Teaching an Old Bird New Tricks Chasing GWs with Swift

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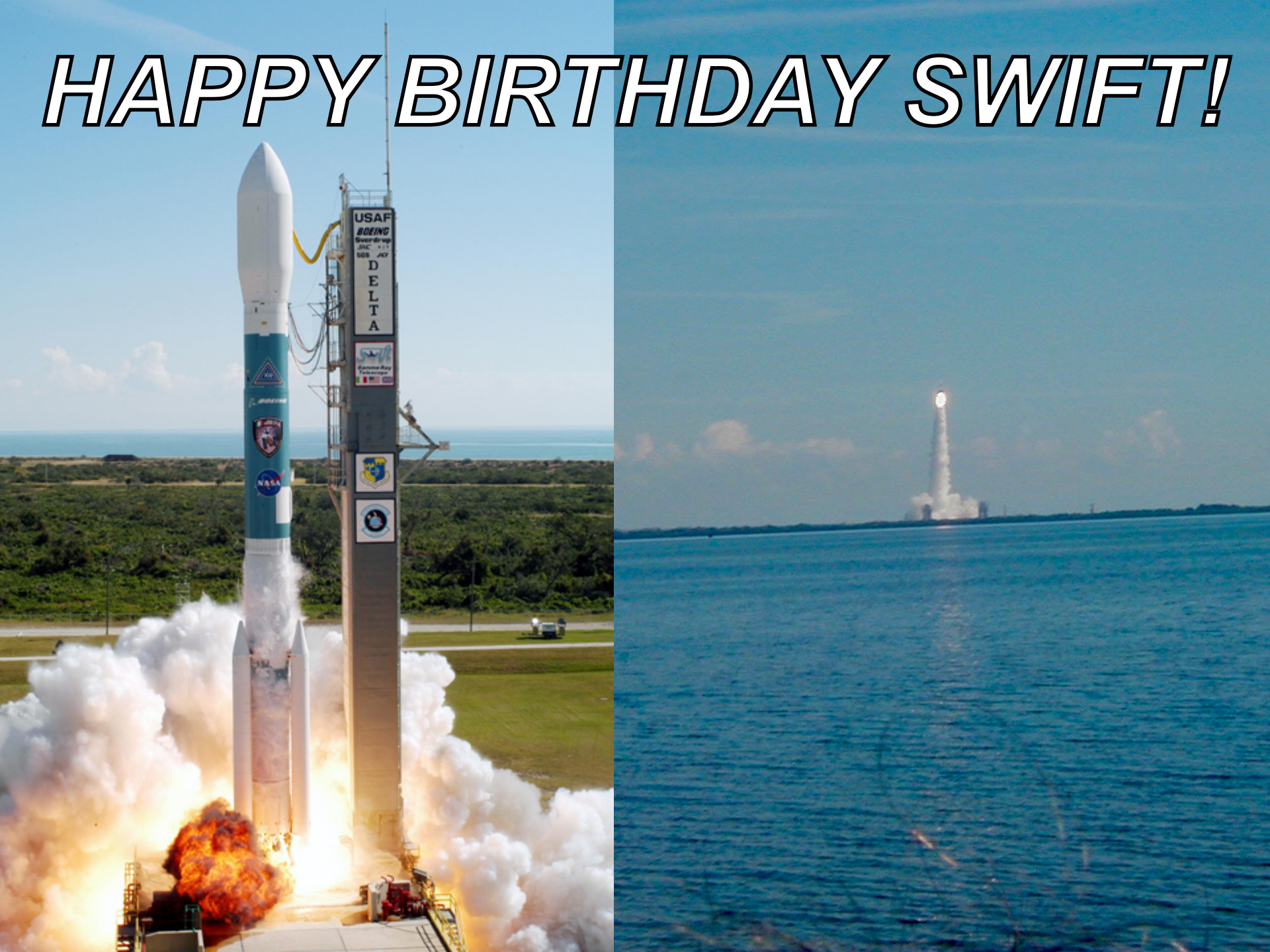
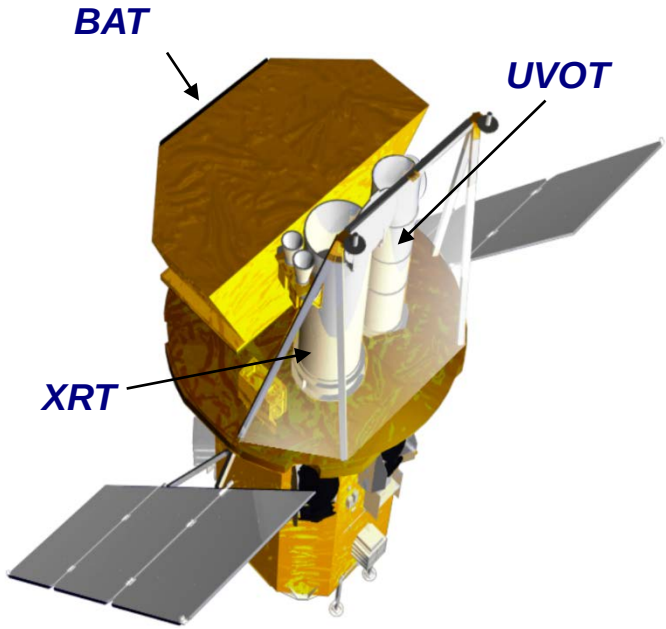
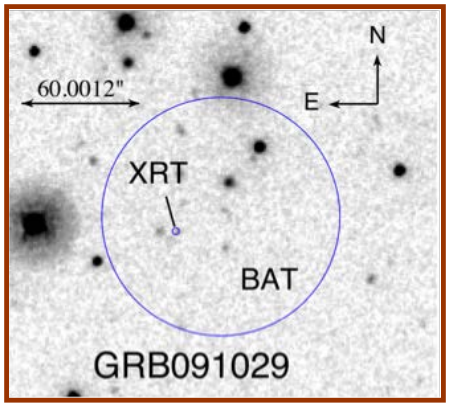
HAPPY BIRTHDAY SWIFT!



