

Swift and the future of TDAMM Astronomy Lessons learned from 20 years of novel operations

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Why Swift is a epochal mission for TDAMM science

- Multi-wavelength observations Space unique Hard X-ray/X-ray/UV all in one package, simultaneously.
- X-ray sources, and discovers new transients.
- Rapid slewing gets you to a GRB fast. Also allows for very high efficiency of cadence high sensitivity monitoring.
- years.

• **Transient discovery -** BAT is a hard X-ray transient all-sky (in a day) monitor. Triggers on GRBs, SGRs, LMXBs, SFXTs. BAT transient monitor tracks brightness of hundreds of

operations (~72%) Allows time domain astrophysics due to ability to perform high

• Constantly evolving ground and onboard software - we don't stand still evolving the operations concept. New observing capabilities have been brought online every few

 Open Target of Opportunity (TOO) program with open data program - Our TOO program is extremely open, with low rejection rates, and our data is made public ASAP.



Swift key developments for TDAMM Science

Swift launched with many of the key capabilities that make it TDAMM capable. However we have added to these capabilities since launch, and are constantly evolving operations.

- Automated TOO uploads (enabled us to do more TOOs without stressing operations team).
- Tiling of circular error regions (enabled follow-up of MAXI) and Fermi LAT sources).
- Tiling of massive error regions (LIGO/Virgo tiling, see later slide).
- Downlink of BAT event data on demand (**GUANO**: Jimmy Delaunay's talk yesterday)
- Development of **Swift TOO API** to enable automated TOO submission.
- Very rapid response TOO capability enabled by TDRSS forward link.

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https://www.swift.psu.edu/too_api

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		swift_too modul Swift_TOO example - 3	le Swift Target of	f Opportunity Sub	mission Example)		
	API version = 1.2, swifttools version = 2.3							
		Author: Jamie A. Kennea (Penn Sta	ate)					
		The Swift_TOO class is used to subm but given the requirements to trigger Here we give a simple example of ho actually complete, but importantly it to	mit Target of Opportunity Swift using algorithmica w to submit a TOO requ will not submit an <i>actua</i>	PRequests for the Swift missi ally determined criteria, this c uest with this class. Note that / Swift TOO!	ion. Before this required mar an now be automated throu t we will enable debug mode	nual filling out of gh the Swift TOC e here, so that the	a web based for API, and this be submission w	orm, class. vill
I	n [1]:	<pre>from swift_too import TOO, F</pre>	Resolve					
		We start by initializing the class and g your shared secret, and can modify it anonymous login to submit a TOO re	giving our username and it as necessary under the equest.	d shared secret. These can be e <u>Update Account Info</u> link. N	e set up <u>on the Swift TOO w</u> lote that unlike other TOO A	<u>rebsite</u> . After you PI classes, you c	log in, you wil annot use	l find
I	n [2]:	<pre>username = "myuser" shared_secret = "mysecret"</pre>						
		OK let's set up the Swift_T00 req I'm not passing my shared_secre it, so it's not necessary to include it in	quest (in this case we'll u et_here, because my co in later requests.	use the swifttools 2.3 sh mputer supports keyring .	orthand, T00 . Also we're s . This records your shared	setting debug mo _secret the fir	ode here. Note st time that yo	that u use
I	in [3]:	<pre>too = TOO() too.username = username # too.shared_secret = shared too.debug = True</pre>	d_secret					
		OK, so what are we going to observe thankfully we have a class called Sw	e, let's start with a name vift_Resolve (we'll us	e, oh say, SMC X-3, that's a c se Resolve for short) for lo	ool object. However, darn, I ooking these up.	can't remember	the coordinate	s, but
I	n [4]:	<pre>too.source_name = "SMC X-3" res = Resolve(name=too.sourc print(f"RA/Dec (J2000) = {re print(f"SkyCoord = {res.skyc</pre>	ce_name) es.ra:.4f},{res.de coord}")	ec:.4f}")				
		RA/Dec (J2000) = 13.0234,-7 SkyCoord = <skycoord (fk5:<br="">(13.02343917, -72.43450</skycoord>	2.4345 equinox=J2000.000) 833)>	: (ra, dec) in deg				
		Swift_Resolve reports back ra Swift_TOO can take a SkyCoord	and dec , but it also r d directly.	reports back as a SkyCoord	I using the skycoord pro	perty if you have	astropy in	stalled.
I	n [5]:	<pre>too.skycoord = res.skycoord</pre>						
		If you use a SkyCoord , it means yo TOOs are stored as decimal RA/Dec	ou can also use more ot in J2000, as this is wha	her coordinate systems or fo t Swift uses. Let's check wha	rmats, rather than just J2000 at the values are.) decimal degree	es. Internally all	l Swift
I	n [6]:	<pre>print(f"RA/Dec (J2000) = {te</pre>	oo.ra:.4f}, {too.d	lec:.4f}")				



Swift receives a lot of TOO requests

- 2024:1824 TOOs in 1 year.
- **2025:** ~**2159 predicted** (extrapolation, but EP + SVOM likely driving jump)!

Why so high?

- TOO program open to anyone in the world.
- TOO acceptance rate has been ~99% for entire mission.
- More and more we are getting automated
 TOOs through our API.
- Swift is hugely capable for a broad section of the community.

