PennState
Eberly College of Science

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.
- **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 X-ray sources, and discovers new transients.
- **Rapid slewing -** gets you to a GRB fast. Also allows for **very high efficiency** of operations (~72%) Allows **time domain astrophysics** due to ability to perform high cadence high sensitivity monitoring.
- **Constantly evolving ground and onboard software -** we don't stand still evolving the operations concept. New observing capabilities have been brought online every few years.
- **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.

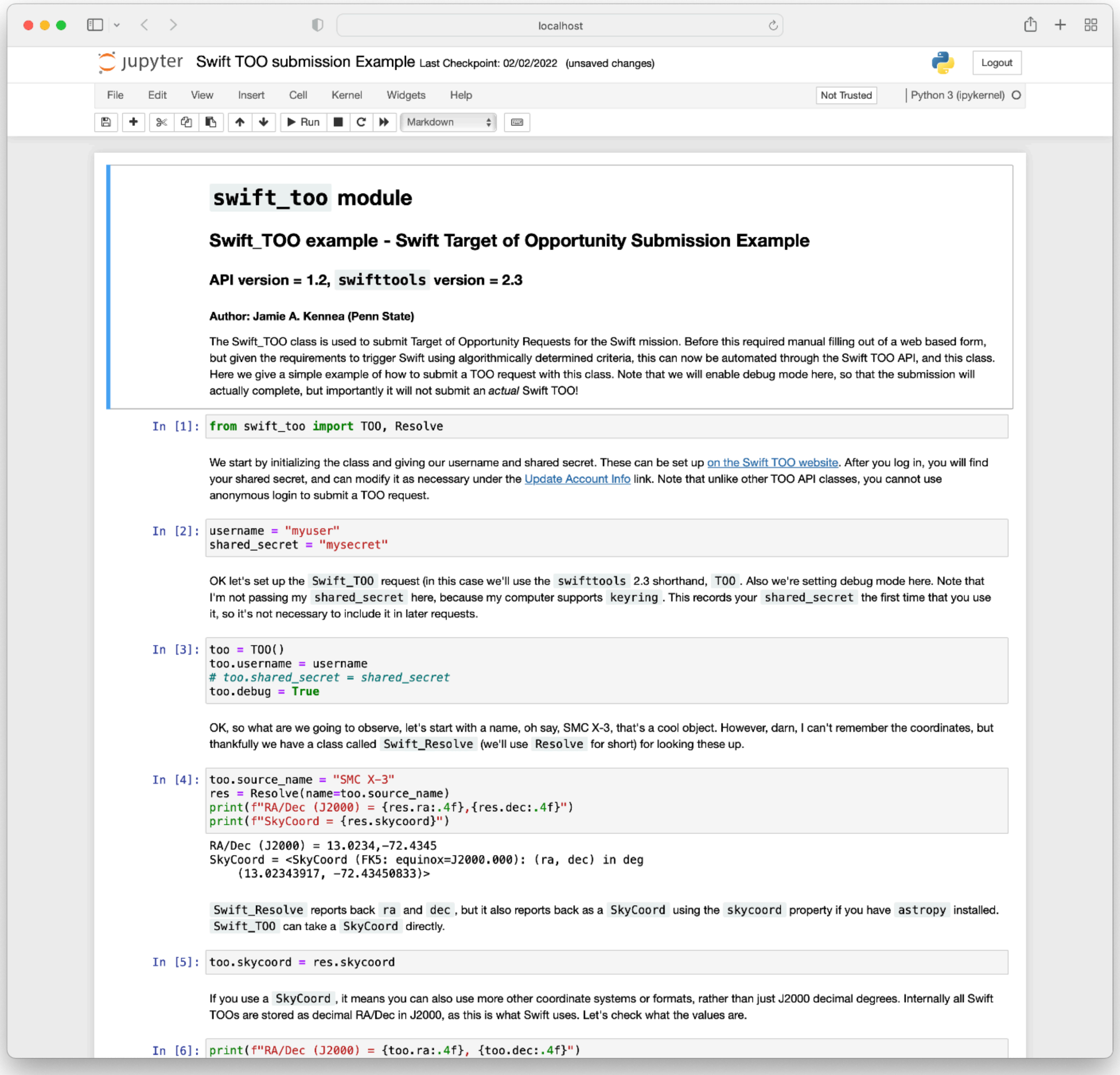
Swift key developments for TDAMM Science

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.

```
# pip install swifttools
```

