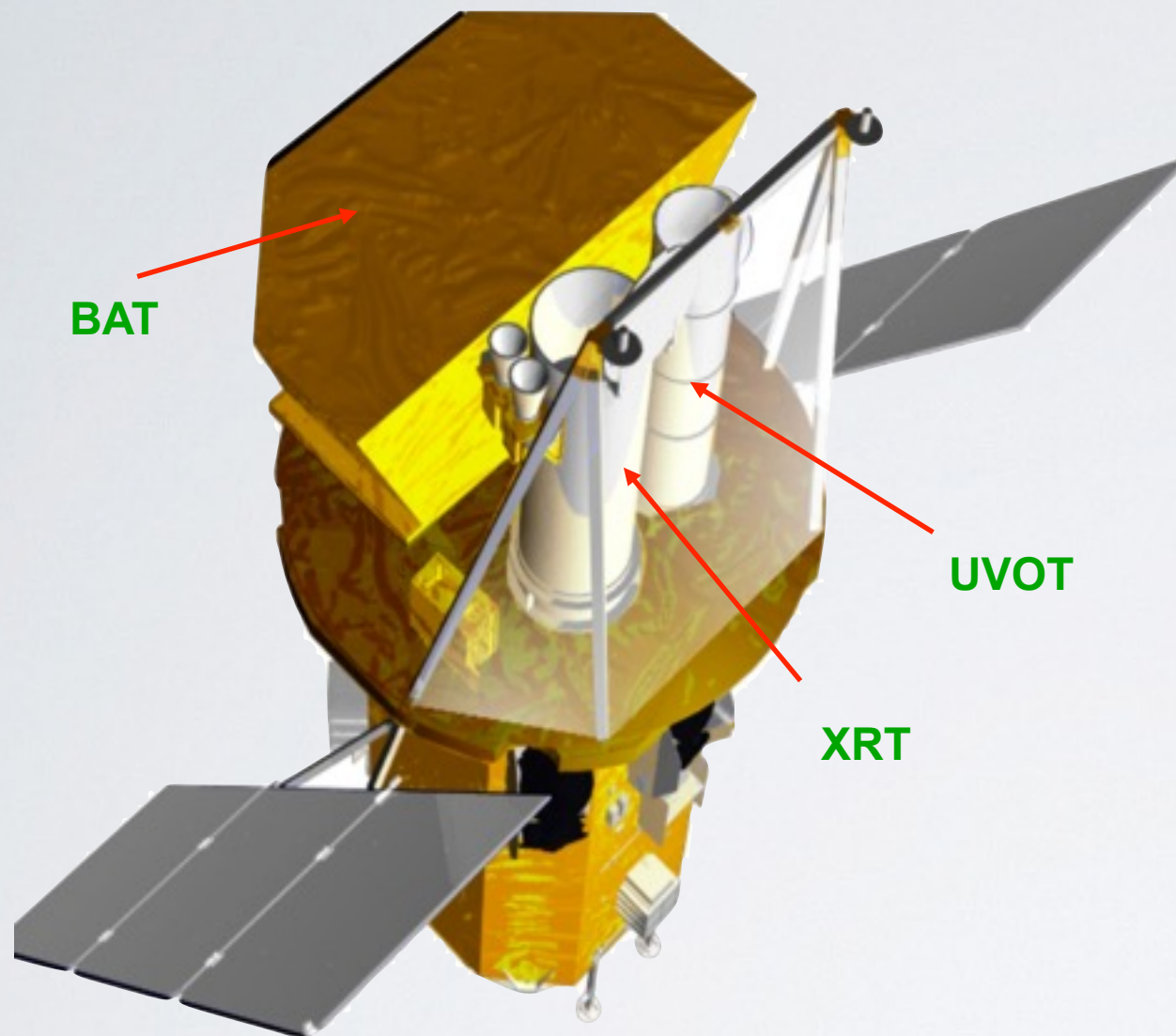


SWIFT AS A FOLLOW-UP TOOL

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 AS A 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 ~ 0.75 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.
 - Sensitive multi-wavelength coverage in pointed observations.
 - Ability to perform regular monitoring of counterparts to determine temporal properties (i.e. "is it fading?")

SWIFT OPERATIONS IN A NUTSHELL

- MOC is at Penn State (about 2.5 miles away from here)
- MOC operates from 8-5pm Monday-Friday.
 - TOO requests come in 5 levels of priority. Priority 1 pages on-call ODS 24/7. Priority 2 pages during working hours (8-5pm Eastern).
 - On-call ODS outside of those hours to respond to priority 1 (<4 hours turn-around) TOOs
 - Often we respond to lower priority TOOs out of hours too.
- Swift can rapidly observe 1 TOO at a time through ground commanding.
 - Ground passes including ground station (usually ~1 per orbit, but there are gaps sometimes of up to 8 hours)
 - TDRSS can be used, but requires FOT presence in MOC, so only used during working hours or for very high priority events.