Number of Swift TOOs per year



Optical surveys drive growth of Swift TOOs

- >600 / 1800 TOOs in a year come from optical transient surveys.
- Mostly these are supernovae and TDEs.
- We are looking forward to this being driven even more when
 Vera Rubin Observatory starts producing transient alerts.

Rise of optical transient TOOs (Nova/SN/TDEs)



GW 170817: TILING Swift observations

• GW170817:

- 744 fields observed by Swift.
- 92% of distanceweighted GW localization covered.
- This type of tiling of galaxies is a unique by a spacecraft is a unique Swift capability.



O3 result S200224A



- Image from Klinger et al. (2020)
- S200224A is a BH-BH merger
- Covered 79.2% (X-ray) and 62.4% (UV) of the GW error region.
- like parameters)

• No candidates seen. Upper limit on isotropic-equivalent blast wave energy = 4.1 x 10^51 erg (assuming GRB



Using Swift search for FRBs

- We trigger off alerts from CHIME and other FRB detectors.
- If error region less than XRT FOV (~12' radius) we try to observe with XRT/UVOT as rapidly as possible using the "AutoTOO system".
- Please read <u>https://arxiv.org/abs/2006.04550</u> for a demonstration of such follow-up (no detection sadly). FRB observed with XRT/ UVOT at T_0 +32 mins.
- Two other FRBs have been followed-up in this way:
 - FRB 20211122A at **T₀+39** minutes (ATEL #15055).
 - FRB 20211211A at **T₀+21** minutes (ATEL #15114).
- In 2023, enabled by advances in Swift operations, we reduced this latency to **T₀+3.9 minutes** (ATEL #16233).
- In 2025, thanks to further refinement of our AutoTOO system, we got on target for a CHIME FRB at T₀+82 seconds! (sadly the wrong coords!)



Urgency 0 TOOs: Rapid response for all

In 2023 for O4 we enabled "Continuous Commanding" reducing latencies for TOOs from hours (typical previous best 14 mins) to seconds, opening up whole new science cases and responsiveness to TDAMM science:

- Possibility of "early warning" slewing to increase odds of coincident BAT detection of NS-NS merger (see paper "Swiftly Chasing" Gravitational Waves across the Sky in Real Time" by Tohuvavohu et al, 2024 *ApJL* **975** L19).
- Enables us to us to commence GW tiling more quickly, and followup counterparts from other telescopes quicker.
- <u>Places triggers from other missions on a level playing field to</u> triggers from BAT.

It should be clear that the ability to immediately command a TDAMM spacecraft to observe has many use cases, and greatly increases science return.

Swift is creating vital heritage for future mission proposals.



Urgency 0 GRB Science

Swift now performs ASAP observations of GCN alerts from SVOM ECLAIRs and Einstein Probe WXT.

- Swift XRT/UVOT means rapid identification of source class and arcsecond resolution observations.
- Results published over GCN and available live at these two websites (thank you Phil Evans):
 - <u>https://www.swift.ac.uk/EP</u>
 - <u>https://www.swift.ac.uk/SVOM</u>

Swift has proven that it can perform rapid GRB observations not only of triggers from BAT, but also from other missions.

Future advanced communications make continuous contact with future spacecraft likely. We no longer need to physically couple GRB detector with the follow-up telescopes. Again this is vital heritage for future missions.





Swift key lessons for future missions

- I believe the next Swift should not be one observatory, but a combination of many.
 - **Constant communications** means that triggering instrument and follow-up instrument do not need to be on the same spacecraft.
 - **Dedicated GRB detection missions:** it's beneficial to not be slewing around all the time doing TOOs to see ultra-long GRBs, faint high-z GRBs and to have higher duty cycle. Likely future GRB detectors will be lower cost and stand alone (e.g. the BlackCAT cubesat).
 - Rapid X-ray follow-up: AXIS should perform rapid response follow-up to measure arc-second afterglow positions, although we may prefer a dedicated mission due to science pressure on AXIS.
 - UV/Optical follow-up UV: maybe UVEX and ULTRASAT can fill this gap. Optical/IR well served from the ground. There are plans for future rapid response optical/UV/IR space telescopes.
- **Open TOO policy** and **Open data policy** ensures a broad audience and more scientific papers! Having multiple groups write papers on the same event is a feature, not a bug, and has lead to more science return from Swift.
- Open collaboration between all missions is key. Swift has always partnered with new and upcoming missions to increase science return, most recently EP and SVOM.











Thank you

- Conclusions:
 - Swift is key mission for Multi-Messenger
 - We have developed a great deal of new capabilities for Swift since launch.
 - Swift's open data policies and open TOO program are key it's success.
 - Swift hopefully will run for a few more years...
 - Please back TDAMM focused SMEX proposals and AXIS for future rapid Xray response.

Theme

 Community-defined coordinated observing concepts for rare and important transient events.

Motivation

 Define and prioritize science cases, triggering criteria, and the essential follow-up observations – ground and space – public and private – desired by the community so that observatory science teams can pre-coordinate plans and efficiently execute communitydriven observations.

4th TDAMM Workshop

Developing community observing plans for rapid follow-up of explosive transients

> Huntsville, Alabama October 27-30, 2025

across