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

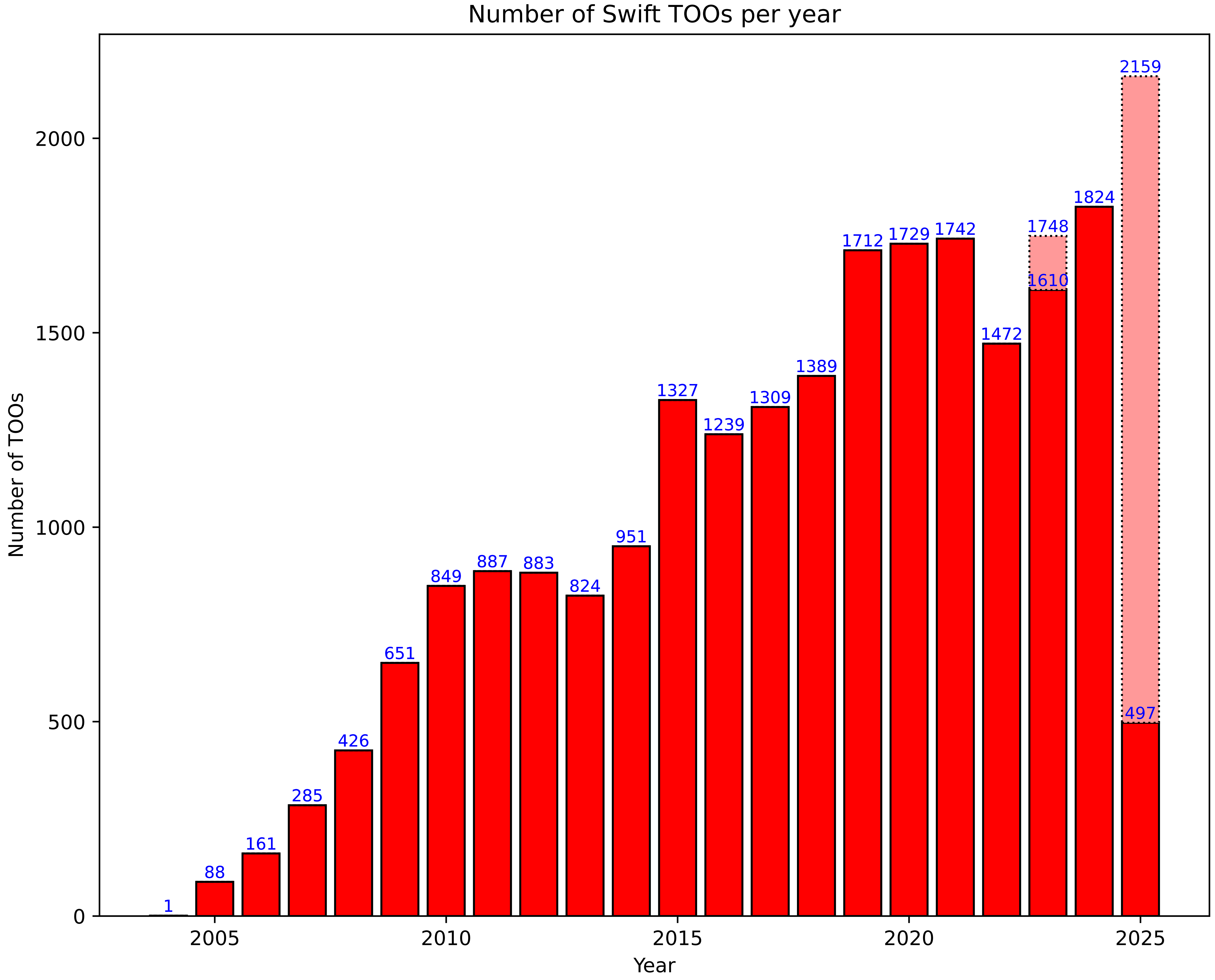


Swift receives a lot of TOO requests

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