TOO INTERFACE

- Swift has a TOO web page which scientists use to submit requests for observations.
 - In 2015 we received 1,222 TOOs as of yesterday. 3.6 TOOs per day!
- We currently accept observations for monitoring and tiling to cover larger errors.
- For some programs (Neutrino, Fermi LAT GRB, LIGO/Virgo GW triggers), we have a backdoor system that allows auto generated TOOs.
 - Can allow for “private” TOOs.

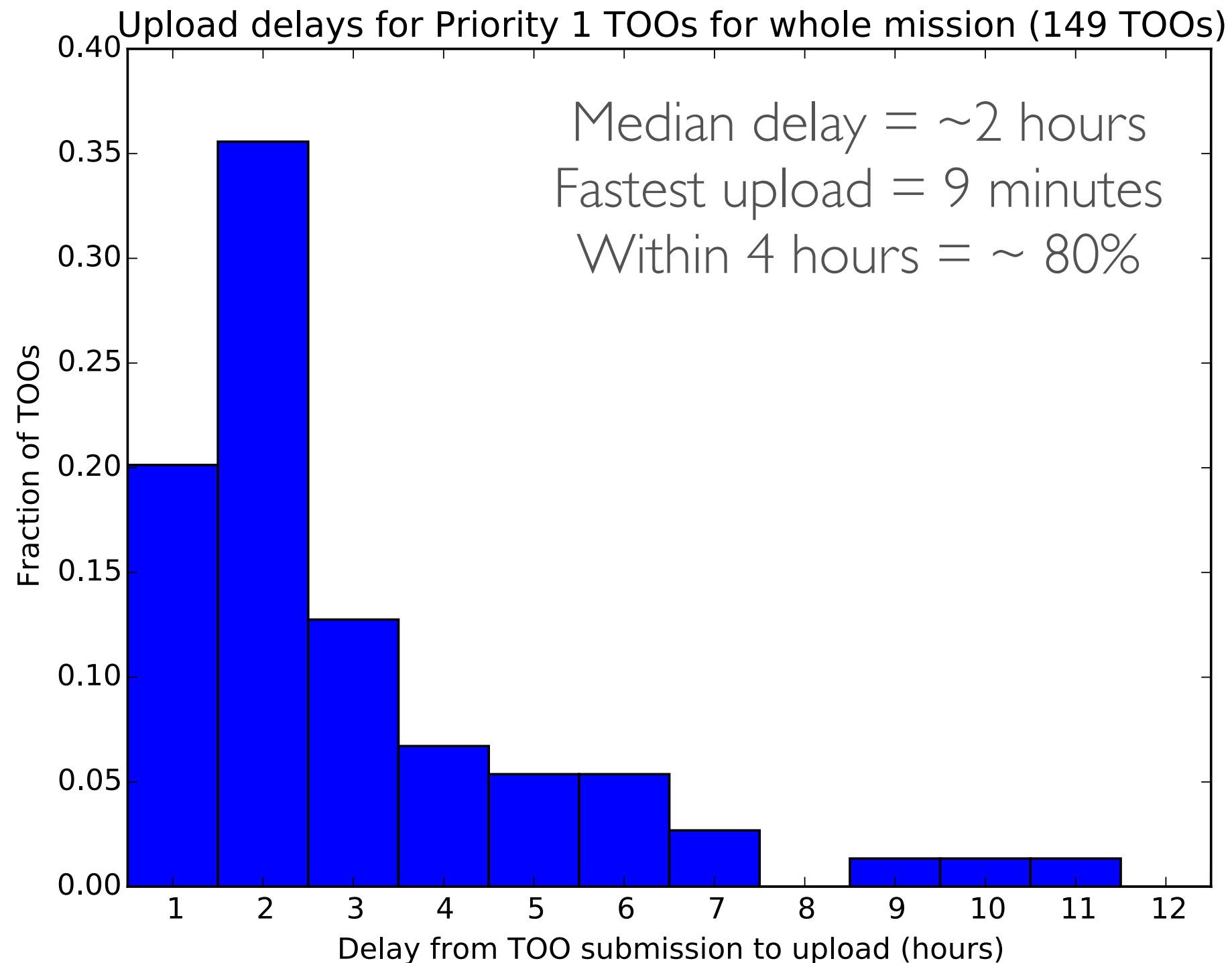
The screenshot shows a web browser window with the URL swift.psu.edu. The page header includes the Penn State logo and the text "Mission Operations Center for Swift". A navigation bar contains links: Home, Mission, Observatory, Operations, and Additional Info. The main content area is titled "ToO Request - Source Information" and contains a form with the following sections:

- Source Name:** A text input field.
- Coordinates (J2000):** A section with instructions: "Use decimal or HH MM SS.ss in each field." and "To check target visibility, please use the [HEASARC](#) or [UKSSDC](#) target visibility calculators." It includes 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.