Swift – The World's GRB Factory

- **GRBs**
  - >1350 GRBs with arcsec positions
  - Primary GRB mission into the future
- **Non-GRBs**
  - >1800 TOOs per year AGN, SNe, novae, CVs, comets, ...
  - First sensitive hard X-ray all sky survey
- **GI program**
  - > 4 oversubscription, $1.2M, 5Ms time per year





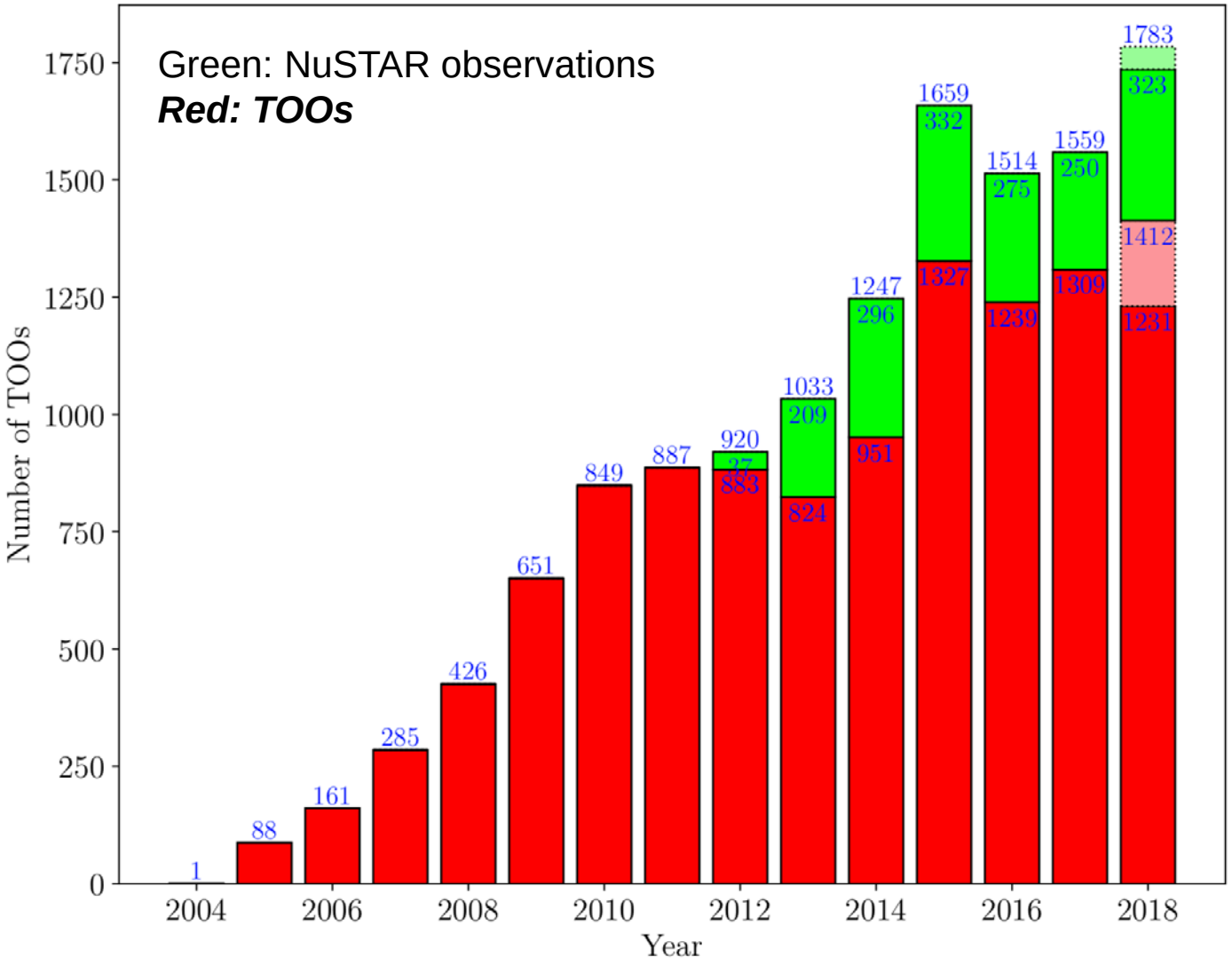
Swift Operations Statistics

SWIFT OPERATIONS STATS

- In the past 28 days (as of Nov 15th, 2019):
  - Swift has received 93 Target of Opportunity (TOO) requests (3.3 per day)
  - 62 different TOO requesters in that time (diverse community)
  - TOOs were for 85 different celestial objects
  - On average Swift observed 94 unique targets per day.
  - Mean exposure per snapshot is 515s, max for scheduling is 1800s (30min), min usually 300s (although smaller with tiling).
- Swift's observing efficiency is ~70-75%. Rest of the time spent slewing and passing through SAA.
- LIGO O3 means that we spend a lot of time tiling LIGO regions with short (80s) exposures, taking hundreds over first 48 hours after trigger.