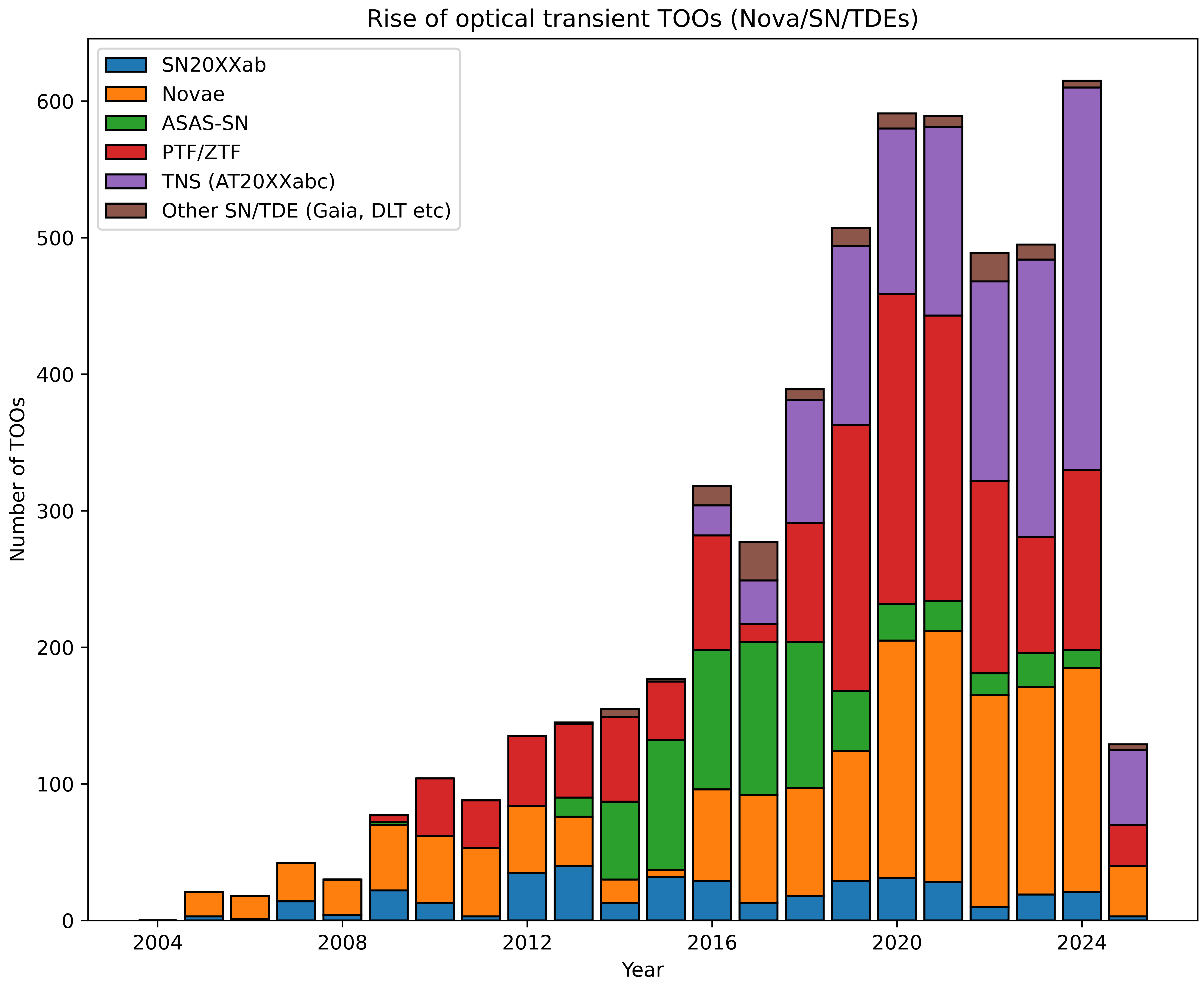
<u>Why so high?</u>

- 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.



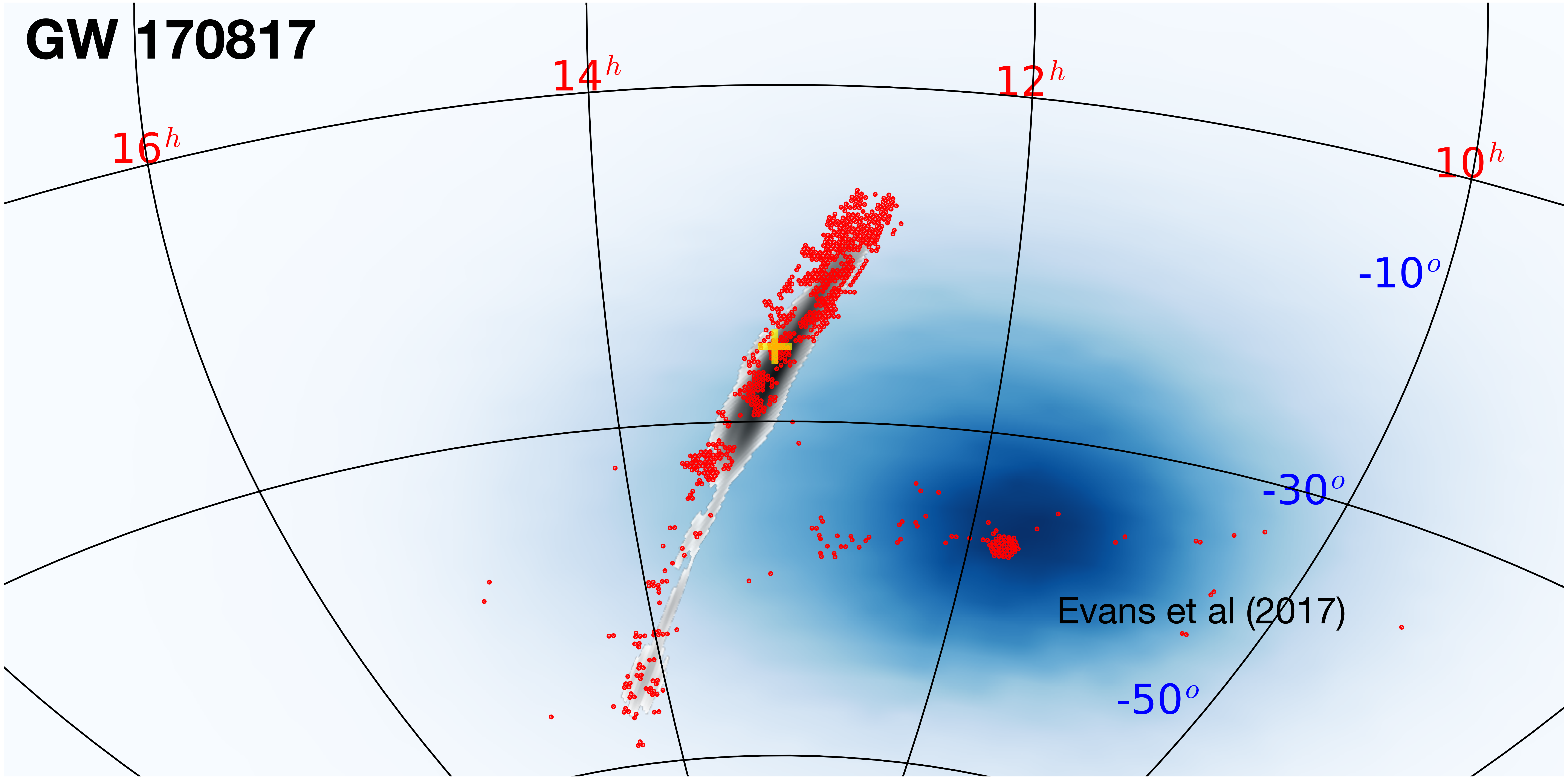
Optical surveys drive growth of Swift TOOs

