Vera C. Rubin Observatory
Rubin Observatory Operations

Target-of-Opportunity Operations During the Science Verification Surveys

Sean Patrick MacBride

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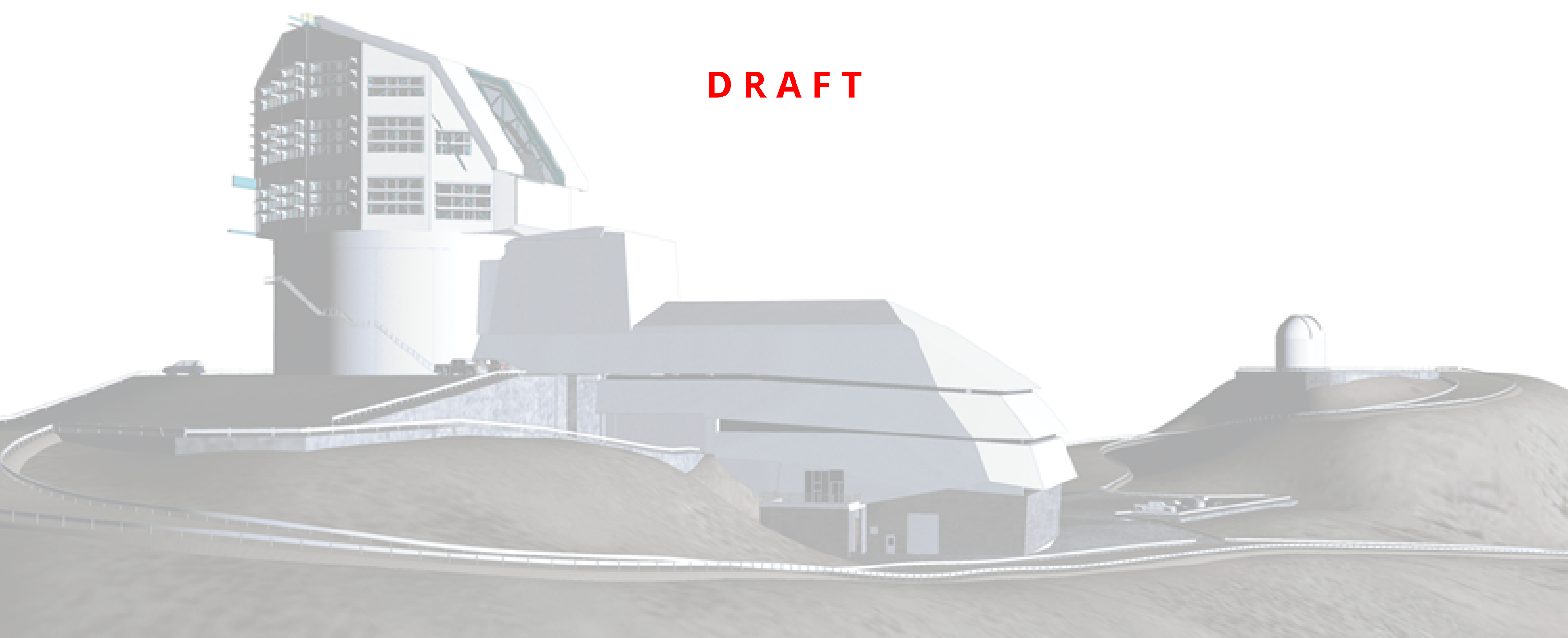

DRAFT

Abstract

We describe the technical implementation of the Rubin Target-of-Opportunity system, the workflow during the early commissioning and science verification period, the responses to real and mock alerts, and lessons learned.

Change Record

Version	Date	Description	Owner name
1	2025-05-29	First revision, covering intro and systems overview.	Sean MacBride
2	2025-07-13	Results from verification and mock triggers	Sean MacBride
3	2025-08-05	Results from 3I trigger	Sean MacBride
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6	2025-12-29	Add DOI	T. Jenness

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Target-of-Opportunity Operations During the Science Verification Surveys

1 Introduction

The LSST covers a wide swath of unique science cases and observation types. Rubin Observatory will enable many scientific discoveries, especially target-of-opportunity (ToO) observations during the early commissioning period.

Rubin Observatory is uniquely positioned to lead ToO observations through the 2020's and beyond due to it's unique technical capabilities. The $9.6\,\mathrm{deg}^2$ field-of-view of the Rubin optical system allow ToO observations to survey a wide area, while the single-visit depth of ~ 24 allows single exposures to observe the southern sky for faint transient phenomena. The combination of the large FOV and deep observations make Rubin Observatory an ideal tool for discovery of ToO phenomena.

The Rubin ToO program encompasses 3% of the LSST, and includes gravitational wave (GW), high-energy neutrino, potentially hazardous asteroids, and other time-sensitive astrophysical phenomena as different targets. Each target has a different observing strategy based on observing conditions, the conditions of the astrophysical event, and other parameters. The observing strategies are the product of community input, and were revised in 2024 (Andreoni et al., 2024). These recommendations were accepted by the survey cadence optimization committee in January 2025 [PSTN-056].

While other components of the LSST are not limited by the specific time of observation, ToO is unique in that the confirmation of a ToO counterpart requires time-sensitive observations, ranging from mere minutes of alert receipt to hours. The unique nature of observations requires different workflows, communication channels, and operations to ensure that ToO observations are valuable to the LSST.

In the forthcoming sections, we describe the state and workflow of the Rubin ToO system during the SV period (section 2), verification of different Rubin components using simulated ToO responses (section 3), the responses to real alerts (section 4), and lessons learned from the early commissioning and science verification period (section 5).

2 Systems Overview

The Rubin ToO system is composed of five distinct components, each responsible for a different aspect of ToO operations and observations.