On the right side of the page, there is a sidebar with a welcome message "Welcome, Jamie Kennea", links for "My ToO Requests" and "Submit a ToO Request", a "Test Request" section with links for "Update Account Info", "Change Password", and "Log Out", and a "Tiled Observations" section with links for "Summary of Requests" and "Admin". At the bottom of the sidebar, there is a row of logos for various institutions: Penn State, NASA, UCL, and others.

<http://www.swift.psu.edu>

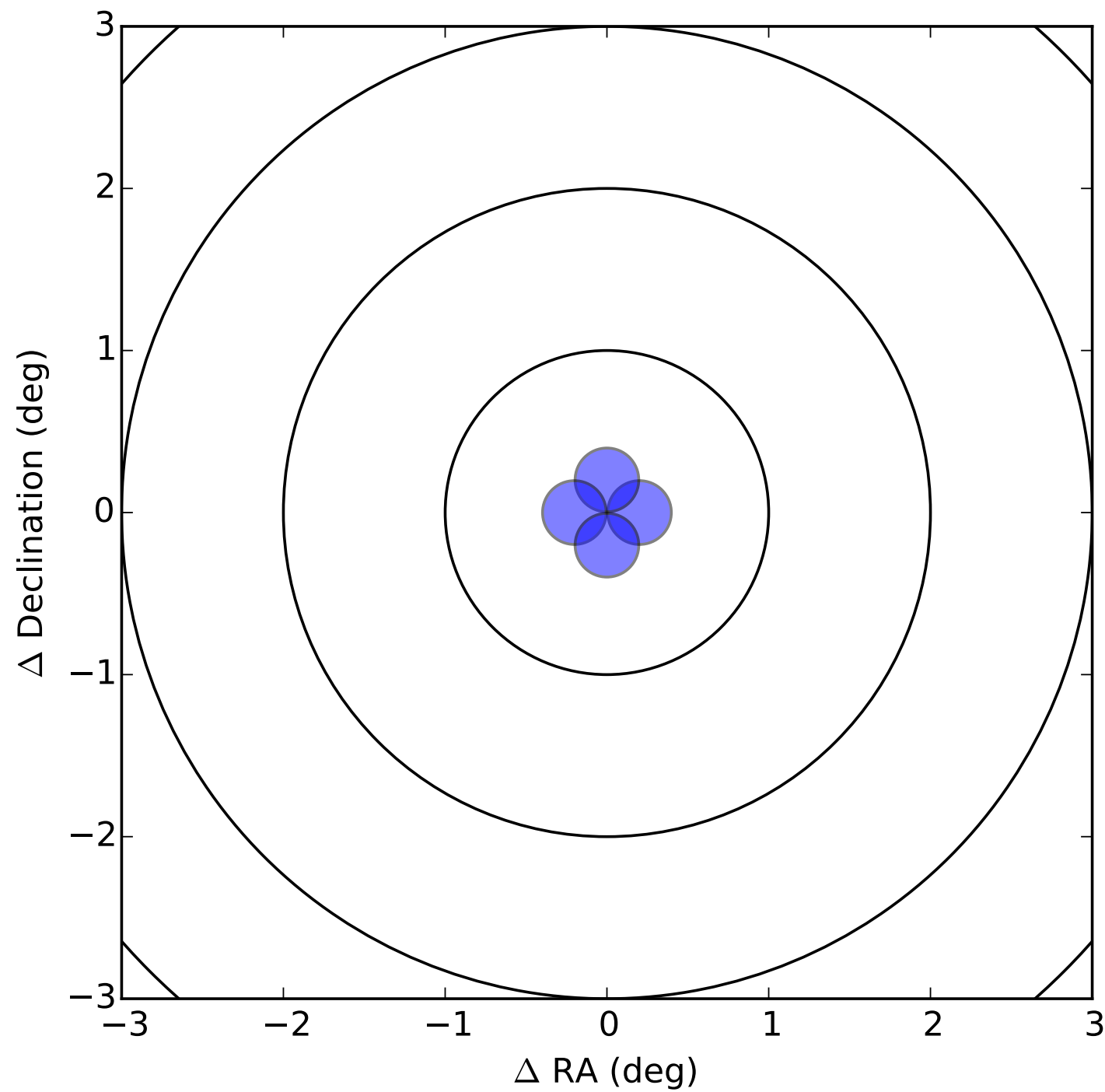
UPLOAD TIME STATISTICS



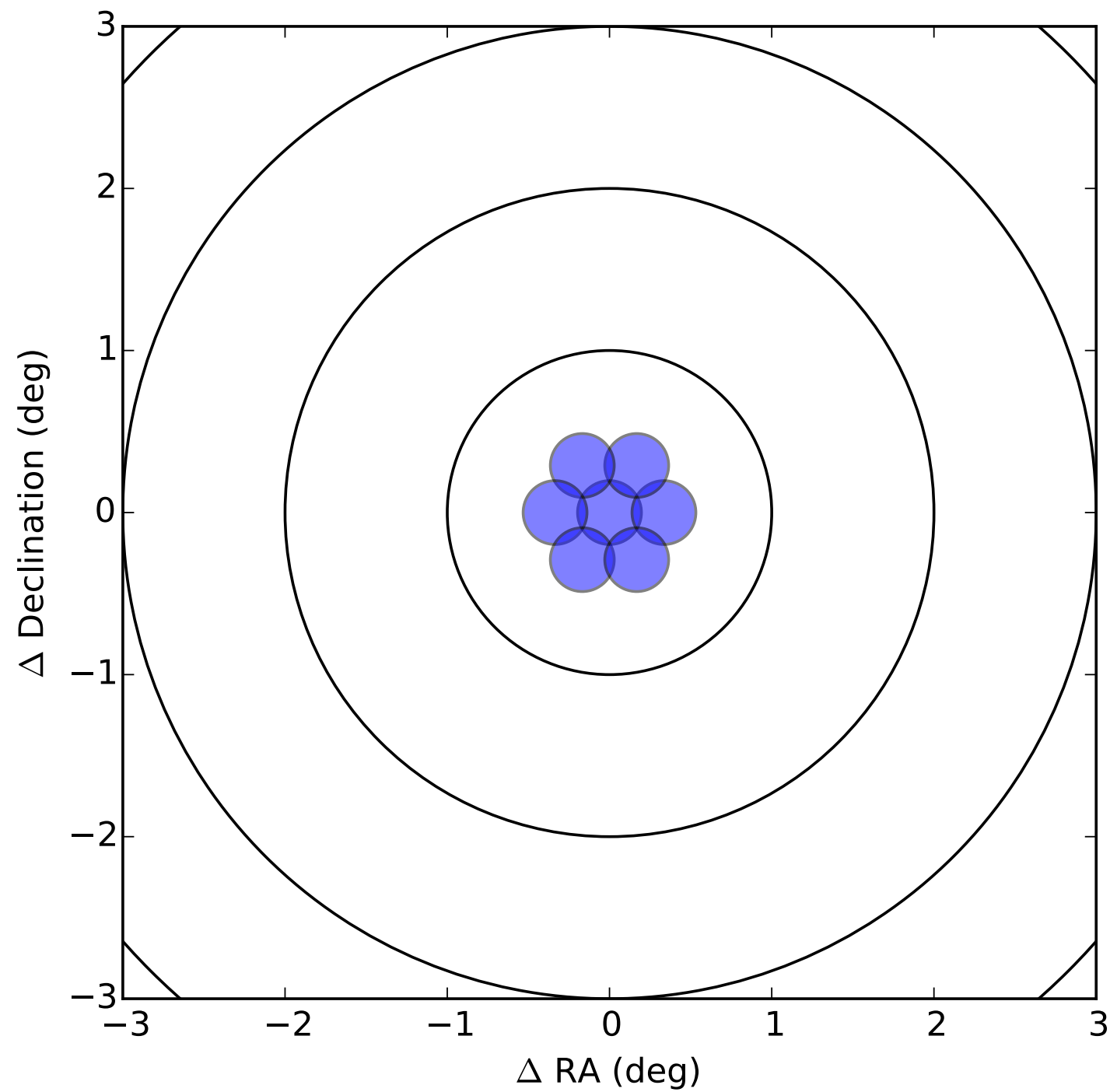
HOW DO WE COVER LARGE REGIONS?