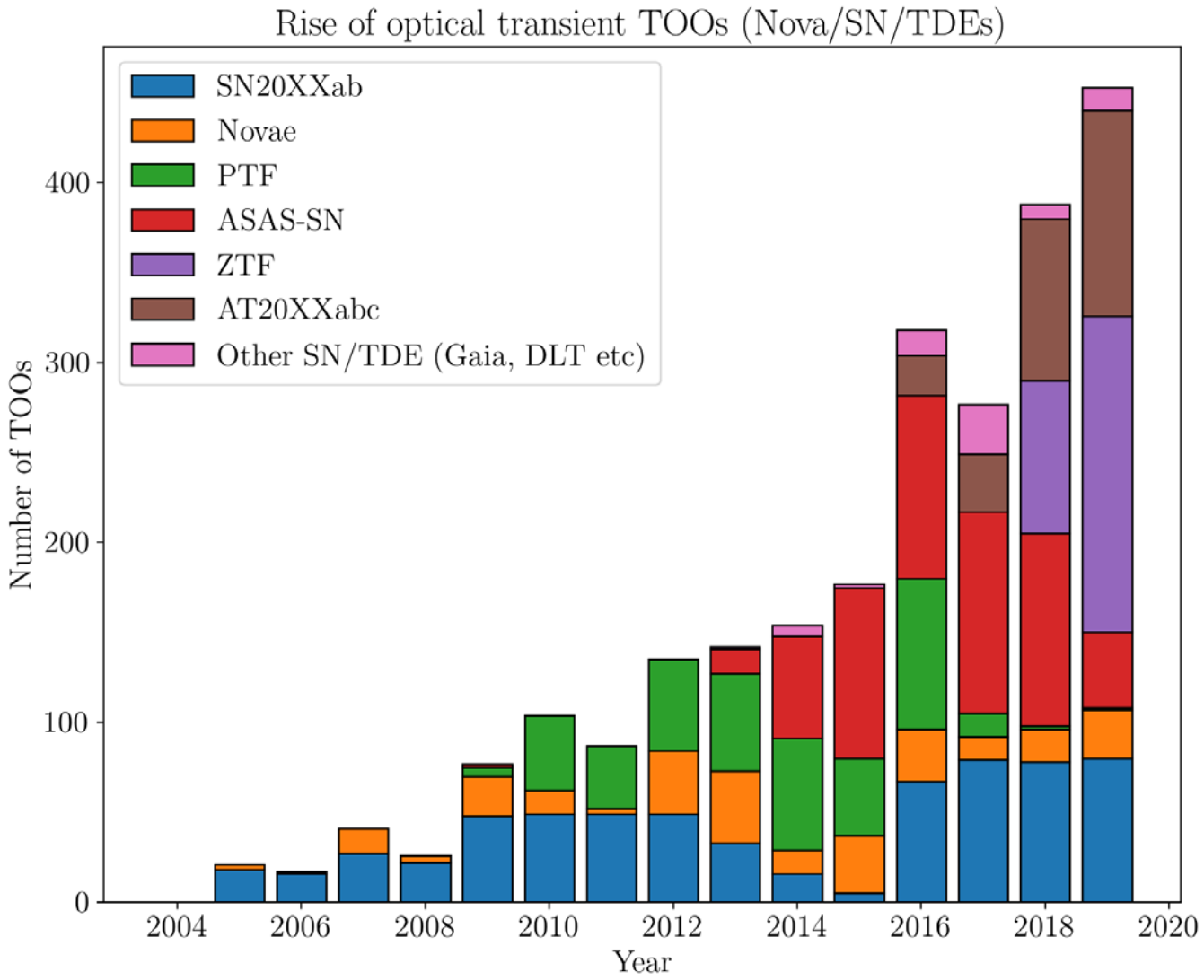
Jamie Kennea

TOOs per year



Jamie Kennea

What's behind the rise in TOOs?



Large Optical surveys driving TOO rates

- **Leaps in the numbers of these TOOs have followed the development of new discovery capabilities.**
  - **Palomar Transient Factory** starting in 2007. Median was 42 TOOs per year, 84 in 2016, the last year of PTF**.**
  - **ASAS-SN:** Since turn-on in 2013, it ramped up to ~110 TOOs per year in 2016-2018.
  - **TNS:** Since 2016, the optical transients named by the Transient Name Server have accounted for more and more. 114 TOOs in 2019.
  - **Zwicky Transient Facility.** ZTF Exploded out of the gate in 2018 with 85 TOOs, and 176 so far in 2019!
  - **Next: LSST** 😲