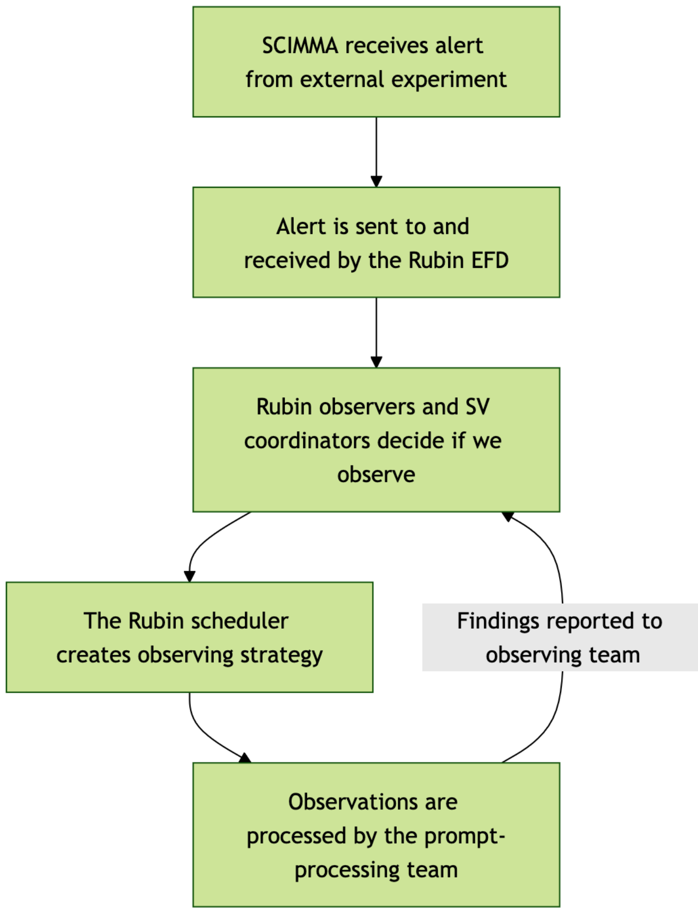

FIGURE 1: The general workflow during the SV period, with the five separate teams and their main responsibilities listed.

2.1 Incoming alert stream

The Rubin ToO system starts at the incoming alert stream. The incoming alert stream is responsible for parsing alerts from external experiments and sending them to Rubin infrastructure.

Rubin Observatory considers ToO alerts from a variety of astrophysical phenomena and experiments, including

- **Gravitational waves:** LIGO-Virgo-KAGRA (LVK) Collaboration
- **High energy neutrinos:** IceCube Neutrino Observatory
- **Potentially hazardous objects:** The NASA Jet Propulsion Laboratory (JPL) Scout and JPL Sentry experiments
- **Galactic supernovae:** The Supernova Early Warning System (SNEWS) and the Super-Kamiokande (Super-K) experiment
- **Lensed GRBs:** LVK and the Neil Gehrels Swift Observatory

All incoming alerts are handled by Scalable Cyberinfrastructure to support Multi-Messenger Astrophysics (SCiMMA) HopSkotch. Alerts are received from different experiments before being assessed for alert quality. Alerts passing our quality filters are then passed to Rubin infrastructure. In this way, all alerts that arrive at Rubin infrastructure are high quality alerts worthy of follow-up. This enables future revisions of Rubin observing strategy related to ToO to be developed internal to the Rubin Scheduler.

Alert quality for Rubin observations is set by the Rubin science community, who developed a set of criteria for ToO observations in their 2024 recommendation (Andreoni et al., 2024). This recommendation has been adopted by SCiMMA to ensure the EFD and Rubin scheduler do not need to perform additional checks of alert quality after EFD ingestion.

2.2 Engineering facility database

The Rubin engineering facility database (EFD) hosts telemetry about every Rubin Observatory component that interacts with middleware - from dome humidity, to focal plane temperature, and even image quality statistics. For ToO purposes, this includes SCiMMA alert packets. These alerts are received at the summit, including skymap information for the alerts.

The Scheduler Commandable SAL Component (CSC) collects telemetry from the EFD and hands them over to the Driver, which formats it in a way the scheduling algorithm understands. By using a general purpose interface for collecting and passing telemetry from the EFD to the scheduling algorithm, it allows us to easily add new data sources as long as the data is in the EFD. This flexible design supports the SCiMMA alert stream, but also manual alert information added by observing specialists or other ToO scientists to the EFD [TSTN-035].

Rubin Scheduler ToO configuration	Strategy from Andreoni et al. (2024)
GW_case_B	GW, neutron star component, gold ($\Omega < 100\,\mathrm{deg}^2$)
GW_case_C	GW, Unidentified source, gold ($\Omega < 100\,\mathrm{deg}^2$)
GW_case_D	GW, neutron star component, silver ($\Omega < 500\,\mathrm{deg}^2$)
GW_case_E	GW, Unidentified source, silver ($\Omega < 500\,\mathrm{deg}^2$)
BBH_case_A	GW, Binary black-hole, dark time, nearby event
BBH_case_B	GW, Binary black-hole, dark time, distant event
BBH_case_C	GW, Binary black-hole, bright time
GW_case_large	GW, large skymaps ($\Omega > 500\,\mathrm{deg}^2$)
lensed_BNS_case_A	Lensed BNS, $\sim 900\,\mathrm{deg}^2$ skymap
lensed_BNS_case_B	Lensed BNS, $\sim 15\,\mathrm{deg}^2$ skymap
neutrino and neutrino_u	High energy neutrino event
SSO_night and SSO_twilight	Potentially hazardous asteroid
SN_Galactic	Galactic supernova
Lensed_GRB	Lensed GRB

TABLE 1: The strategy naming used in the Rubin Scheduler (left) to execute the community observing strategy recommendations (right).

2.3 The Rubin Scheduler

At Rubin Observatory, the software that decides when to observe for the LSST is distributed by the `rubin_scheduler` software package. In the `rubin_scheduler` software package, the Feature Based Scheduler (FBS) module encodes the current best approach to achieving the objectives of the LSST. The `rubin_scheduler` also contains a simulation mode to generate simulated surveys at high speed, which is useful in simulating different conditions and ToO alerts.

In section 3.2, references to the Rubin scheduler refer to the simulation mode. In all other sections, mentions of the Rubin Scheduler refer to the FBS implementation within the scheduler CSC, taking images in support of the LSST for the Rubin Observatory.

SCiMMA alerts passed to the EFD will have metadata associated with them that denotes the alert type. This piece of metadata is passed to the Rubin scheduler to execute the appropriate strategy, as listed in table 1.

GW observing strategies are differentiated by the 90% confidence interval area (Ω) from LVK alerts. Unidentified GW sources and NS component sources of similar skymap size (i.e. gold or silver) follow identical strategy. Binary black-hole event strategy is differentiated by the distance of the event and the observing conditions (dark or bright time). All strategies except for large GW skymaps and lensed GRBs have been tested and verified in the Rubin Scheduler (see section 3.2.1-3.2.2). Large GW skymaps require specific coordination with the SCOC to cover the area, and lensed GRBs do not have an explicit strategy recommendation in Andreoni et al. (2024).

2.4 The Prompt Processing Pipeline

Alerts generated by the LSST prompt processing pipeline are LSST's real-time data product derived from image data. For prompt-processing to function at full capacity, template coverage of the sky must exist in the region of interest. In the commissioning and early operations era, templates will not be available in many areas, and hence standard alert processing will likely not be used to disseminate candidates.

Where LSST templates exist, standard LSST processing can proceed as normal, and is currently operating. In regions of insufficient or uncovered template coverage, custom processing will be required. A team of Rubin staff with experience in difference-imaging analysis has been assembled to support on-call processing of ToO areas that are insufficiently covered by existing Rubin templates.

