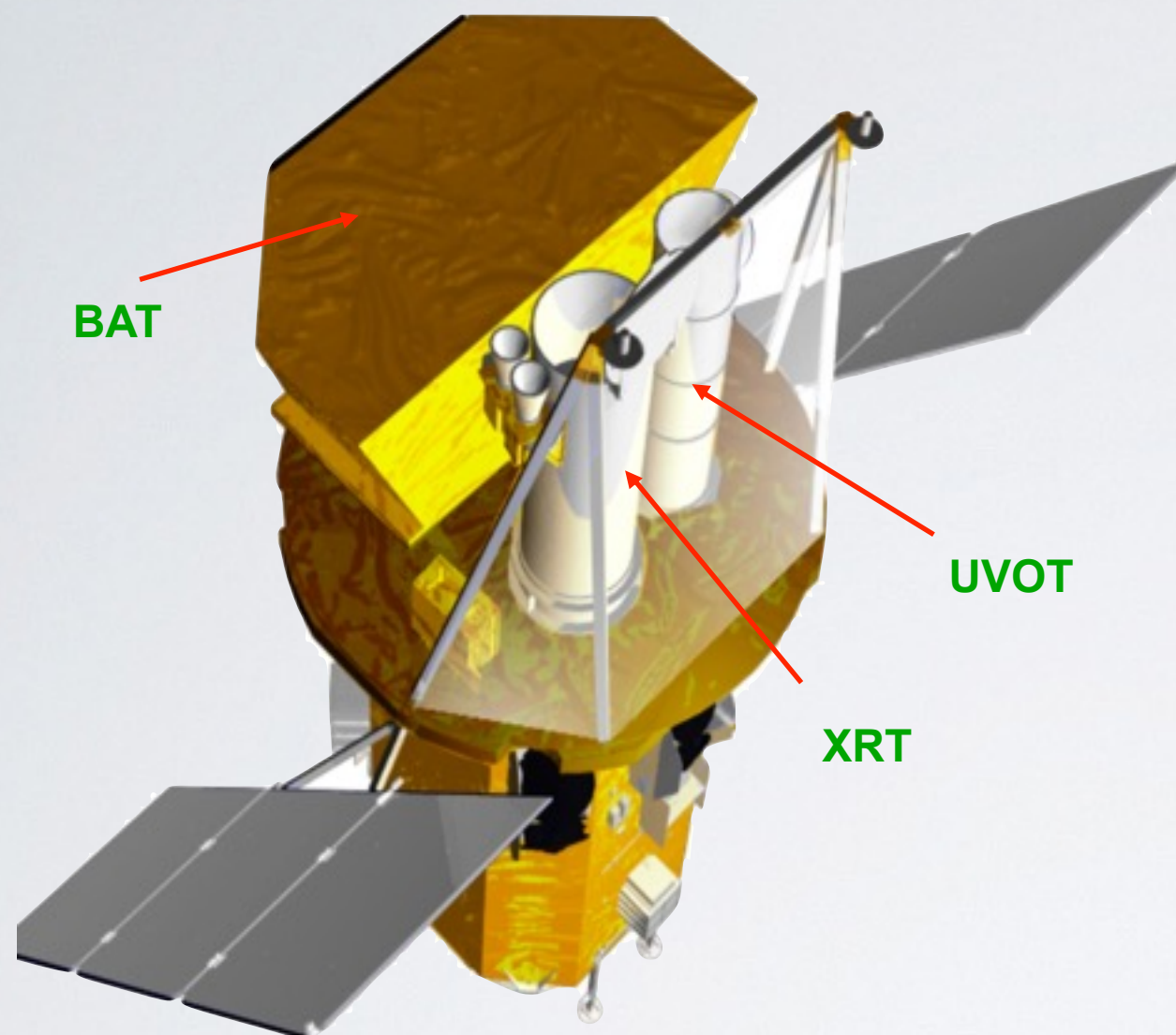


SWIFT AND GRAVITATIONAL WAVE COUNTERPART FOLLOW-UP

JAMIE A. KENNEA (Penn State)

SWIFT



- **Burst Alert Telescope (BAT)**

- 15-150 keV
- 2 sr field of view
- CdZnTe detectors
- Detects ~100 GRBs per year

- **X-Ray Telescope (XRT)**

- 0.3-10 keV
- 23.8 arcminute diameter FOV (~0.12 sq degree)
- few arcsecond (as good as 1.8'') positions
- CCD spectroscopy