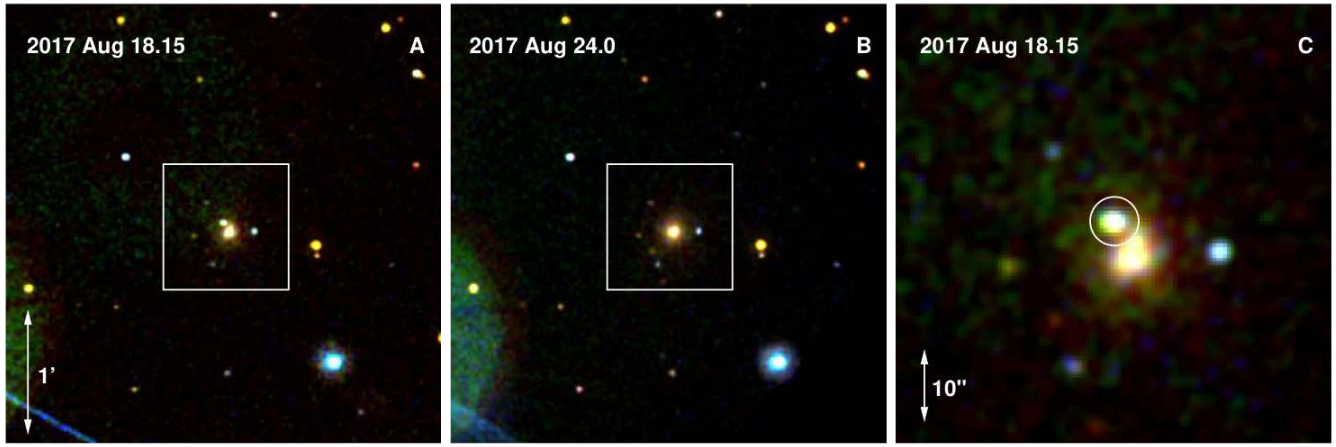
Jamie Kennea

Swift as an E-M counterpart finder

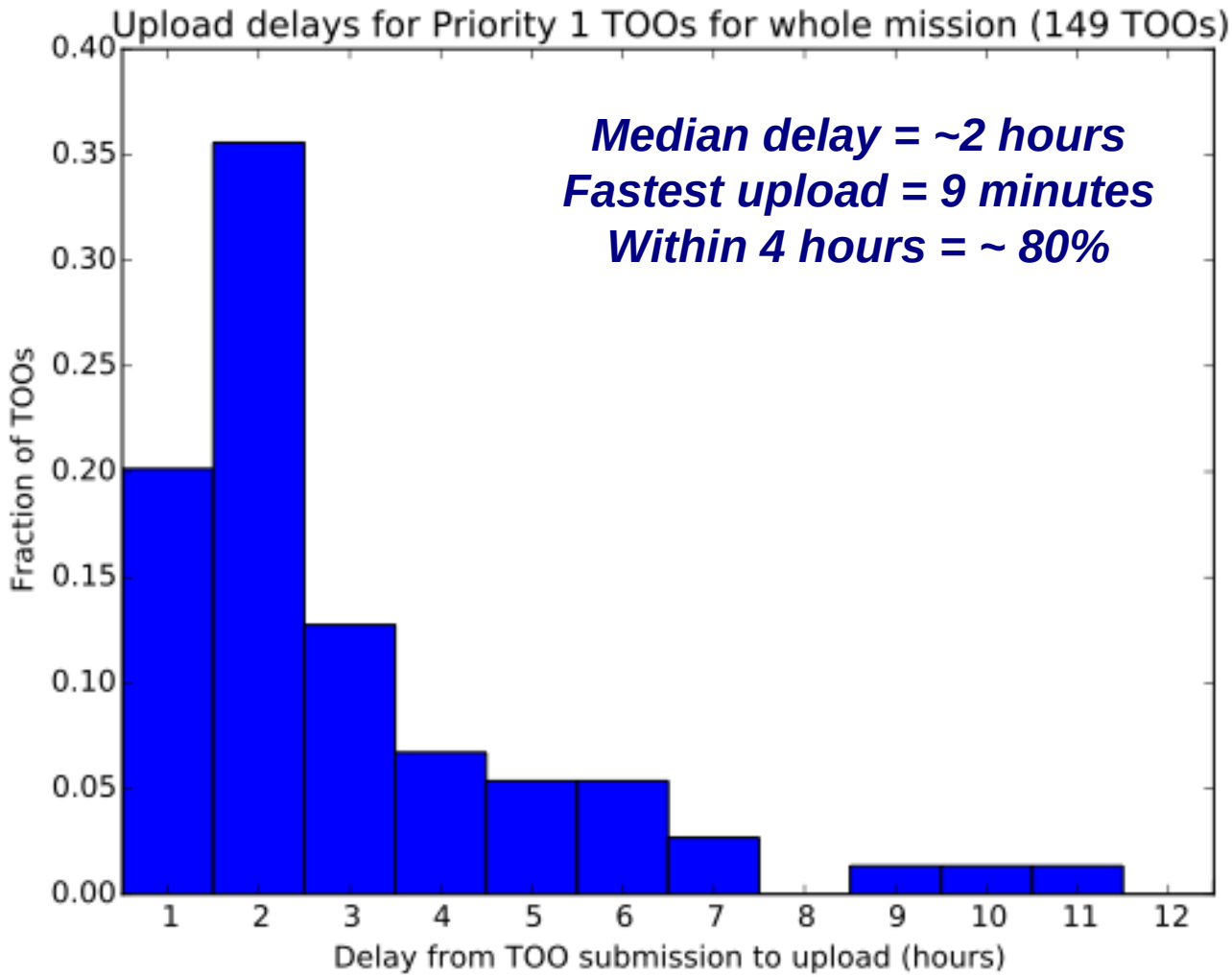
- **Swift's unique capabilities:**
  - Performing rapid Target of Opportunity (TOO) observations
    - TDRSS and Groundstation uploads with low latency.
  - Rapid slewing allows for high efficiency/low overhead observing
    - Swift average slew rate ~0.6 deg/second.
  - Ability to see a large area of the sky over a short period (96 min orbit) vs ground based observatories waiting for night-time, and latitude limited viewing areas.
  - Can do regular followup to check for fading (with wavelength coverage from optical-UV-Xray)

Multi-messenger TOOs

- Into the crowded field arrives the dawn of Multi-Messenger Astrophysics!
- Now we're triggering on events from LIGO/Virgo (Gravitational Waves) and IceCube/Antares (Neutrino detections).
- Neither of these localizes particularly well (GW is especially bad), requiring novel and/or large scale observation strategies.
- These require fast response. e.g. The UV counterpart of GW170817, detected by Swift, was gone within 24 hours.