In the case of insufficient Rubin template coverage, two options exist for custom image processing:

- **Difference imaging with external template sources:** template coverage exists from other southern-sky galaxy surveys. The best instrument for alternative template sources is DECam, and the feasibility of template generation with DECam is currently being evaluated.
- **Self-templating:** By taking images over multiple epochs, it is possible to pursue a ToO with a fast evolving lightcurve by observing rapid changes in photometry. The epoch of observation would need to be modified for the ToO to maximize the probability of detecting the variable lightcurve.

Both methods are available to the on-call processing team, and the method of choice will be pursued based on the existing template coverage and alert type of the ToO.

2.5 The Observing and Science Validation teams

In a non-commissioning environment, ToO observations are automated with minimal intervention by observers or ToO scientists. In the era of early Rubin operations, this is not the case. Owing to the commissioning of other Rubin Observatory systems and minimal Rubin template coverage in early operations, ToO observations will require significant intervention and support from the Rubin science community and the prompt-processing groups.

In line with the recommendations from the SCOC [PSTN-056], a ToO advisory committee has been formed. While this committee is not the exact implementation as described in PSTN-056, it serves a framework for the group during the transition to operations. The aim of this committee is to assess the viability of pursuing a ToO during the early operations period. The decision to pursue a particular ToO event, in no particular order, is based upon the following criteria:

1. The preparedness of the Observatory to respond to a ToO
2. The scientific impact of a Rubin-led discovery
3. The level of disruption to the SV surveys

The Rubin-commissioning ToO advisory committee is composed of Rubin Observatory members with a wide range of expertise. The current committee members are:

- Sean MacBride - Rubin ToO coordinator and LSST-Camera expert
- Zeljko Ivezic - Rubin Construction Project Director
- Bob Blum - Rubin Operations Director
- Keith Bechtol - System Verification and Validation Scientist
- Robert Lupton - Commissioning scientist
- Yousuke Utsumi - LSST-Camera expert and ToO Scientist
- Raffaella Margutti - TVS Multiwavelength Characterization and Counterparts Coordinator
- Eric Bellm - Prompt processing and alert production lead

- Federica Bianco - Deputy project scientist
- Tiago Ribeiro - Scheduler scientist and software architect
- Shreya Anand - Rubin-LVK Liaison
- Deep Chatterjee - LVK Liaison

3 System verification

3.1 Incoming alert stream

SCiMMA delivers alerts to Rubin infrastructure through Hopskotch. Hopskotch is a service which provides a publish-subscribe capability for astrophysical alerts. Hopskotch sends a data packet to the Rubin EFD with a standard schema, which can be found in appendix B.

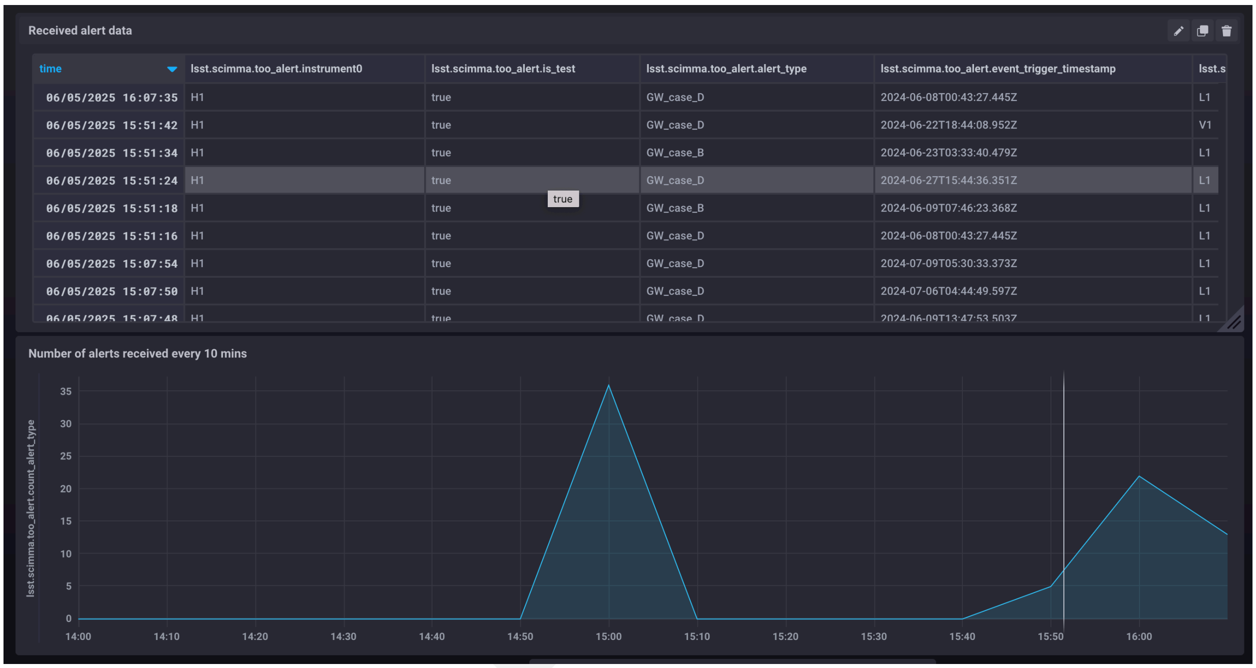

FIGURE 2: The results of the SCiMMA end-end test, demonstrating that alerts are received at EFD from the SCiMMA alert stream.

The data sent in an alert packet is received at the EFD, where the scheduler CSC collects it. On June 5, 2025, the SCiMMA group demonstrated the capability to send ToO alert packets to the Rubin EFD, including metadata, skymap data, and alert identifiers.

3.2 The Rubin Scheduler

The individual alert types have different community defined strategies, as listed in Andreoni et al. (2024). Early iterations of these strategies have been implemented to the Rubin scheduler, but never tested with skymaps reflective of the alert type. To verify the individual strategy output, we performed tests on simulated ToO's in the Rubin scheduler, using relevant alert, sky, and LSSTCam filter conditions.

ToO strategy from ToO 2024 recommendation	Testing result
GW: NS, gold	Pass
GW: unidentified source, gold	Pass
GW: NS, silver	Pass
GW: unidentified source, silver	Pass
GW: BBH, dark time, nearby event	Pass, with caveats
GW: BBH, dark time, distant event	Pass
GW: BBH, bright time	Pass
Neutrino	Pass
Potentially hazardous asteroid	Pass

TABLE 2: The results of strategy testing in the Rubin scheduler for anticipated SV strategies.

To test each ToO strategy, a simulated LSST survey was injected with a ToO of the relevant type and skymap characteristics. The ToO was then handled by the scheduler, which planned and executed the observations following the recommendations from Andreoni et al. (2024). We summarize the results in 3.2.1-3.2.2, and provide the complete results of these simulations in appendix A.