- >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.



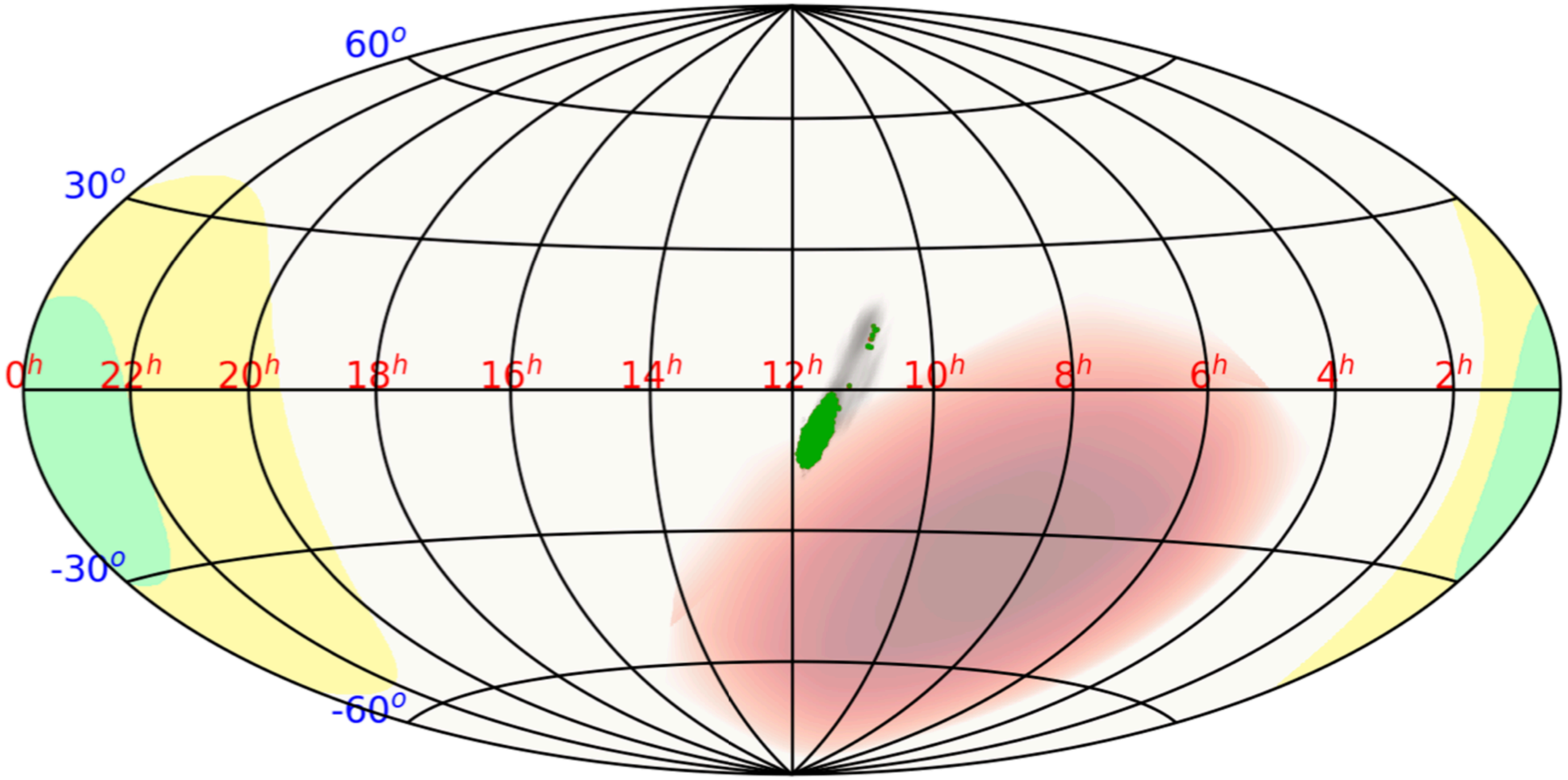
GW 170817: TILING Swift observations

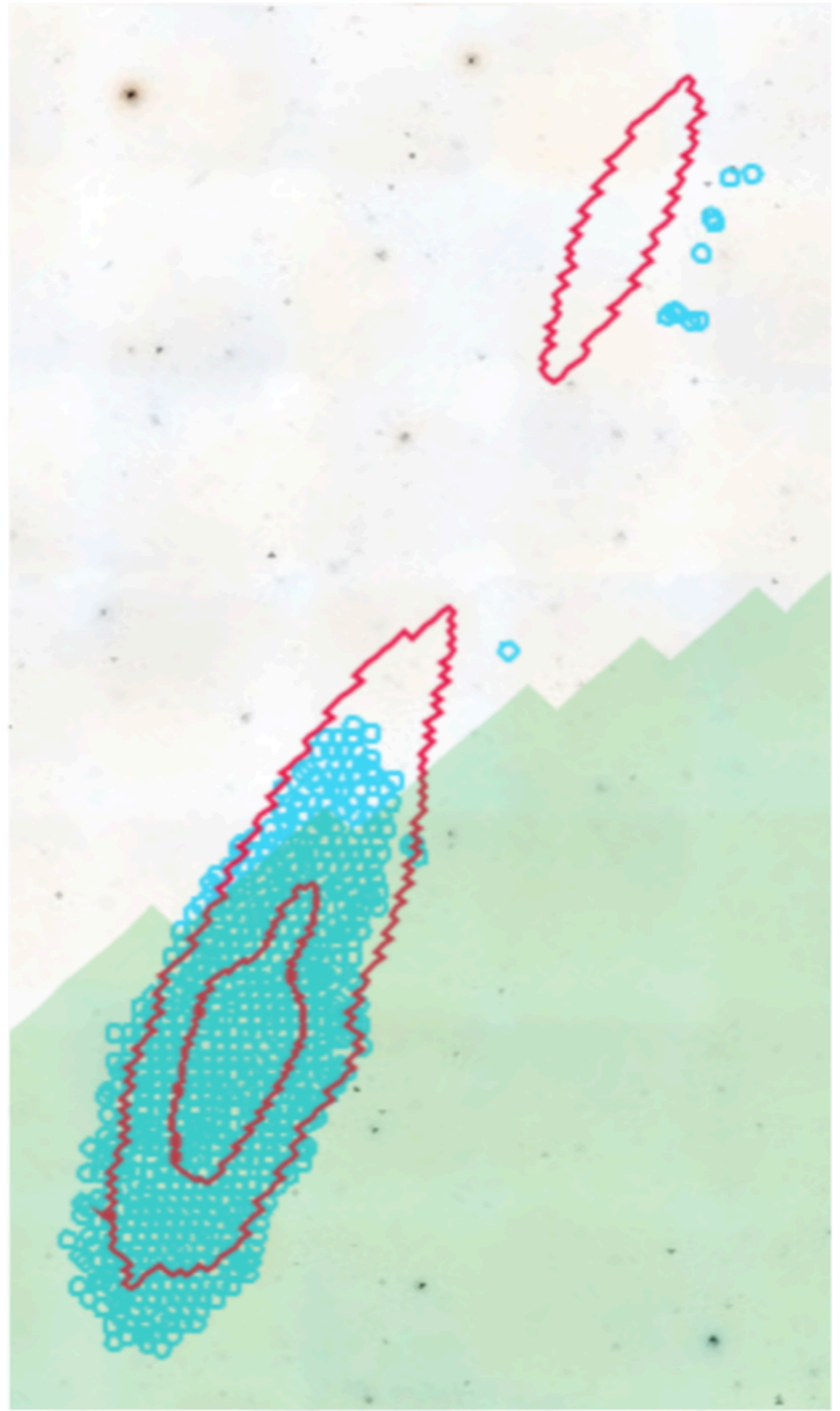
- GW170817:
  - 744 fields observed by Swift.
  - 92% of distance-weighted GW localization covered.
- This type of tiling of galaxies is a unique by a spacecraft is a unique Swift capability.



