s and $\sim$2.5 s long) and attempts to locate the transient utilizing an onboard centroiding algorithm. If the transient is bright enough to be detected in this exposure, this location will be telemetered to the ground through TDRSS within minutes of the initial detection. XRT will perform observations in Auto state, where the CCD will be read out in either in Windowed Timing (WT) or Photon Counting (PC) mode based on the brightness of the new transient (for a description of XRT modes see Hill et al., 2004). If PC mode data is taken, event data are telemetered to the ground through TDRSS for the first orbit, and event reconstruction and astrometric correction, utilizing UVOT data (e.g. Evans et al., 2009), allow for a position to be determined with accuracies up to 1.5 arcsec radius, with XRT data alone allowing an accuracy of up to 3.5 arcsec radius (all errors quoted at 90% confidence). UVOT also takes observations of the field and telemeters these through TDRSS, allowing for a rapid localization of any optical counterparts of the transient within minutes of detection (see for example, Fig. 1).

BAT triggered response allows for very rapid reporting of the location of a new X-ray transient to the community, typically within seconds of detection through GCN alerts, and approximately 10–25 min through GCN Circulars. In addition for X-ray transients, the *Swift* team will issue a report on the coordinates, along with a preliminary spectral analysis to the Astronomers Telegram website (ATel), which is the most common way of reporting new transients in the X-ray transient community.

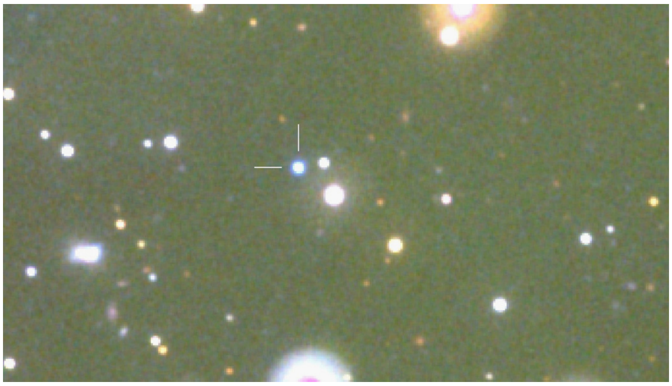

**Fig. 1.** Example of the localization of an X-ray transient with UVOT, in this case the transient is the blue star in a cluster of three objects near the center of the image.

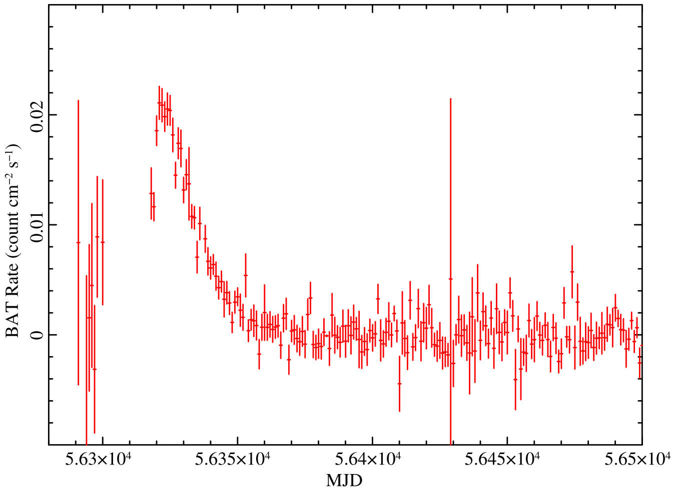

**Fig. 2.** *Swift*/BAT Hard X-ray Transient Monitor light curve of Swift J1753.7-2544 with daily bins. Swift J1753.7-2544 was first detected on January 24th, 2013.

### 2.2. *The* Swift/*BAT Hard X-ray Transient Monitor*

In addition to transients detected by the BAT triggering algorithm, the *Swift*/BAT Hard X-ray Transient Monitor (Krimm et al., 2013) is a software based transient monitor that utilizes BAT data taken during normal observations. The BAT Transient Monitor has a sensitivity of approximately 5.3 mCrab in a day, allowing for the monitoring of many bright known sources, as well as the detection of new transients. The primary benefit is the ability to detect sources down to a much fainter level than needed to trigger BAT (100–200 mCrab; D. Palmer, *private communication*), meaning slow-rising transients can be detected much earlier than with BAT itself.

The *Swift*/BAT Hard X-ray Transient Monitor web site contains light curves for over 1000 sources, with approximately 250 of these being detected on a daily basis. Since February 2005 it has discovered $\sim$20 new X-ray transients. An example of a light-curve of an X-ray transient discovered by the BAT Transient Monitor, *Swift* J1753.7-2544 (Krimm et al., 2013), is shown in Fig. 2.

When a new transient is discovered using this method, observations are triggered through the *Swift* Target of Opportunity (TOO) program, and follow-up typically consists of a short PC mode observation in order to localize the source, follow-up by observations in WT in order to characterize the spectrum and timing nature of the source. Results of these observations are reported by the *Swift*