3.2.1 Anticipated ToO strategies during the SV period

As recommended by PSTN-056, PHA and high-energy neutrino alerts should start as soon as possible. Additionally, given the LVK observing schedule, all GW alerts should start as soon as possible to maximize the overlap of GW alerts and Rubin observations. Therefore, all strategies from table 1 except for galactic SN, lensed BNS, and large GW skymaps are considered required for SV.

All SV-required ToO strategies passed validation tests in the Rubin scheduler. Minor complications with the BBH, dark time, nearby event strategy were identified during testing. Particularly, the cadence of (1, 3, 8, 10, 40) nights of observation in the ugi filter set is not guaranteed, since the u-band is removed from the camera on a 14-day cadence. There is the possibility that the u band will not be available for all planned nights of observation. Depending on the circumstance, either the cadence of observation should be adjusted, or the filter set should be adjusted to gri, which will always be available in LSSTCam.

ToO strategy from ToO 2024 recommendation	Testing result
Galactic SN	Pass
Lensed BNS	Pass, with caveats
GW: large skymap	Not supported

TABLE 3: The results of strategy testing in the Rubin scheduler for additional ToO strategies.

3.2.2 Additional ToO strategies to be pursued during SV

While galactic SN, lensed BNS, and large GW skymaps are not expected during the SV surveys due to lower event rates, implementations exist in the Rubin scheduler, and the scientific impact of any of these ToO's is significant. Support for these ToO's remains a priority and events during the SV period should be pursued without reservations, provided the observing strategy is implemented and ready.

The galactic SN strategy passed validation tests. Discussions about using a different scheduler configuration for the case of a galactic SN are ongoing, and additional testing may be required to evaluate this option. The lensed BNS strategy passed, with some caveats about epoch timing. Epoch timing is affected significantly by set/rise time, since the requested number of observations on a given night in either the large or small sky-area case is near a complete night. The priorities of inaccurate epoch timing or fewer visits is currently being discussed with the Rubin science community. For large GW skymaps, coverage should be coordinated with the SCOC and the survey strategy team. For the duration of the SV period, the Rubin ToO program will not support these kinds of alerts.

3.3 Preparation for full system tests

The previous verifications in sections 3.1 - 3.2 were needed to validate individual components of the ToO workflow from figure 1. With the previous components validated in isolation, it is imperative to test the system in its entirety. To do so, we injected a mock ToO event in a previously imaged region, and considered the case where template images either exist or do not exist. Considering both of these cases covers the complete parameter space of PP conditions, with a non-templated region being the more likely possibility during SV.

For both cases, we consider observations of the same region of the sky where templates exist. In the non-templated test case, we ignore existing templates to provide a 1:1 comparison to the typical PP workflow.

Alternative template sources have been imported from the DECADE (Anbajagane et al., 2025), DES DR2 (Abbott et al., 2021), and DELVE (Drlica-Wagner et al., 2022) surveys. The confluence of these surveys provides continuous coverage over the LSST footprint in DECam g-r-i-z bands, and coverage in the southern galactic cap in the DECam Y band.

3.4 Test event: New Horizons field

We triggered a ToO on the night of July 6, 2025, to evaluate the system readiness and latency in bespoke image processing. We focused on an area centered at (285.2,-19.8), known as the New Horizons field. This area is an optimal choice for evaluating the performance of the custom image processing pipeline using DECam templates, as Rubin had already acquired templates in multiple bands at the time of observation.

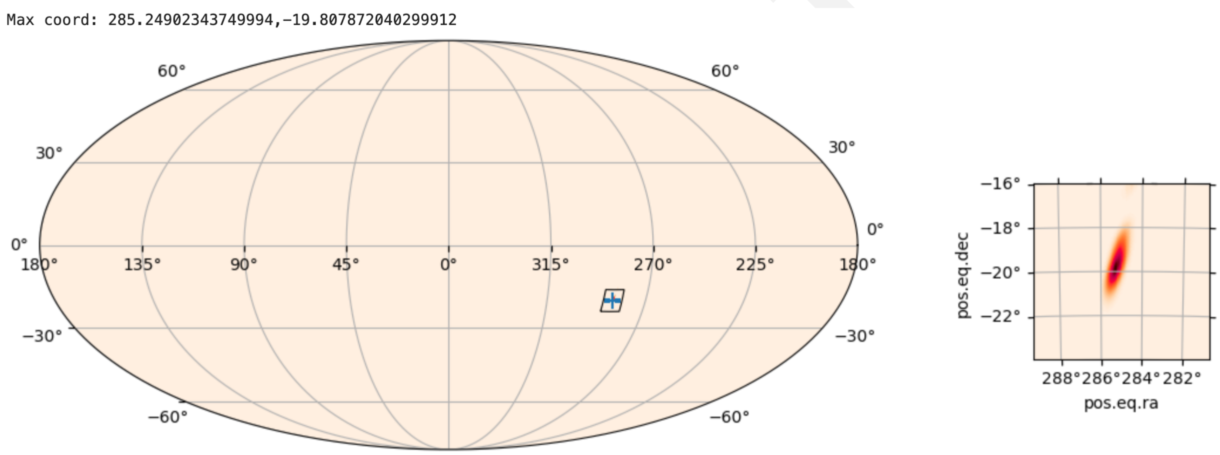

FIGURE 3: The injected skymap for the new horizons ToO test

The injected alert schema follows the LVK AVRO schema. This provides a direct test of the alert handling and record formatting to the EFD. To simulate an object on the new horizons field, we ran simulations of BBH GW events to generate realistic multi-order skymaps. We modified several parameters in the alert packet to pass the alert criteria thresholds, including the `HasNS`, `HasRemnant`, and `classification` fields.

The observing strategy was configured as follows:

- **Visits**: 2 visits per epoch
- **Epoch timing**: 0, 1, 2, and 24 hours

- **Bands**: griz for the first three epochs, ri for the final epoch
- **Exposure times**: 30 seconds for each visit
- **Safety masks**: Avoid direct wind, with a maximum speed of 20 km/h. Avoid the moon, with a lunar avoidance zone of 30deg.

For this test, we elected to only observe the first two epochs.

Event	Timestamp / Details
Alert injected to SCiMMA	03:22:54
Alert received at EFD	Received successfully
Alert processed by Scheduler CSC	03:32:07
First Observation Epoch Start	03:33:47
Notes	Filter change errors encountered
Filter Counts	g: 10, r: 7, i: 7
First Observation Epoch End	04:24:28
Second Observation Epoch Start	04:53:24
Filter Counts	g: 9, r: 7, i: 7, z: 7
Second Observation Epoch End	05:27:59

TABLE 4: Timeline of alert ingestion and observation epochs, where timestamps are from night of 2025-07-07 (UTC)

Evaluation of the image processing for this event is ongoing, and has been impacted significantly by the USDF outage that began on July 7, 2025.