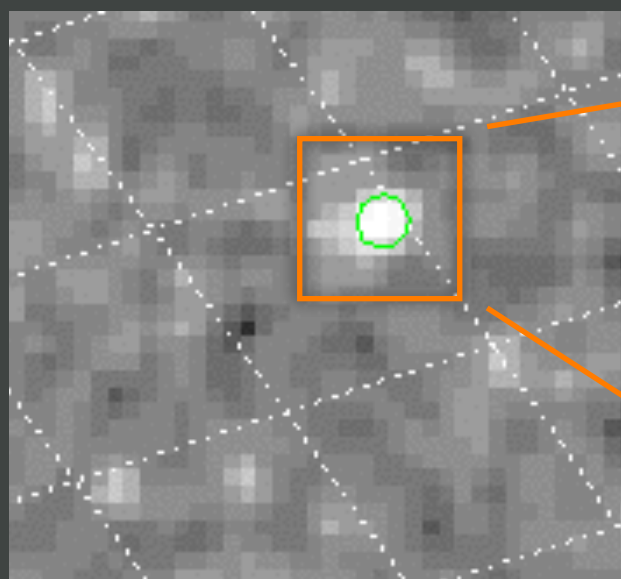
- **UV/Optical Telescope (UVOT)**

- 170 – 650 nm
- 17 arcminute width square FOV (~0.8 sq degree)
- Sub-arcsecond positions
- Grism spectroscopy
- 6 UV/optical broad-band filters
- 22nd mag sensitivity (filtered)

SWIFT DETECTS A GRB

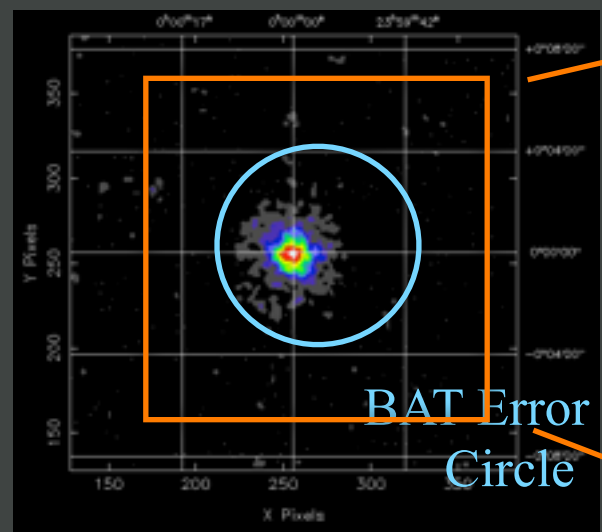
1. Burst Alert Telescope triggers on GRB, calculates position to $\sim 1 - 3$ arc-minutes, transmits to ground via TDRSS and distributed by GCN.
2. Spacecraft autonomously slews to GRB position in 1-2 minutes
3. X-ray Telescope: ~ 5 arcsec prompt, ~ 2 arcsec delayed position (distributed via GCN ASAP)
4. UV/Optical Telescope images field, transmits finding chart to ground
5. The Swift team analyzes the data in real time and sends out notice to the community in $\sim 5 - 20$ minutes.

BAT Burst Image



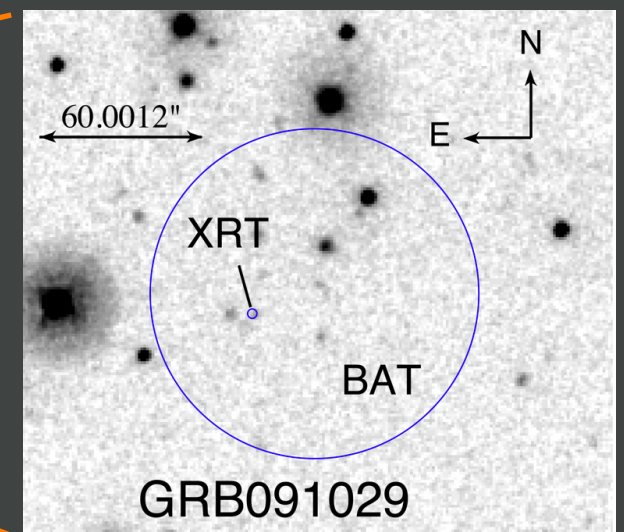
T~30 sec

XRT Image



T~100 sec

UVOT Image



T~300 sec

SWIFT AS A GW COUNTERPART FINDER

- BAT triggering on a short GRB that ALIGO detects is clearly the “best case scenario”.
- Swift’s power however is it’s capability of performing rapid Target of Opportunity (TOO) observations in order to search for things that it did not detect itself.
- For the rest of this talk I will discuss the mechanics of how Swift can quickly perform searches of LIGO error regions for afterglow candidates.