- IPN, Neutrino and GW trigger error regions are often larger than the FOV of XRT/UVOT.
- In-built tiling can cover hexagonal regions
 - 4, 7 point tiling utilized frequently by Swift
 - 19, 37 point tiling recently approved for use and tested (*not yet available to community*)
 - 37-point tiling still only covers 1 degree radius error circle!
 - Can cover larger regions by uploading multiple TOO's over multiple passes (e.g. IPN error regions).
 - Inefficient and slow, plus large strain on Swift Team!

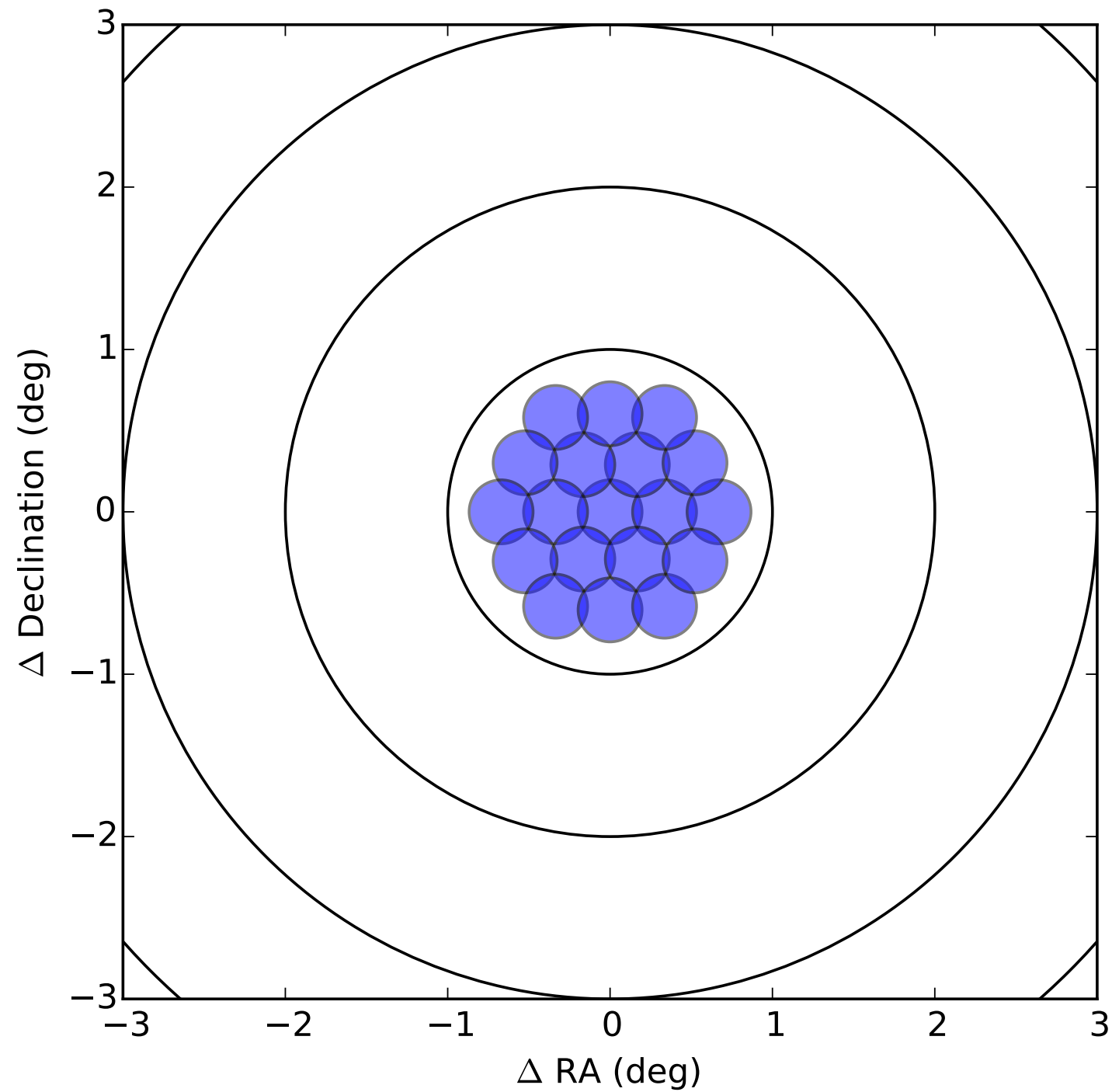
4-POINT TILING



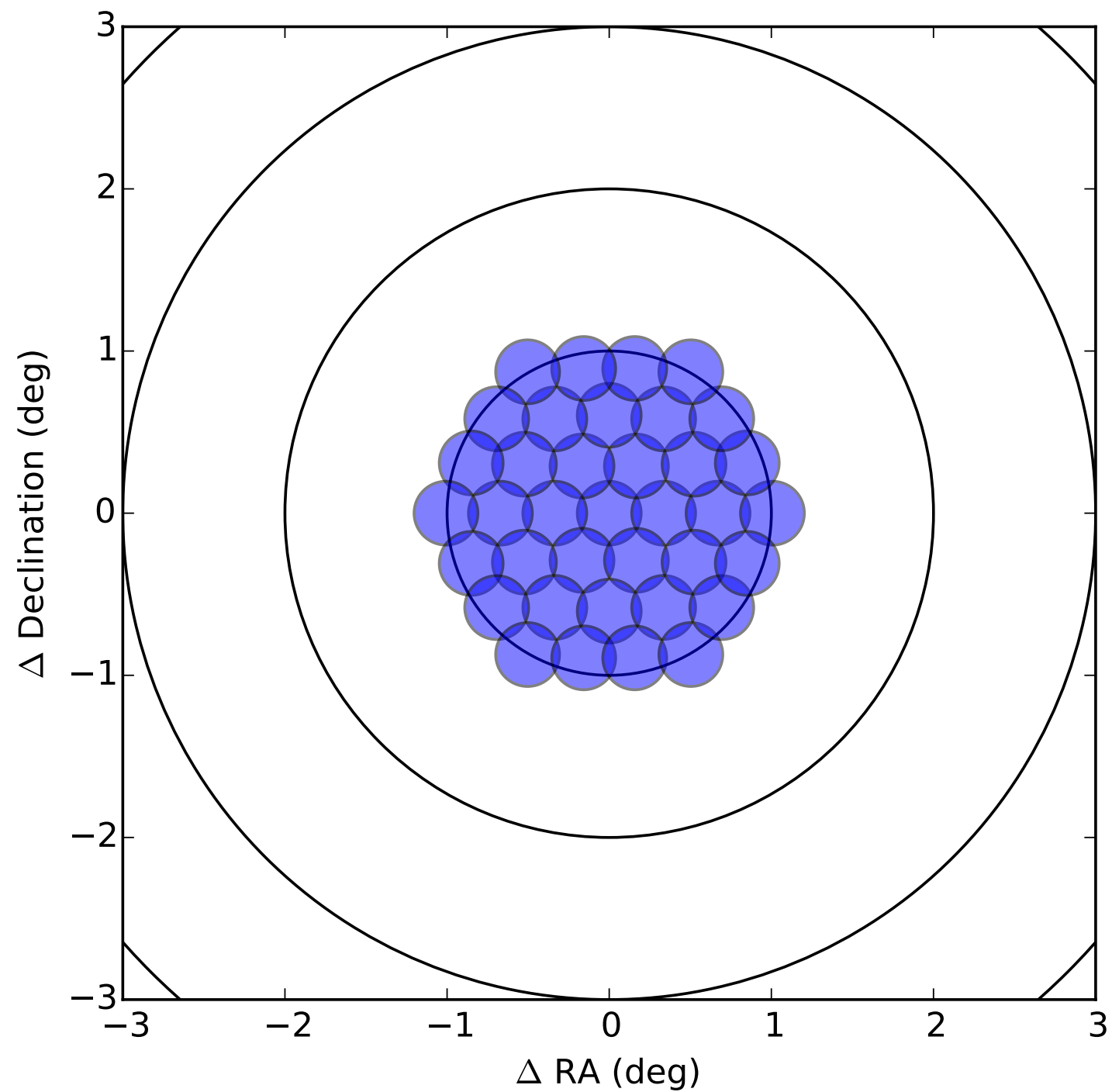
7-POINT TILING



19-POINT TILING



37-POINT TILING



MASS TILING TECHNIQUE

- Generate list of tiles that cover the large error region by tiling.
- Create from this a pre-planned science timeline (PPST) by merging these pointings with the current onboard plan.
- Upload this PPST to replace the on-board running PPST at the next ground station pass. Observations commence immediately.
- Minimum exposure time is 60s per field (hard limit). But with XRT $\sim 10\text{-}20$ mCrab sensitivity in 60s, so still useful for bright transients!
- Observations of a maximum of 450 targets in 24 hour period (set by onboard buffer size).

PROS AND CONS

- Pros

- Only way to cover large number of sources / sky area
- Can be done without FSW change - FSW change only allows us to get on target quicker.

- Cons

- Will knock out a lot of targets when we're concentrating on GW follow-up!
- BAT triggering severely impacted by short dwell time on tiles.
- Slow to start due to need to wait for ground station pass.