In review of the activities of this test, the Rubin ToO group found many places where improvement is needed for efficient operations during the LSST. Topics that are underlined reflect changes that have not yet been validated or implemented to the Rubin system.

- **Flush time**: Each ToO survey has a flush time, where upon receipt of an associated ToO, will flush scheduled observations from the observing queue out to a specified date. By enacting a flush time, we keep observations from lingering past when they should be executed. For an operational ToO, the flush time should reflect the latest expected time when a ToO observation is still scientifically relevant.
- **Alert payload changes**: We identified two places where the alert payload received at the EFD could be immediately improved. First, adding fields for the area of the maximum probability RA/DEC would provide the scheduler with an initial pointing to maxi-

mize the probability of ToO discovery for early observations. Additionally, detailed probability location information to the healpix map passed to the EFD is another area that can drastically improve ToO observing performance. At present, the skymap passed to the EFD is a mask, where unmasked healpix pixels are observed by Rubin. By adding detailed probability information, we can begin moving toward an optimal tiling pattern that prioritizes high probability regions of the sky, alongside the other safety masks.

- **Pointing generation**: In the present implementation, the ToO uses a fixed pointing grid for a single night. While this is satisfactory for testing, the initial pointing grid is not specific to the ToO. In an optimized scenario, point centers could be placed to ensure that maximum coverage of the ToO area is achieved without unnecessary repeated visits.
- **Script failure behavior**: When we experienced a script failure in the first epoch of observation during a filter change from from $r \rightarrow z$ band, the z band observations were not acquired, skipping the entire band of observations. While this was a test event and the scientific loss was minimal, this behavior is not desired. Additional changes are needed to the Rubin scheduler to repeat ToO observations that failed due to faults in Rubin Observatory.
- **Alert updates**: Often, external experiments will send updated alert packets that reflect extended analysis of external astrophysical sources. The updated localizations in update alerts are usually smaller than the initial alerts that are received at the EFD. The best approach for handling update alert packets is to update the EFD record that is ingested by the scheduler CSC. However, this does not account for the scheduler checking the EFD for the updated map localization. This improvement would use the most reliable data released by external experiments and decrease the total ToO observation time to better balance observing time with the other LSST surveys.
- **Stopping an observation**: Rubin Observatory is optimized for discovery. It remains an open question among the scientific community and SCOC at which point Rubin observations of a ToO should be stopped. The current implementation is such that all requested ToO observations be completed. It is operationally important to have a stop functionality implemented to prevent additional observations of ToO's that may be scientifically irrelevant, as retractions are commonly published by scientific collaborations on occasion.
- **Scheduling time of observation**: In the current implementation, the scheduled time of observation of a ToO is based upon the first available time of observation, i.e., when the ToO target is not blocked by any of the safety masks. While this strategy ensures that if a

ToO is observable, it will be scheduled by the Rubin scheduler, it does not maximize the observing conditions for a ToO event based upon airmass, lunar separation, object rise and set times, the estimated time of observation, and other factors. Scheduling a ToO at an optimal time ensures that the data quality for an interrupt is optimized. Remaining work is needed in this area.

- **Metadata**: ToO surveys should have a unified metadata scheme for ease of record retrieval. Going forward, the agreed schema for `target_name_base` is `ToO_science_specifier`, where `science` is associated with a specific science case (i.e. GW, neutrino, SSO, etc.) and `specifier` (optional) is associated with a sub-strategy of that science case (i.e. for GW, gold, silver, or BBH).

- **Safety masks**: The scheduler configuration for the test event had minimal safety masks, only for wind and lunar avoidance. To rectify this in the future, the standard safety masks have been added to all ToO's. This includes lunar avoidance, bright planet avoidance, high wind avoidance, avoidance of specific areas on the sky, standard thresholds for alt/az limits on the TMA, and a basis function to avoid pointing toward sunrise late in the night during commissioning. While these standard safety masks have been designed to maintain safety of LSSTCam and the TMA for maximum efficiency during SV and the LSST, some of these criteria may be relaxed considering the time-sensitivity of certain ToO's. Evaluation is ongoing to determine what safety masks can be relaxed to maximize ToO science quality while maintaining safety of Rubin Observatory.

- **Scheduler CSC lookback time**: The scheduler CSC has a lookback time, which when enabled, will look back in time by a fixed amount of time to ingest new alerts. For testing the ToO system, this time was set to fifteen minutes, such that spurious alerts with invalid schema or for the purpose of testing are not picked up for on-sky observation. Following our first test of the ToO system, this time has increased to two hours. For long term operations, this time should be increased to 18 hours minimum, to support ingestion of alerts that were received after dome closure at the end of the night. In event of dome closure due to weather or performance issues, this time should be increased, possibly temporarily, to pick up any ToO alerts that were generated during the downtime.

- **Multi-night observations**: Since we elected to observe only the first two epochs for this test event, we did not evaluate if the scheduler would schedule observations upon a new initialization on a different day. We have since validated that multi-day observations will be scheduled by the Rubin scheduler through testing at BTS.

4 ToO Responses During the SV Period

4.1 3I/ATLAS

3I/ATLAS was discovered on 1 July 2025 by the ATLAS survey telescope at Río Hurtado, Chile (Seligman et al., 2025). It is the third interstellar object confirmed passing through the Solar System, after 1I/'Oumuamua (discovered 19 October 2017) and 2I/Borisov (discovered 29 August 2019). Given the rarity of the object and the excitement generated within the Rubin scientific community, we elected to test the ToO system on 3I/ATLAS.

Many other science exposures of 3I/ATLAS have been obtained, as the object has been in the Rubin SV survey footprint for some time before its official identification. Here, we focus only on observations triggered by the ToO system.

4.1.1 Night of July 12, 2025

After consultation with the solar-system science unit, we devised an observing strategy for 3I/ATLAS that would maximize the probability of extracting color information, and determining its rotational period.