Upload time statistics



Planning Automation Status

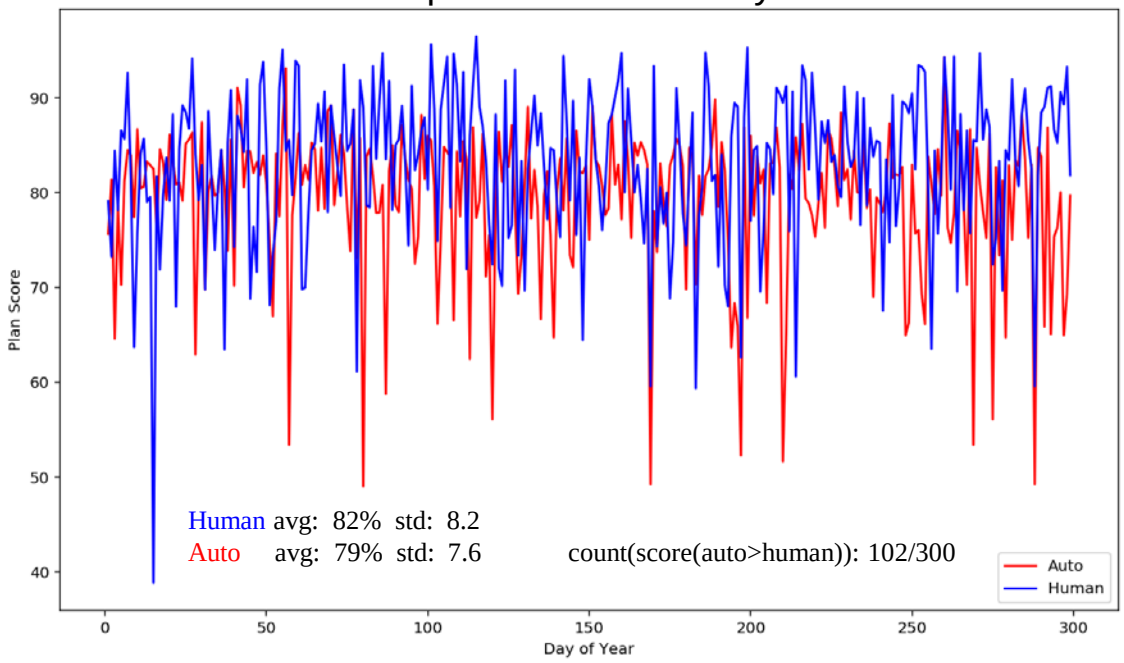
-Aaron Tohuvavohu & Jeff Gropp

- Current Automation can outperform humans consistently if allowed to run for ~20 mins.
- 'Rapid' option (avg runtime 100 seconds) has avg score within 3% of humans, and outperforms ⅓ of time. (see fig ---->)
- Can produce both normal PPST format, and PPTOO format plans.
- Automated run over 300 days of 2018 produced 6 failures. All of these bugs have been addressed. Rerun produced 1 failure. (0.3% rate)
- Even failed runs can be edited by humans to make acceptable, and cut the production time from ~5 hours to < 1 hour.
- All plans produced are safe for spacecraft.

Future:

- Clear room for even better performance, and we know how to do it.
  - Project we can have 'rapid' option outperform humans >90% of time.
  - Within 1% of humans >99% of time
- Currently implementing wide-field tiling capability (LIGO)
- New science opportunities apart from rapid response and higher efficiency:
  - BAT biasing for LIGO or Fermi has been tested, is feasible.