SWIFT OPERATIONS IN A NUTSHELL

- **FOT** command Spacecraft, look after health and safety, monitor trends, perform day to day engineering tasks.
- **SOT** plan observations, communicate with observations, receive and process TOO's (approvals by PI Neil Gehrels), send plans/TOO's to FOT.
 - Observatory Duty Scientists (ODS) main interface between SOT and community. ODS can approve TOO's out of hours.
- MOC operates from **8-5pm Monday-Friday**.
 - On-call ODS/FOT outside of those hours.
 - On call person cycles weekly.

TOO INTERFACE

- Swift has a TOO web page which scientists use to submit requests for observations.
 - In 2014 we received almost 1000 TOOs!
- We currently accept observations for monitoring and tiling.
- For some programs, we have a backdoor system that allows auto generated TOOs from an email.

The screenshot shows a web browser window with the URL `swift.psu.edu`. The page header features the Penn State logo and the text "Mission Operations Center for Swift" next to a stylized "Swift" logo and a sun icon. A navigation bar includes links for Home, Mission, Observatory, Operations, and Additional Info.

The main content area is titled "ToO Request - Source Information" and contains a red warning: "Please be prepared to fill-out the entire form in one sitting or in about an hour." The form includes several input fields and sections:

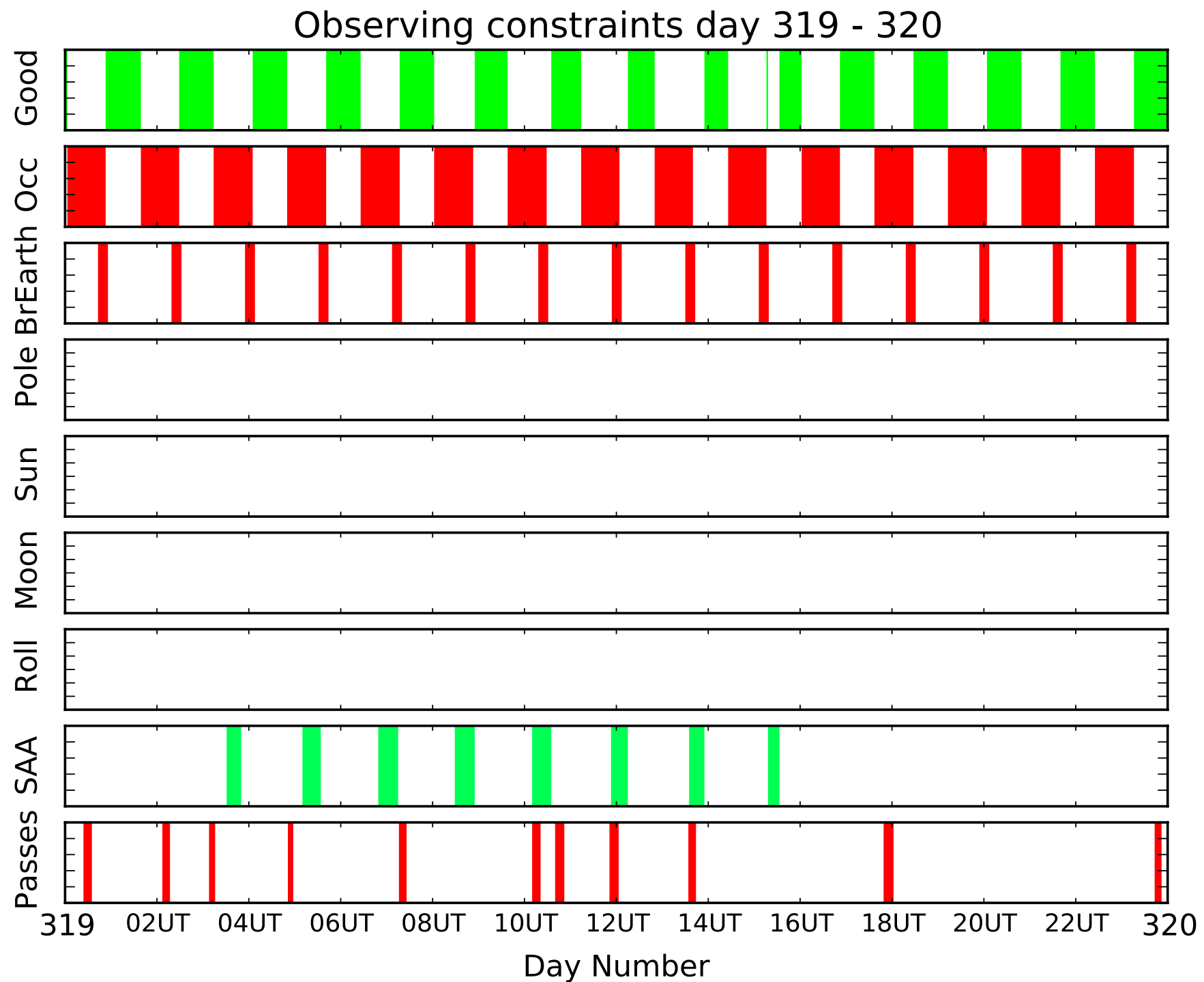
- Source Name:** A text input field.
- Coordinates (J2000):** A section with instructions to use decimal or HH MM SS.ss in each field. It includes links for [HEASARC](#) and [UKSSDC](#) target visibility calculators. Below are input fields for R.A. and Declination.
- Position Error (If Applicable):** A section with a label "90% Confidence Radius" and an input field for arcminutes.
- Type or Classification:** A list of radio button options: AGN, Be Binary System, Comet or Asteroid, Dwarf Nova, GRB, Nova, Pulsar, Supernova, and X-Ray Transient.