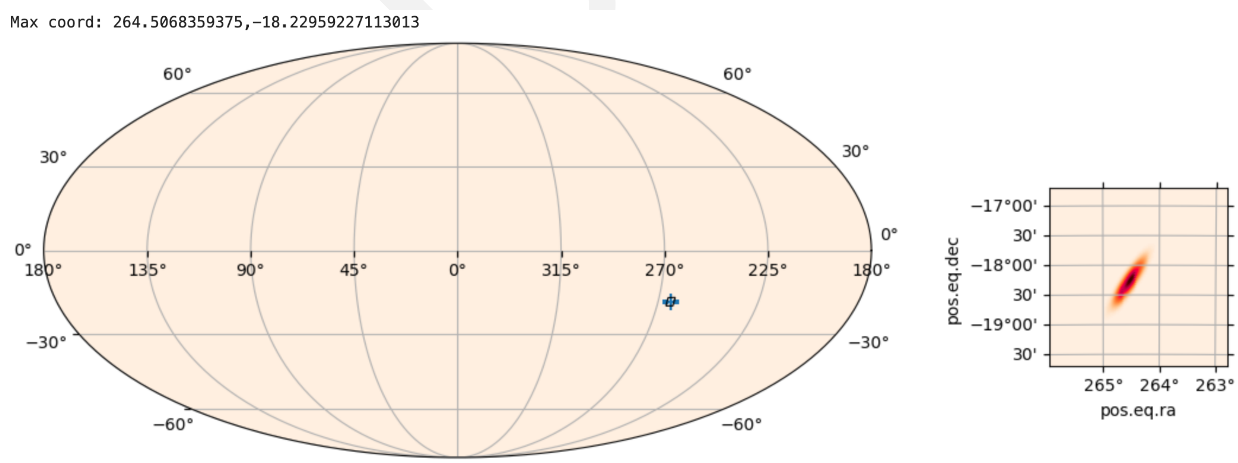

FIGURE 4: The injected localization skymap for 3I/ATLAS ToO observations on the night of July 12, 2025.

The observing plan was as follows:

- **Exposure times**: 30 second exposures.

- **Epochs**: One epoch at zero hours from alert receipt.
- **Visits**: Four visits for the single epoch.
- **Filters**: grizY for the single epoch.
- **Dithers**: Dither between exposures with a maximum of 0.01 degrees (36 arcseconds).
- **Safety masks**: The full suite of safety masks used by the SV surveys.

Since the localization area of 3I/ATLAS is extremely small (< 1 deg^2), the injected alert localization was refined to fit within the nearest single NSIDE=32 flattened healpix pixel, which is the format utilized by the Rubin scheduler.

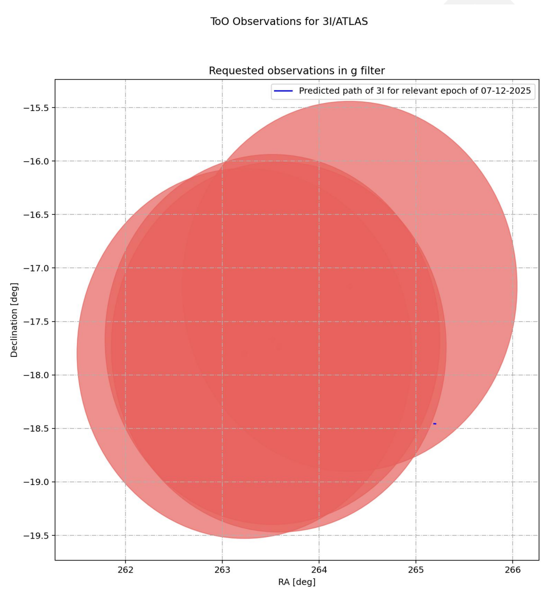

FIGURE 5: The requested observations as generated from the scheduler configuration, with the predicted path of 3I/ATLAS during the observation epoch shown. Identical pointings were generated for i, r, z, and Y bands. Plotted circles are centered at the central pointing, with a radius reflective of the LSSTCam FOV.

The alert was injected to the SCiMMA alert stream at 2:39:12 UTC, and received at the Rubin EFD. ToO observations of the 3I/ATLAS field began at 3:09:13 UTC shortly after the SV + ToO scheduler configuration was enabled, starting with observations in g band.

With four visits in the scheduler configuration, the expectation for observations was to have four visits per pointing in each filter, with the small dither between successive visits. Then, after the observations of a single filter were complete, the filter should change and proceed with observations in a different filter.

The behavior of the scheduler during this ToO was subtly different. After observations in all five requested filters were obtained, the scheduler repeated the tilings an additional three times, totaling four cycles of observations in each filter. This repetitive cycle of four identical tilings appeared reflective of the configured visits.

Evaluation of the image processing for this event is ongoing, and has been impacted significantly by the USDF outage that began on July 7, 2025.

Event	Timestamp / Details
Alert Injected	02:39:12 UTC
Received at Rubin EFD	Successfully received
Alert processed by Scheduler CSC	03:08:09
Observations begin	03:09:13
Cycles	4 total cycles through all 5 filters
End of ToO Observations	05:48:52

TABLE 5: Timeline of ToO observations for 3I/ATLAS on 2025-07-13, with times shown in UTC.

The filter and visit behavior raises notable issues about this ToO observation from an operational perspective:

- **Visit timing**: In the event of more than one visit in a single exposure epoch, the visits should be executed consecutively before changing filter. This minimizes the number of filter changes needed to complete the requested exposures, prolonging the lifetime of the filter exchanger hardware and maximizing survey efficiency.
- **Visit locations**: The area supplied to the Rubin scheduler for this ToO alert was one single healpixel of the $\texttt{NSIDE} = 32$, closest to the target. Under the current tiling method, the boresight-pointing grid stays fixed, and can have multiple pointings inside a single $\texttt{NSIDE} = 32$ pixel. Based on the repetitive behavior of exposures, there are currently two hypotheses for the pointing behavior.
  1. The scheduler identified two pointings inside the healpix pixel, and imaged them with a dither in between.
  2. The scheduler identified four pointings inside the healpix pixel, and imaged them with a dither on the initial pointings 2-4.

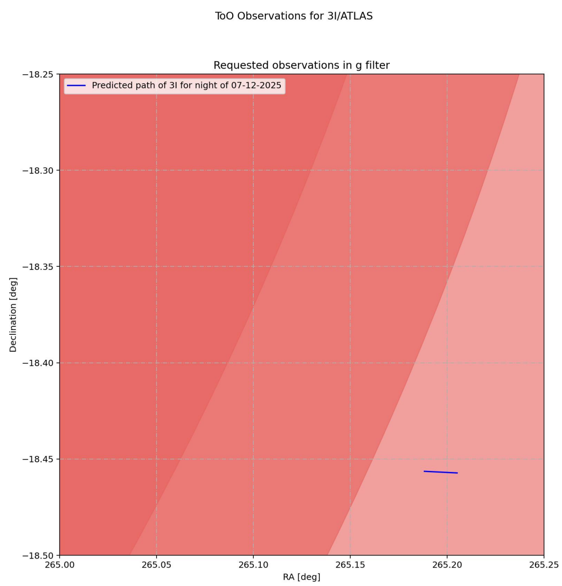

FIGURE 6: The same as figure 5, but a closeup of the predicted orbit. One exposure per band, per visit, captured 3I/ATLAS in its predicted orbit.