Results of 'rapid' run over 300 days in 2018



GW170817 – First EM counterpart

Fermi

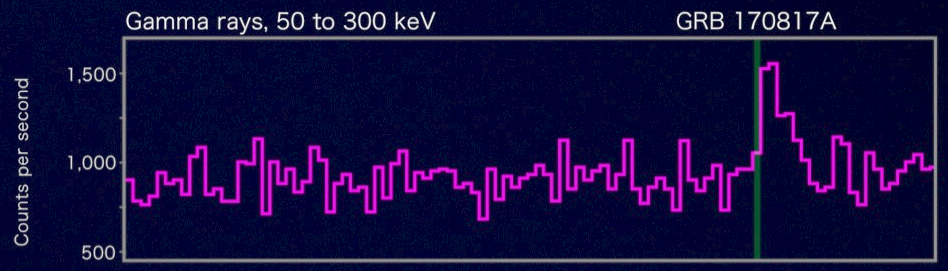
Reported 16 seconds after detection

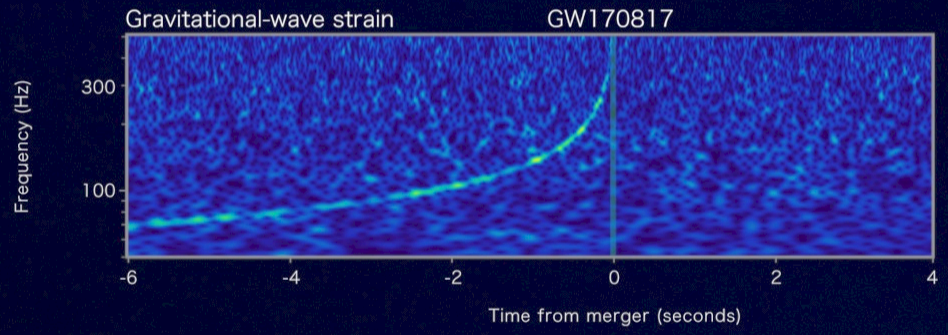
LIGO-Virgo

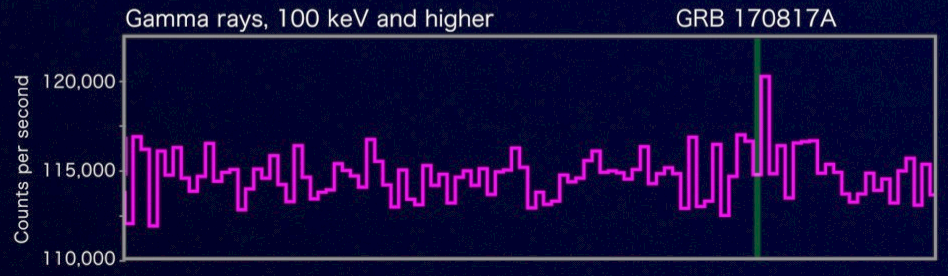
Reported 27 minutes after detection

INTEGRAL

Reported 66 minutes after detection







GW170817 – Swift Followup

Swift response time: 16 minutes after EM target announced!