The right sidebar contains a welcome message for "Jamie Kennea" and links for "My ToO Requests", "Submit a ToO Request", "Test Request", "Update Account Info", "Change Password", "Log Out", "Tiled Observations", "Summary of Requests", and "Admin". At the bottom of the sidebar is a grid of logos for various institutions including Penn State, NASA, UCL, and others.

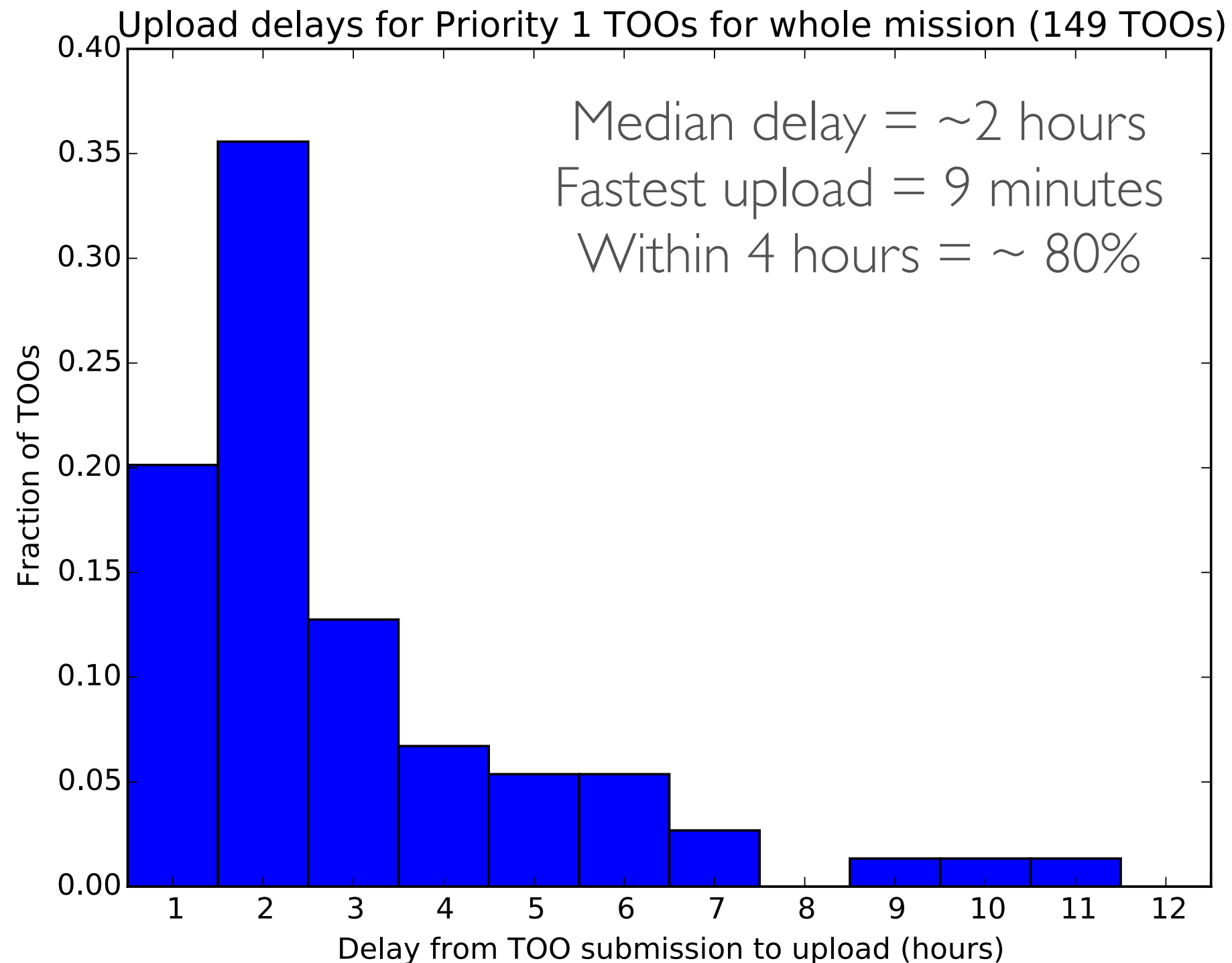
HOW QUICK CAN WE UPLOAD?