The pointing behavior needs further investigation to fully understand what is going on. However, immediate improvements can be made by defining a pointing grid for the ToO that has pointings centered on each healpix location. While this is **not** a final solution, this allows us to disentangle the root issue of visit timing vs. visit location behavior.

4.2 GW event S250725j

The gravitational wave event S250725j is a high-SNR binary black hole event that was observed by the LVK detector network at 04:09:58 UTC on 2025-07-25. S250725j was localized to a 90% area of 18.6 deg^2, meeting the alert quality criteria for a BBH event from Andreoni et al. (2024).

After discussion within the Rubin-commissioning ToO advisory board, we elected to trigger a ToO on S250725j.

4.2.1 Night of July 28, 2025

The observing plan was as follows:

- **Exposure times**: 30 second exposures.
- **Epochs**: Epoch spacing as requested in Andreoni et al. (2024) (see below).
- **Visits**: one visit per epoch.
- **Filters**: u-g-r requested, u-g-i observed (see below).
- **Dithers**: Dither between exposures with a maximum of 0.01 degrees (36 arcseconds).
- **Safety masks**: The complete suite of safety masks used by the SV surveys.

Epoch spacing for this ToO was planned around log-spacing observations over nights, resulting in observations on nights 1-3-8-10-39 after the alert is received. In practice, the observations from the night of 2025-07-28 were the only observations obtained due to a combination of weather constraints and other commissioning activities.

The filter request for a binary-black hole merger of this distance and type is u-g-r bands. Due to an engineering problem with the FCS of LSSTCam, the g band was not available. As a result, we set the observing strategy to observe in u-r-i bands.

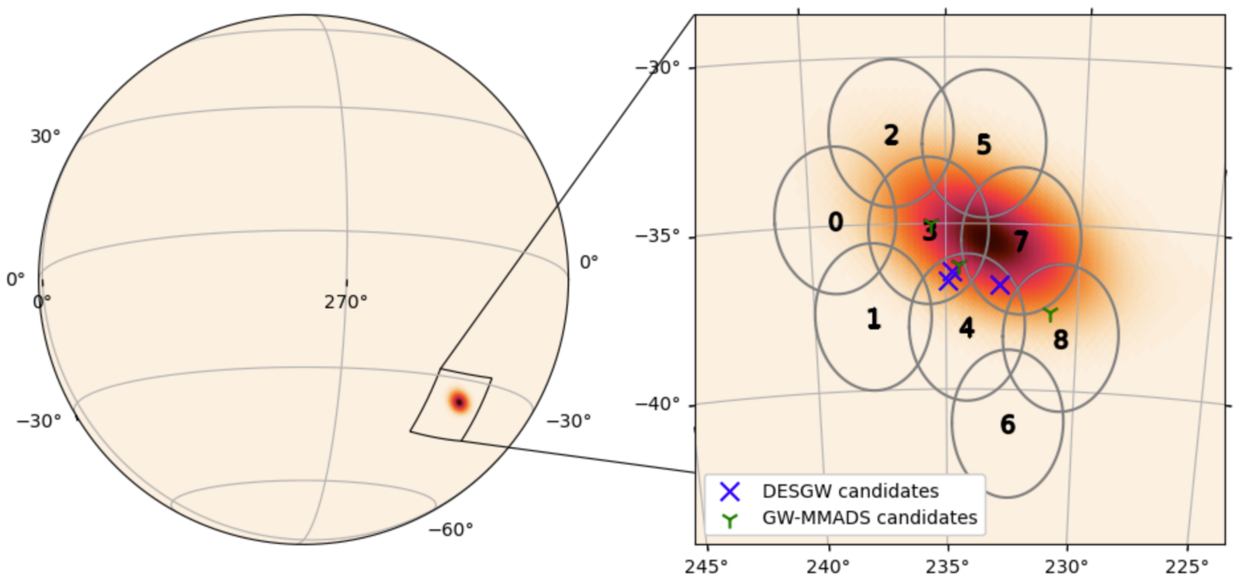

FIGURE 7: Left: The skymap of S250725j, showing the localization area concentrated near (234°, −35°). Right: The pointings acquired as part of the 2025-07-28 observations shown in grey circles. The area covered by the Rubin pointings covers 94% of the LVK localization probability. Candidates reported by other observing teams using DECam are shown overplotted on the skymap.

The alert packet was submitted to the ToO alert stream at 02:16:22.407 UTC, and received at the Rubin EFD at 02:16:25 UTC, approximately 3 seconds later.

Conditions on the night of observing were nominal. We reached a median depth of 24.1 mag in r band, 23.8 mag in the i band, and 23.6 in u band. An issue in the Scheduler CSC caused the field to be observed two times, mimicking previous ToO tests where the Scheduler CSC continued observing the field of a ToO until the scheduler configuration was disabled.

4.2.2 Pointing efficiency

This ToO is the first test on-sky of a ToO area that is larger than a single Rubin pointing. Therefore, this event provides a unique opportunity to evaluate the efficiency of covering a ToO area to completion. For all GW ToO events, the relevant area that needs to be covered is the 90% area. A detailed analysis of point efficiency for this event can be found in the `ToO-analysis-tools` github repository.