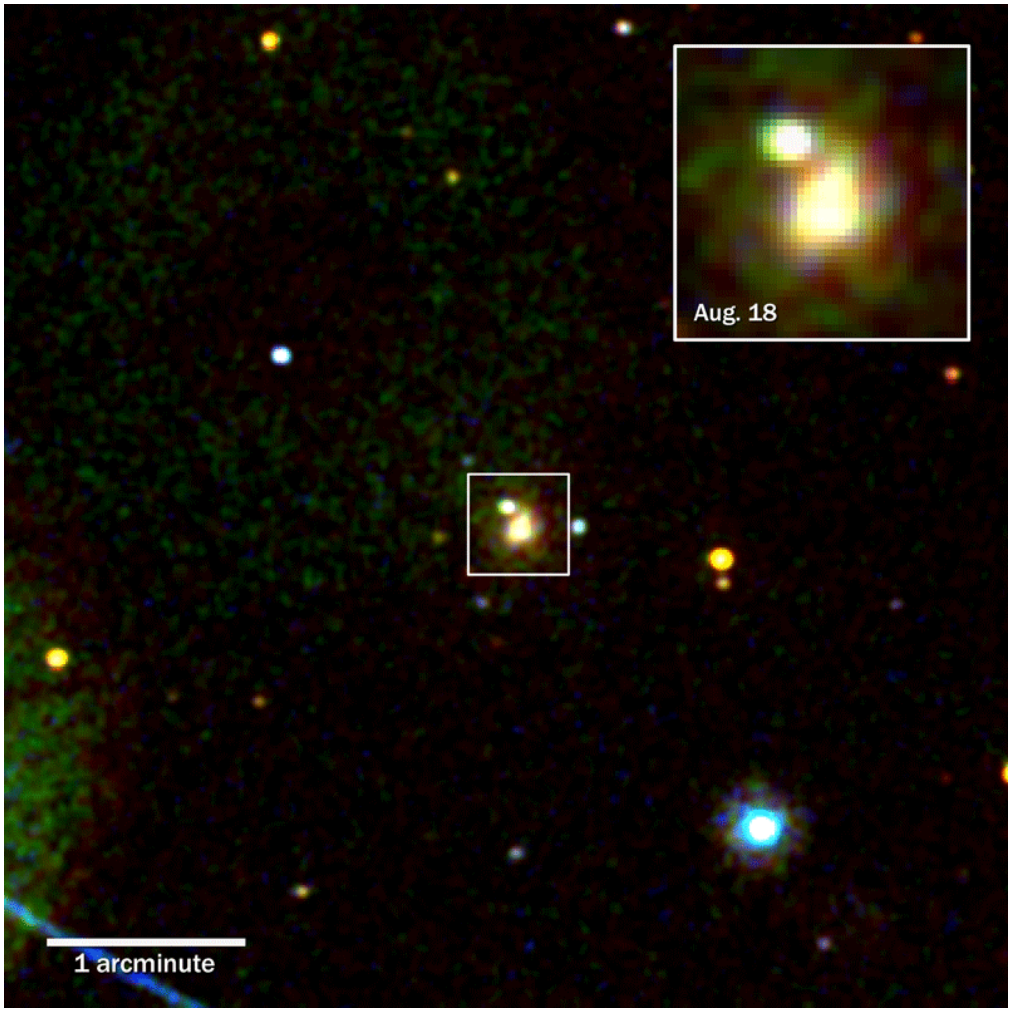
Covered 750 fields

92% of error region covered

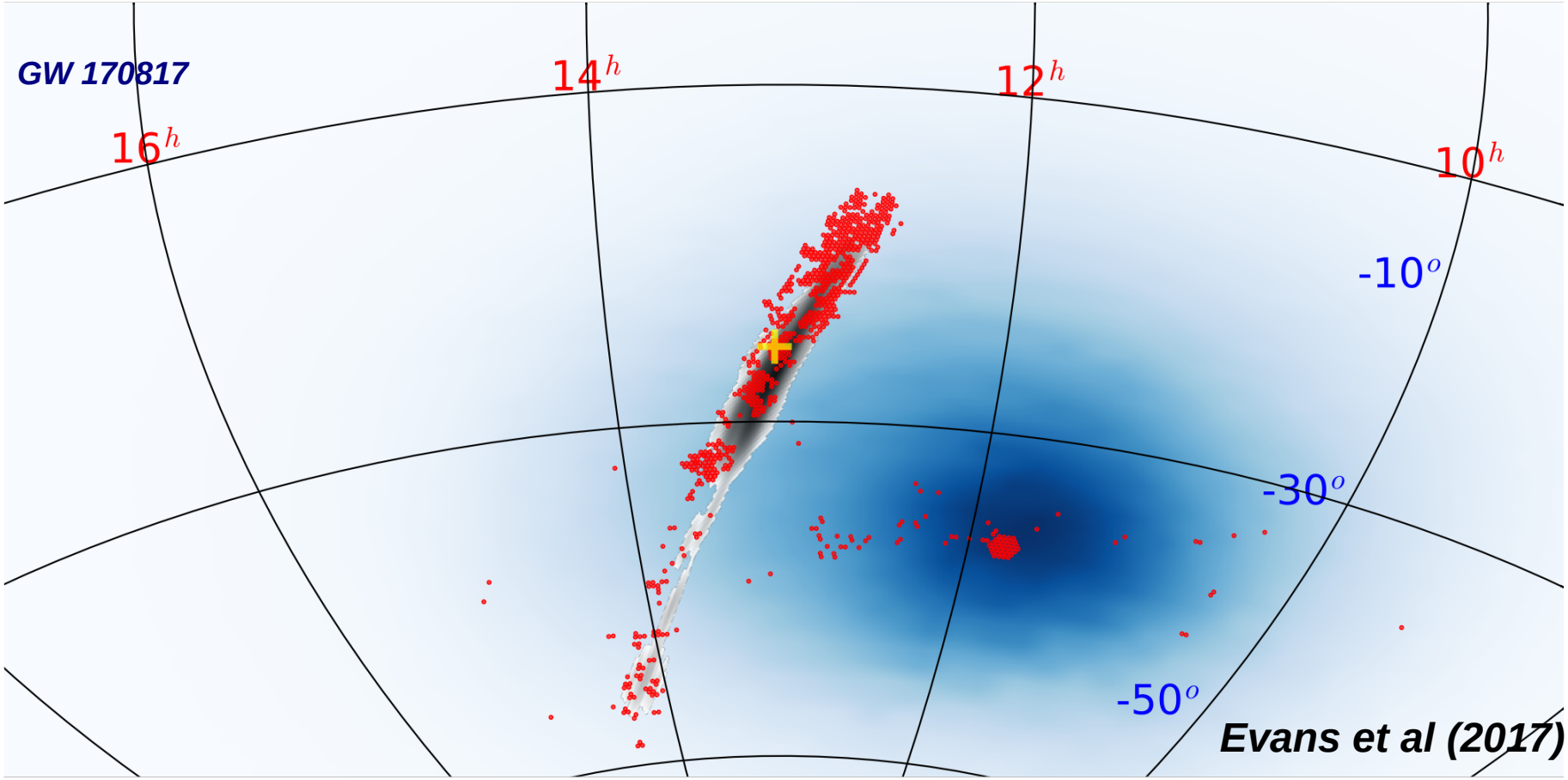
~200 ksec on AT 2017 gfo

Discovered UV emission

Most stringent limits on other X-ray and UV transients in error region

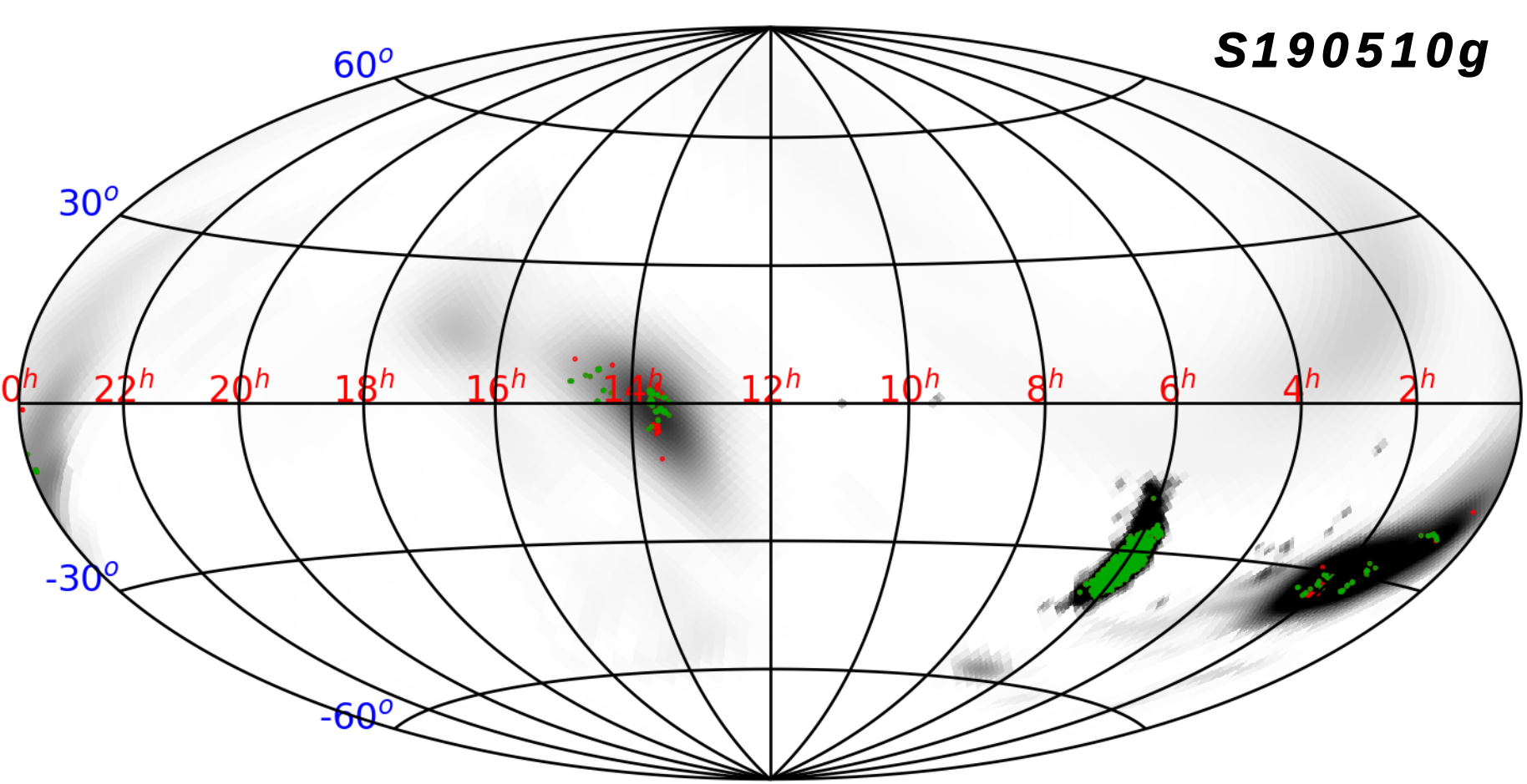


TILING LIGO ERROR REGIONS



- **GW170817:**
  - 744 fields observed by Swift.
  - 92% of distance-weighted GW localization covered.

Example o3 follow-up



- **S190510g: 67% of the probability region covered by Swift observations in 977 pointings.**

HOW Does Swift deal with So many TOOs?

- **Despite record breaking number of TOO requests in 2019, we're doing a good job actually performing them.**
  - We consider reaching 80% of the requested exposure time as being "done".
  - We reached this goal for **91%** of all approved TOOs in 2019. 83% are 95% complete.
- **How do we do this?**
  - Firstly, Swift is extremely capable and fast. Rapid slewing means high efficiency when performing many short observations.
  - We continuously re-develop our planning software and on-board software to cope with the changing landscape.
    - Recently updated onboard software so instead of one TOO at a time, we can do many, in the case of GW follow-up, hundreds.
  - We have automated our planning software, so science plans can be generated quickly (daily) and if necessary, re-written on the fly in minutes.
  - Understanding community - they understand that even in space, sometimes it's too cloudy to observe their object.

Other Swift OPS developments

- **Automated TDRSS pass operation (Oct 2019)**