- Groundstation uploads:
 - Typically 9-12 ground-station passes per day.
 - Not all ground-stations are at the same location, so time between passes varies.
 - Sometimes as short as 20 minutes, sometimes 5-6 hours.
 - Uploads can be performed out of hours without FOT involvement.
- TDRSS:
 - TDRSS uploads can be scheduled at any time 24/7 with a 15 minute overhead.
 - TDRSS uploads outside of working hours require calling in on-call FOT, so add time of travel into MOC (~15-45 minutes) to already 15 minute overhead.
 - **For majority of cases, ground-station uploads will be adequate/faster than TDRSS.**

EXAMPLE VISIBILITIES



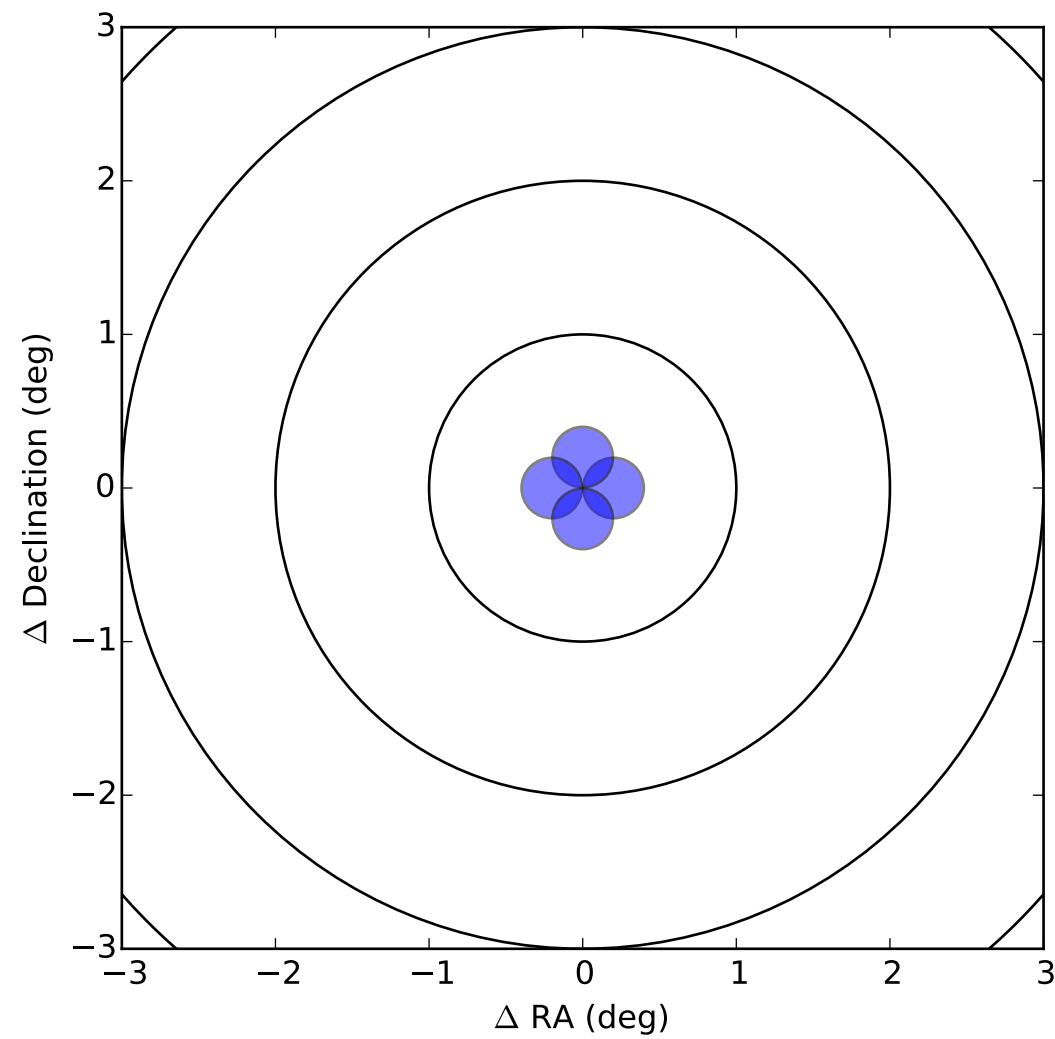
UPLOAD TIME STATISTICS



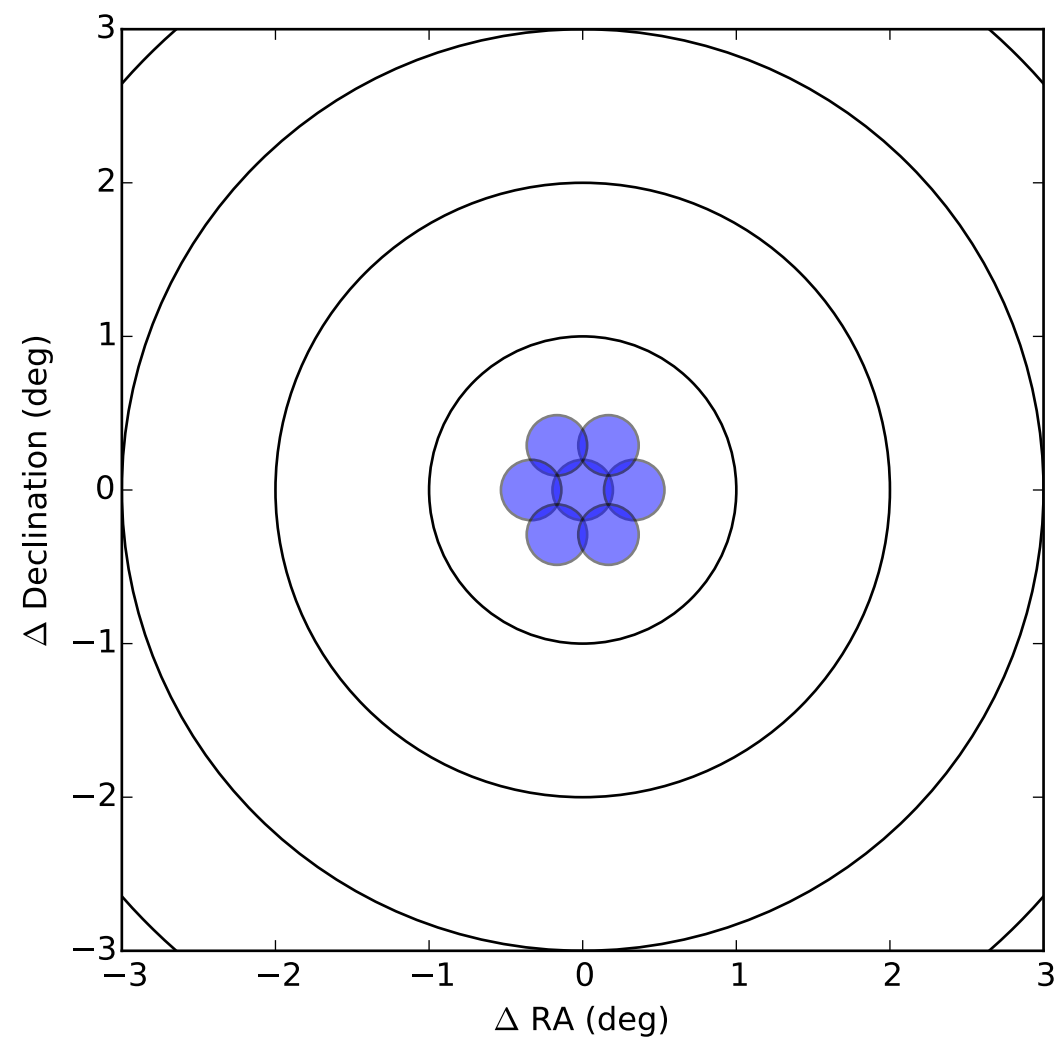
HOW DO WE COVER LARGE REGIONS?