O3 result

S200224A

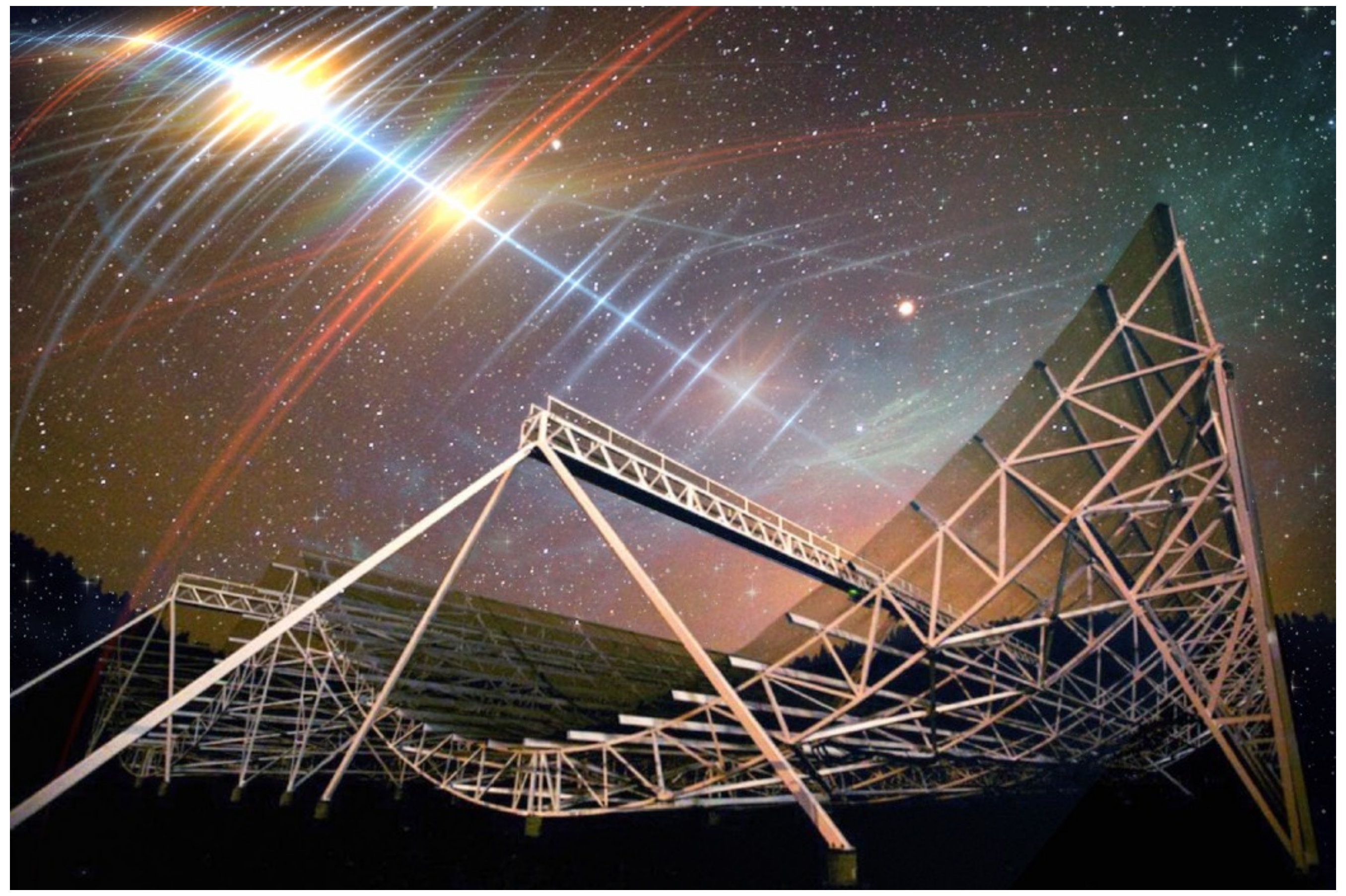


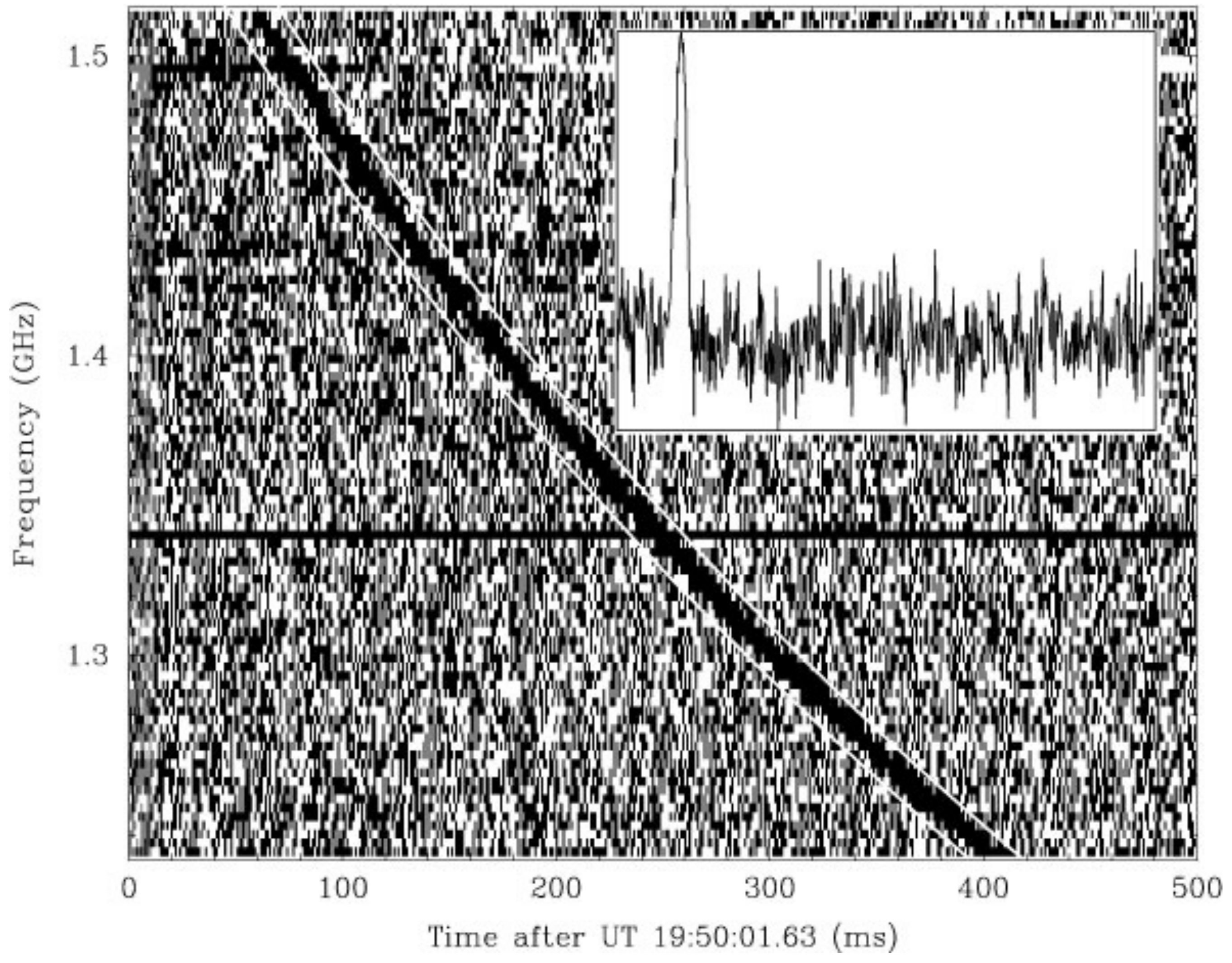


- Image from Klinger et al. (2020)
- S200224A is a BH-BH merger
- Covered 79.2% (X-ray) and 62.4% (UV) of the GW error region.
- No candidates seen. Upper limit on isotropic-equivalent blast wave energy = 4.1 x 10^51 erg (assuming GRB like parameters)

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 https://arxiv.org/abs/2006.04550 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 **T_0+39** minutes (ATEL #15055).
  - FRB 20211211A at **T_0+21** minutes (ATEL #15114).
- In 2023, enabled by advances in Swift operations, we reduced this latency to **T_0+3.9 minutes** (ATEL #16233).
- In 2025, thanks to further refinement of our AutoTOO system, we got on target for a CHIME FRB at **T_0+82 seconds! (sadly the wrong coords!)**