  - Can now pre-schedule TDRSS passes and use them without FOT on console. Preschedule TDRSS in pass gaps, reduce latency.
- **Automated TDRSS pass scheduling (Dec 2019?)**
  - This will reduce latency for rapid TOO follow-up with Swift down to ~15 mins.
- **Automated BAT event dumps (May 2019)**
  - BAT event data is too large to dump, but is much more sensitive for searching for EM counterparts of GW events.
  - We now auto-dump BAT event data whenever a GW event occurs (and others, IceCube, FRB)
  - Automation of TDRSS passes will allow this to happen for ~90% of all GW events. Right now it has to happen within 30 mins of a pass.
- **Automated TOO uploads (2020+?)**
  - Once we automate TOO submission, TDRSS pass scheduling and pass operation, the only latency left is the human-in-the-loop.
  - For very high importance events, we could auto-upload TOO observations to Swift, without the human intervention. Could be a game changer for catching events like UV/Opt/X-ray FRB emission?

New Observing mode - new projects

- **Ability to perform observations of many, short exposures opens up a new mode of operation for Swift!**

- **Large area surveys:**

  - Surveying whole of SMC weekly in ~24ks, down to a sensitivity of ~5% $L_{EDD.}$ SMC is packed full of HMXBs, Be/X-ray binaries and we tend to only see them go into outburst when INTEGRAL scans SMC.

  - Synoptic Galactic Bulge survey in progress. Next M31? LMC?

- **GRB localization:**

  - Better coverage of IPN error boxes

  - Localization of select GBM GRBs?

- **Others?**

  - Astrophysical Neutrino sources (e.g. IceCube counterpart TXS 0506+056)

  - Fast Radio Bursts (when automated FRB pipeline complete)