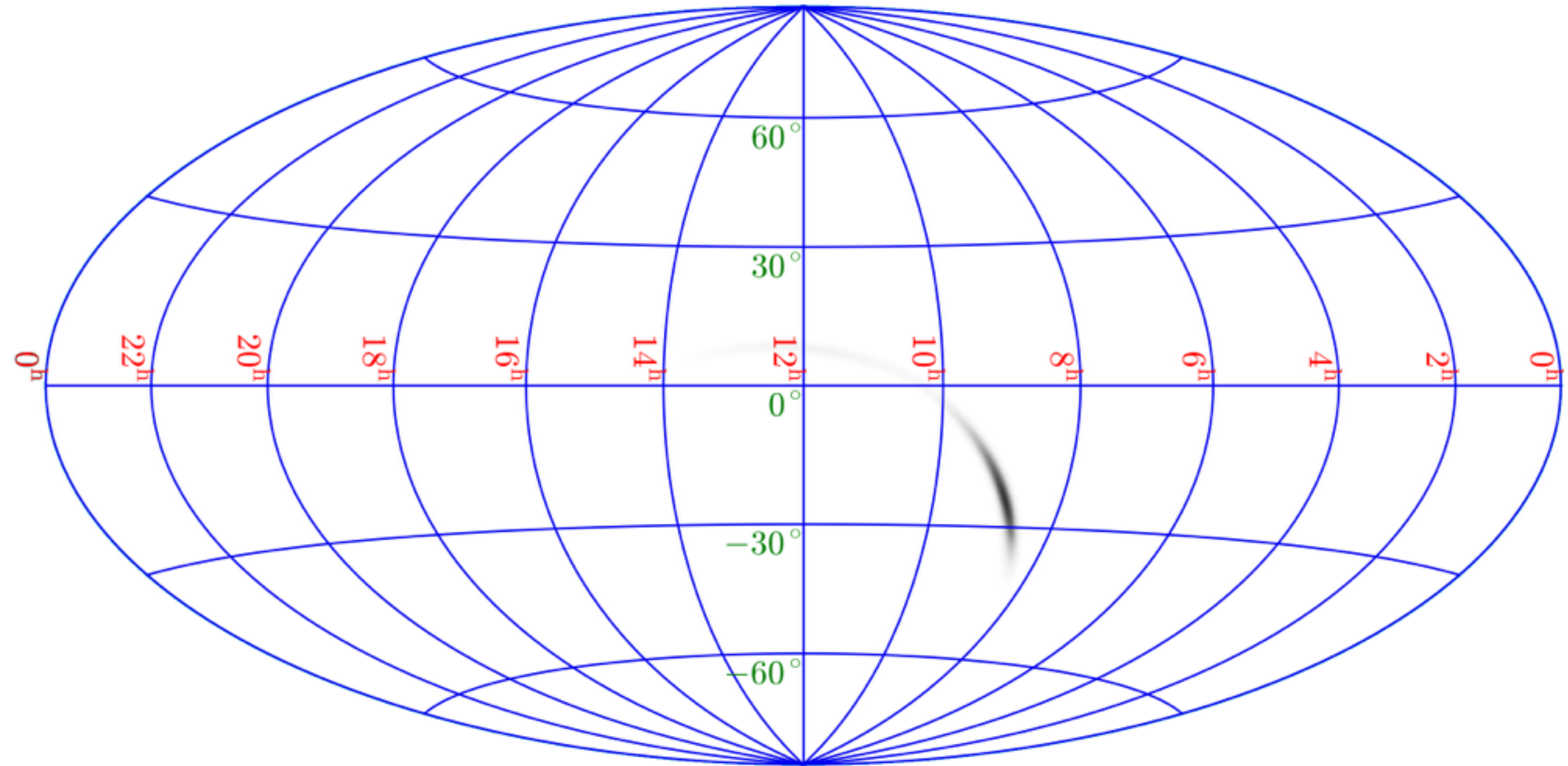
STATUS

- 19 and 37 point tiling has been tested and approved for use.
 - Importantly shows that many short (45-60s) exposures can be performed by Swift without harming spacecraft.
- Software to generate PPSTs from LIGO error regions has been written and tested.
- On-board testing of large scale tiling already began
 - 1 orbit test of 60s per-tile exposures performed and successful.
 - 4 orbit test to be performed imminently.