- In-built tiling can cover hexagonal regions
 - 4, 7 point tiling utilized frequently by Swift
 - 19, 37 point tiling available but never tested/utilized.
 - Can cover larger regions by uploading multiple TOOs over multiple passes (but will take forever to cover GBM error boxes)
- Uploadable lists of RA/Dec to cover non-circular error boxes.
Requires BAT FSW update, in development...
- PPST Jamming concept.

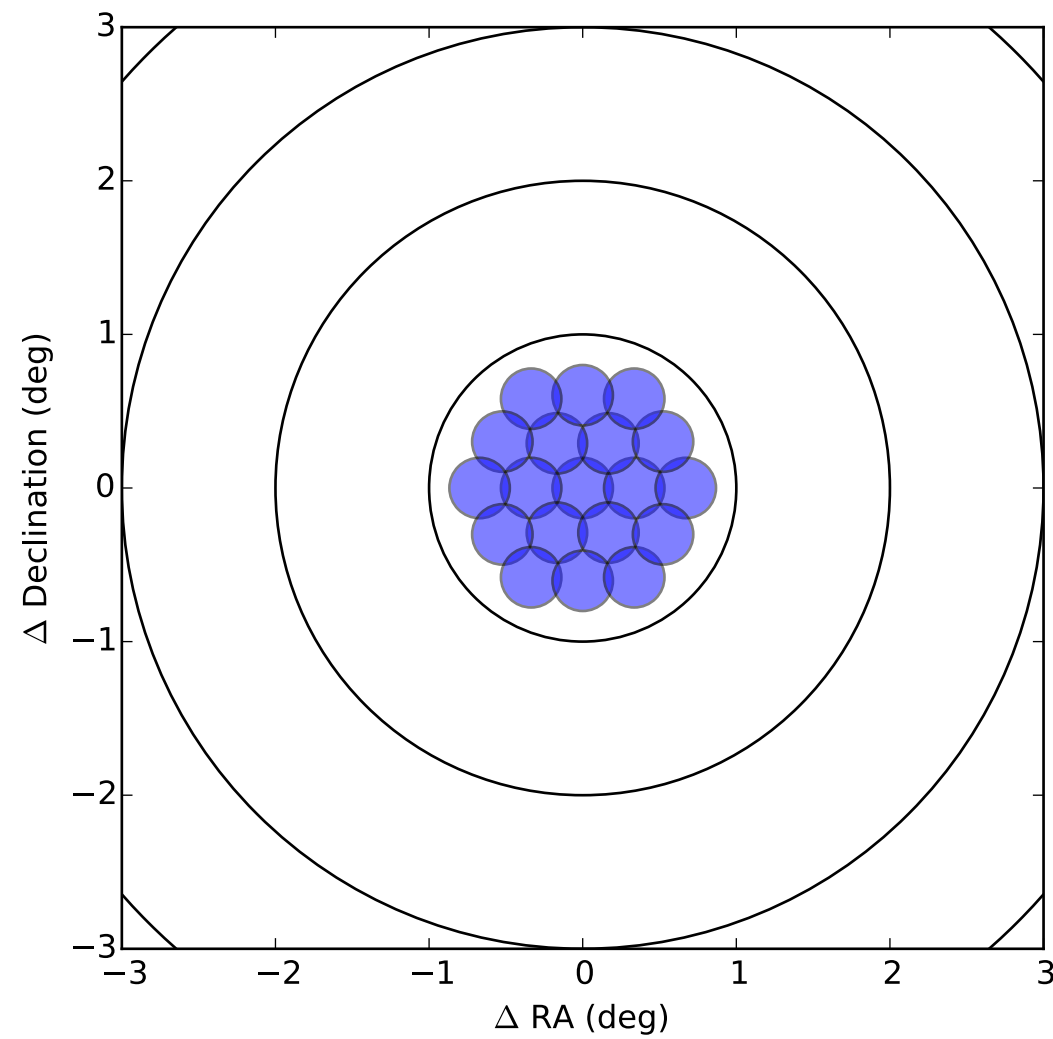
4-POINT TILING



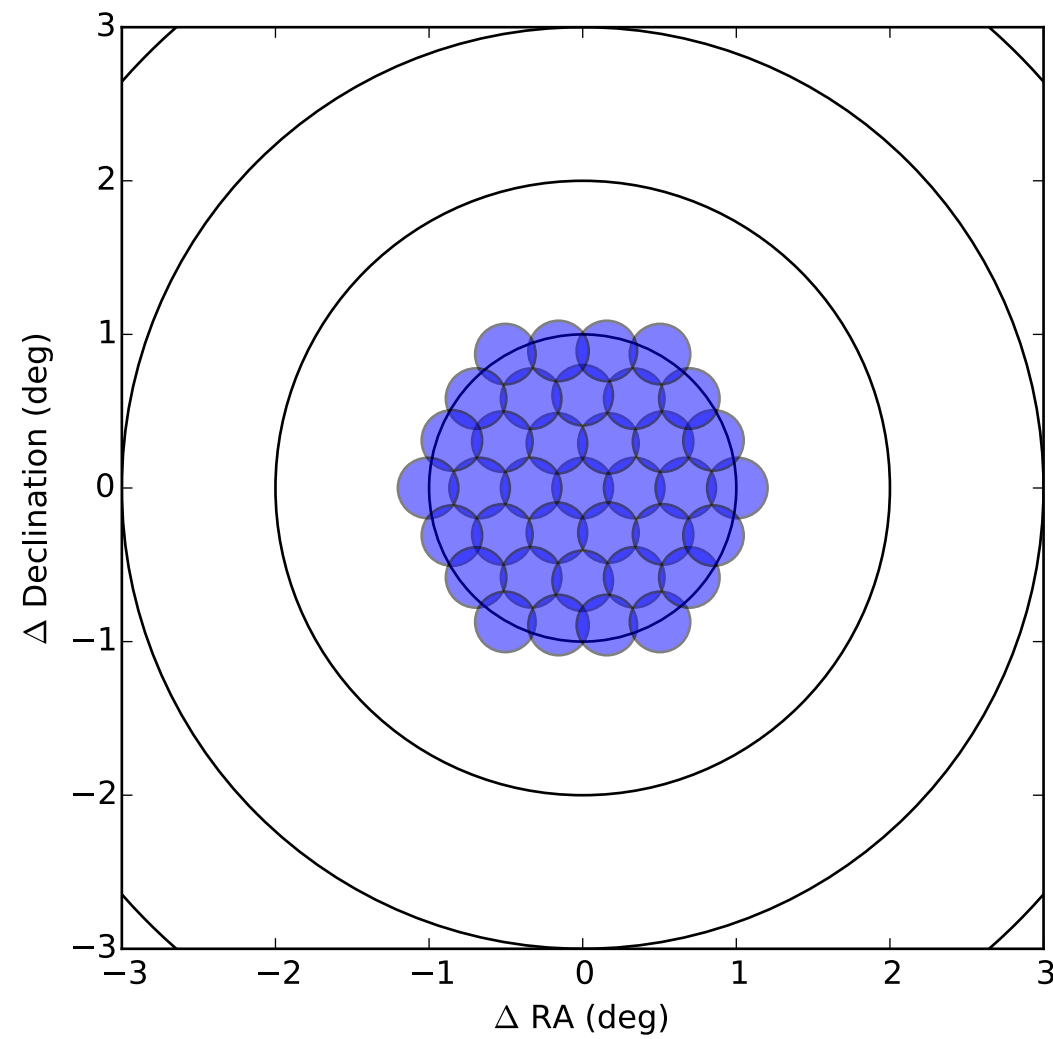
7-POINT TILING



19-POINT TILING



37-POINT TILING



PPST JAMMING

- Alternative is to upload a PPST to S/C that contains all the pointings required to cover error box/region.
 - PPST would replace current onboard schedule.
 - Upload could only happen at groundstation pass
 - PPST created using automated software, likely a larger impact on other science that Swift is performing. However there would be a non-zero overhead time to create the new PPST.
 - May require non-negligible updates to planning software to allow this to work.
- **Without FSW updates, this the only viable way of covering error boxes that cannot be easily covered by tiling.**

AUTO ANALYSIS OF DATA

- For GRB/Neutrino tiling we (Phil Evans @ University of Leicester) auto analyze the data to find potential counterparts.
- Can easily expand this system to cover search for counterparts from tiling of GBM error regions and/or LIGO error regions.
- Of course, the larger the area covered, the more likely to find spurious sources.
 - Will need some follow-up of likely counterparts later on to confirm fading.

CONCLUSIONS

- Swift is prepared to try to find electromagnetic counterparts of GW triggers other than those seen by BAT or GBM, but will be significantly challenging.
- Typically Observations will start at best within 15 mins of trigger. Median time is ~ 2 hours. Not clear if this can be improved easily.
- Likely going to need some changes in Swift operations to cover large error boxes.
- Possible BAT FSW coming online in future can help.
- “PPST Jamming” may allow us to cover larger error regions right now, with relatively low latency, but will require some development.