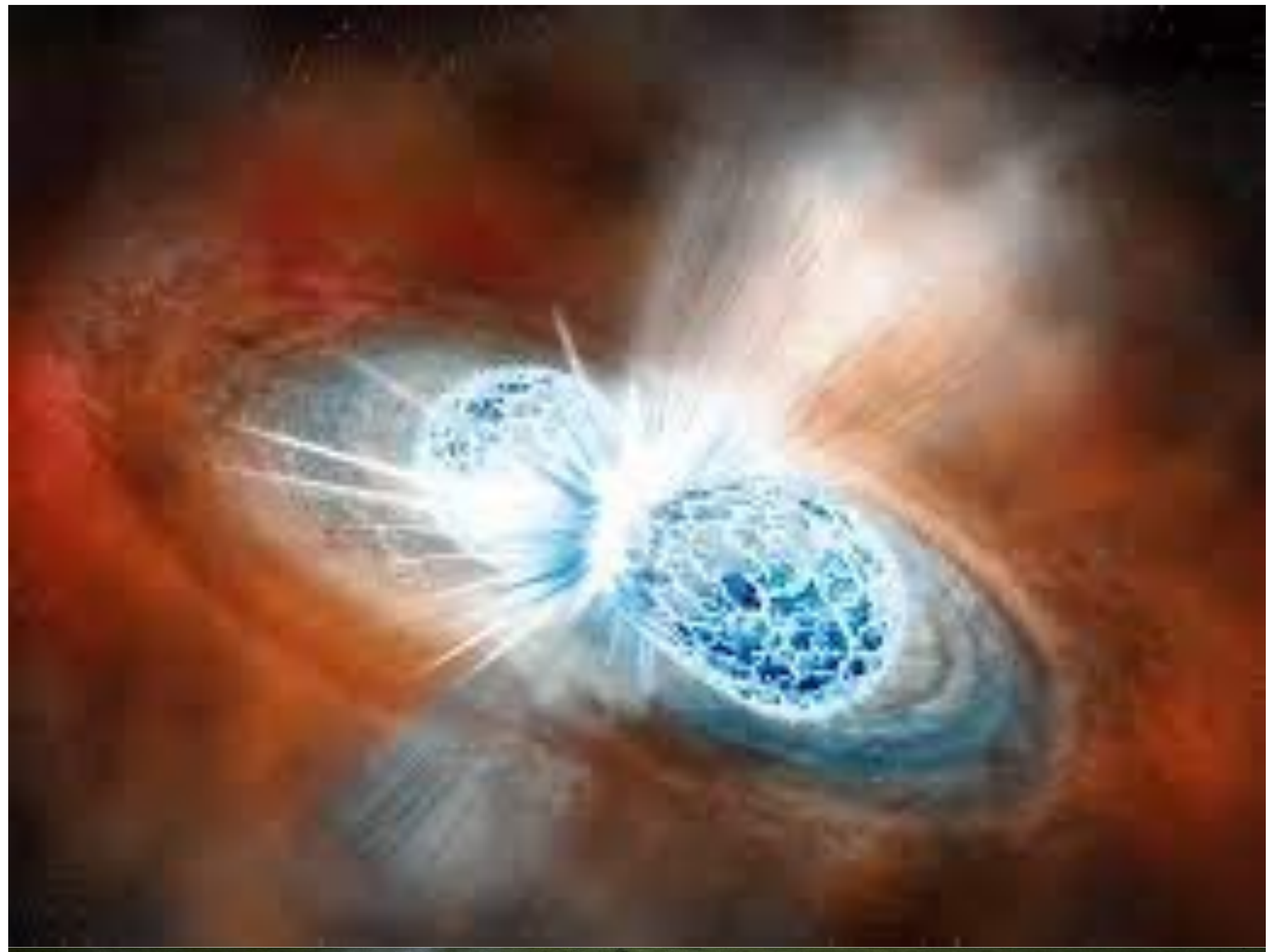
Urgency 0 TOOs: Rapid response for all

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 follow-up counterparts from other telescopes quicker.
- Places triggers from other missions on a level playing field to 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.

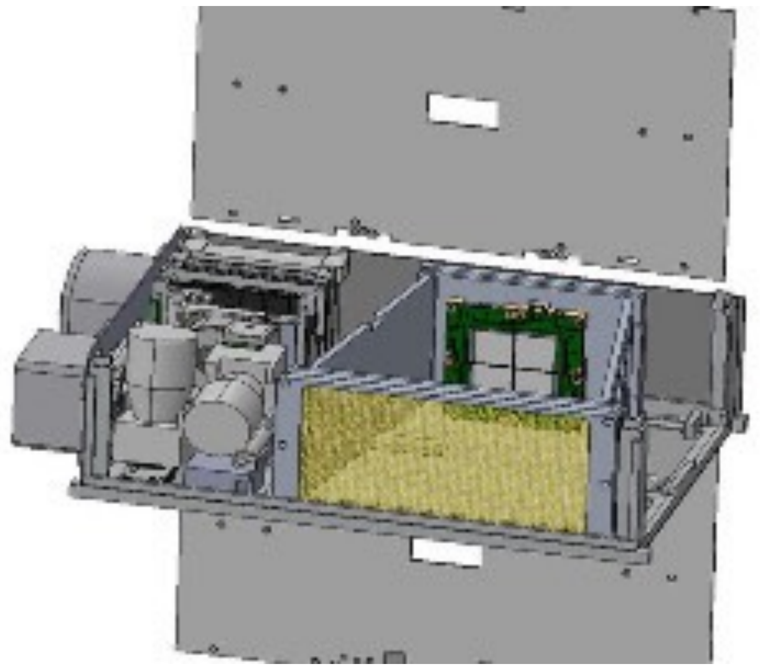
- Swift XRT/UVOT means rapid identification of source class and arc-second resolution observations.
- Results published over GCN and available live at these two websites (thank you Phil Evans):
    - https://www.swift.ac.uk/EP
    - https://www.swift.ac.uk/SVOM

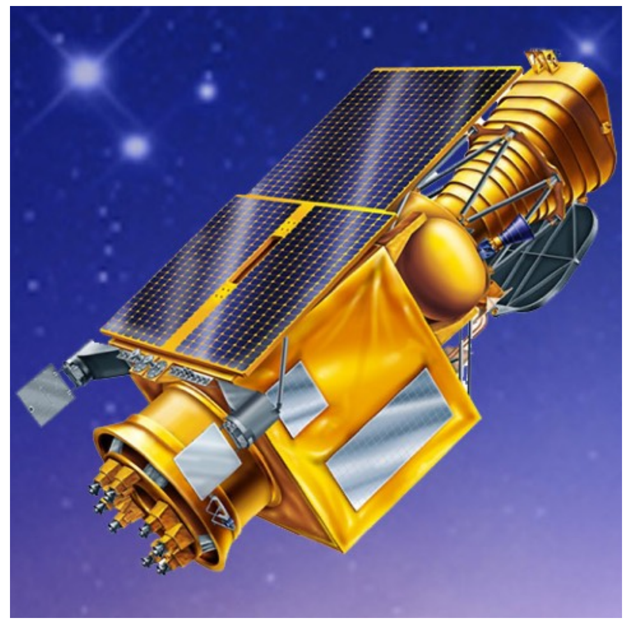
Swift has proven that it can perform rapid GRB observations not only of triggers from BAT, but also from other missions.

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 X-ray 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 community-driven observations.