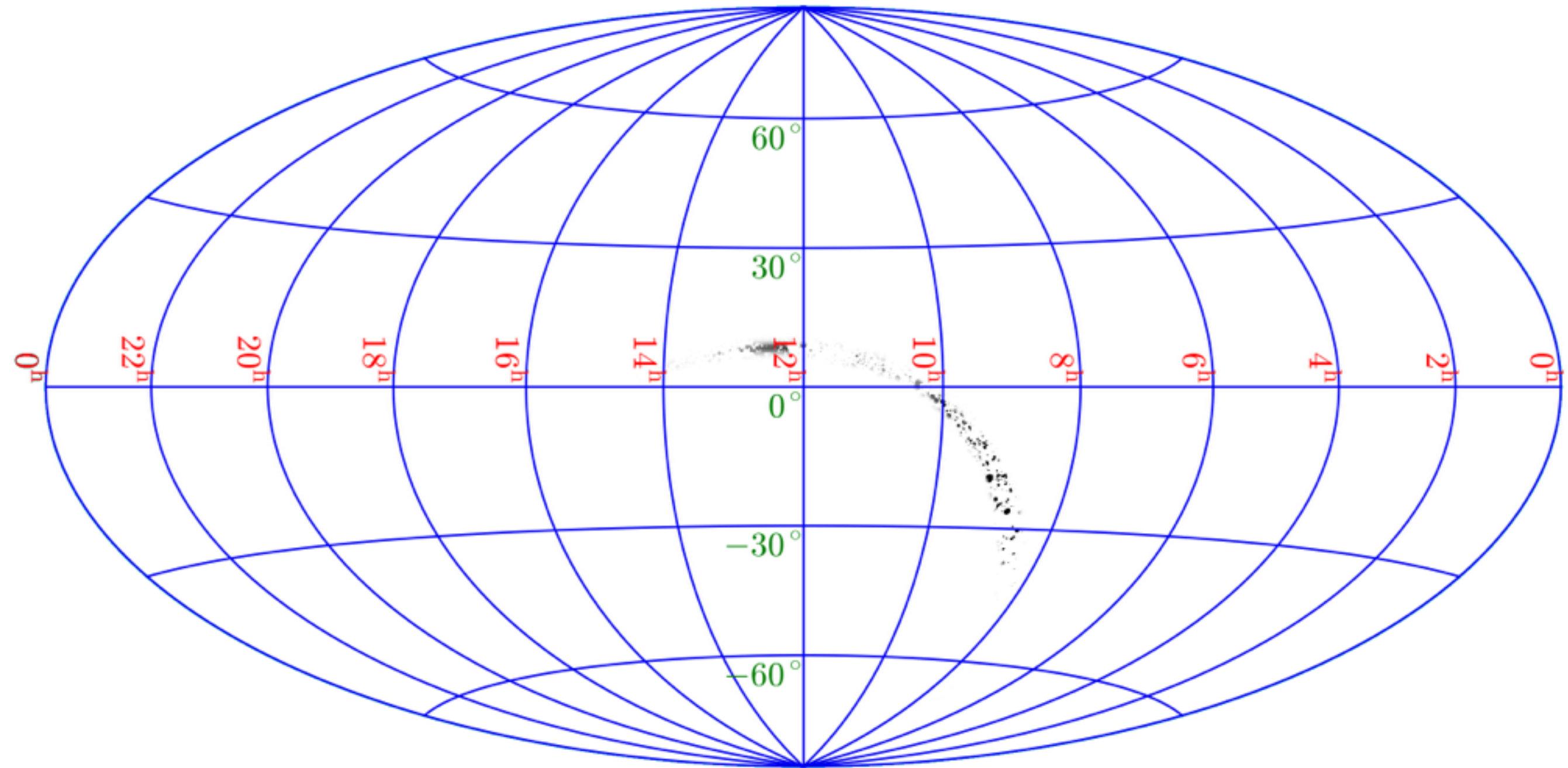
PLAN FOR LIGO/VIRGO TRIGGERS

- Trigger on compact binary coalescent events.
- Take BAYESTAR error region, convolve with Galaxy Catalog to target nearby galaxies.
- Upload PPST containing as many 60s exposures of the LIGO error regions for 48 hours to look for prompt emission.
- For following three days take as many 500s exposures of these galaxies again, in order to look for off-axis afterglows.
- Process validated for on-board use very soon. Waiting for the next trigger to occur.

EXAMPLE BAYESTAR MAP



CONVOLVED WITH GALAXY CATALOG



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CONCLUSION

- Swift is the only observatory capable of performing rapid, multi wavelength (optical/UV/X-ray/Hard X-ray) observations in response to TOO triggers.
- Swift use has been focused on following up objects with relatively well known localizations (coverable in 1-7 XRT pointings)
- New capability allows coverage of large areas of the sky with short exposures (60s) - used to look for LIGO/Virgo EM counterparts - but can be used for any number of projects tiling larger error regions.