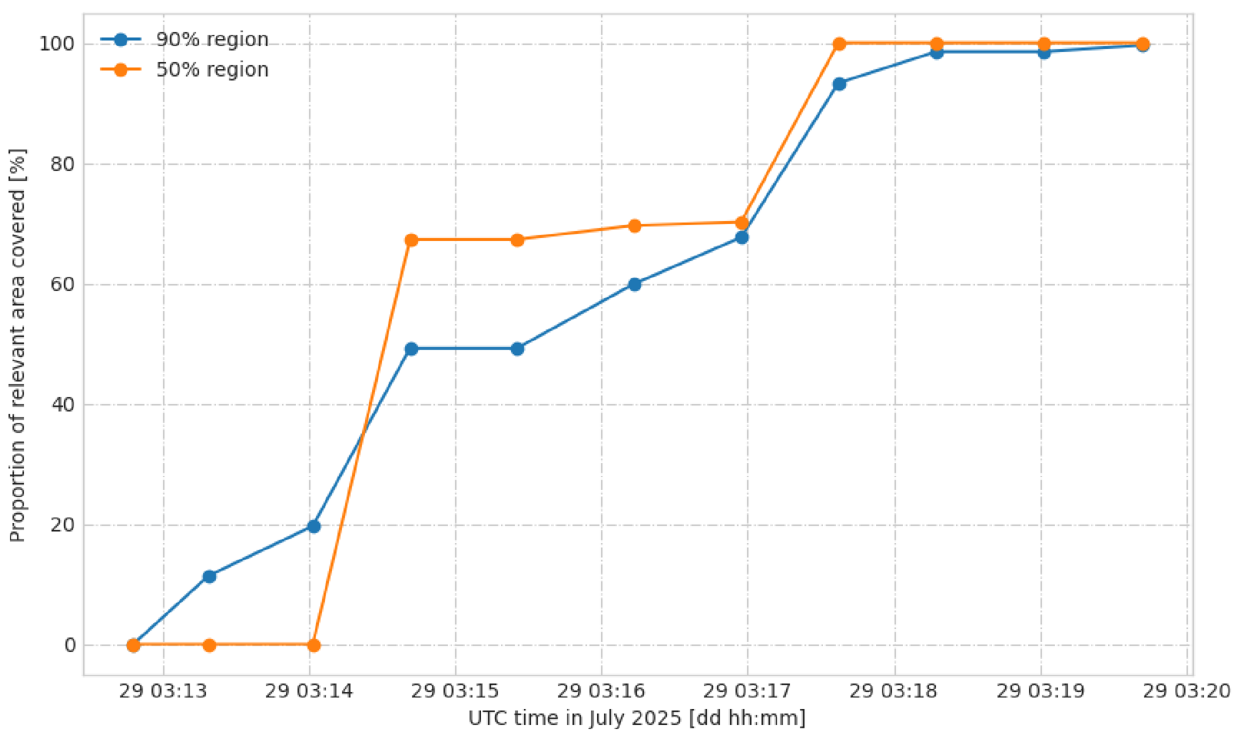

FIGURE 8: The efficiency of covering the area of S250725j, represented as a proportion of the 50% and 90% localization areas.

For each pass in each filter, 100% of the 50% probability region was covered, and 99.576% of the 90% region was covered. Additionally, the 50% region was covered at a rate of 1.64 deg^2/min, and the 90% region was covered at a rate of 4 deg^2 /min.

4.2.3 Image processing and candidate vetting

To process and analyze the observations from this event, we used the bespoke image processing pipeline as described in section 3.3. For this region of the sky, template level coadds from DES DR2 were available.

The location of this GW event is nearby the galactic plane, and therefore a crowded field. Proximity to the galactic plane causes well known problems with the WCS solution. The issues with the WCS solution in search images propagates to the difference images, resulting in many

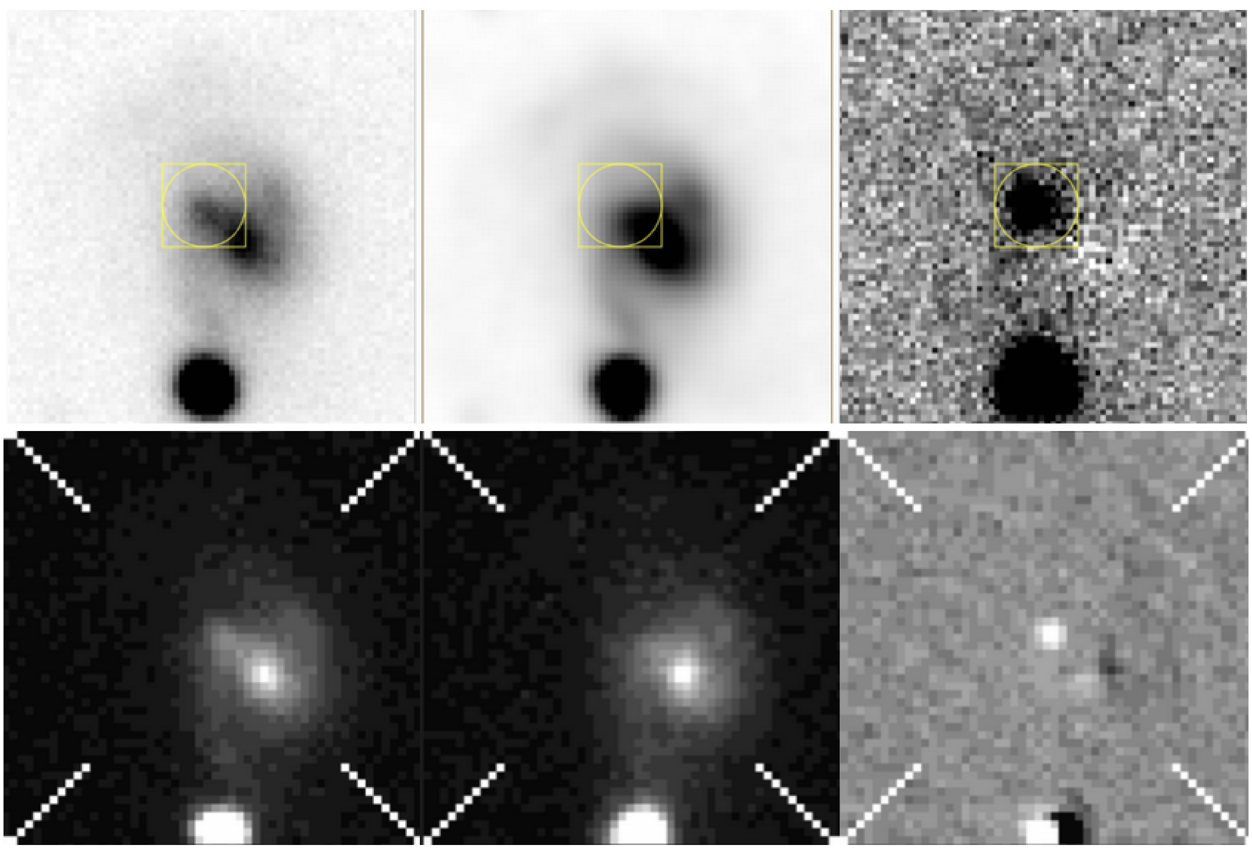

FIGURE 9: AT2025sib, one of the four reported Rubin candidates in GCN 41595, as viewed by LSSTCam and DECam, each with a field of view of 14” on each edge. The top row of images are from Rubin Observatory, the bottom row of images were taken with DECam. Search (left), template (center), and difference (right) images. The template images for Rubin difference imaging are from DES DR2 co-additions for this region of the sky.

bad subtractions, dipoles, and other artifacts in the difference images.

After processing the relevant visits through the bespoke image processing pipeline, we applied a minimal set of flags to remove visits that have dipoles, cosmic rays, and other artifacts. Despite this quality cut, we identified ~ 25k DIA candidates per visit, which far exceeds the ability of human vetting capabilities.

After assessing the excess of candidates from the bespoke image processing pipeline, the analysis group pivoted to review of transient candidates reported by other teams using DECam (see figure 9). The results of the inspection of DECam candidates were reported in GCN 41595 (MacBride et al., 2025).

5 Lessons learned from SV ToOs

The first activations and testing of the Rubin ToO program has been a resounding success. Depite these achievements, many areas of improvement remain for the ToO program to operate efficiently over the ten year LSST. The items listed below are in addition to the technical improvements from sections 3.4 and 4.1.

1. **Consolidation and Availability of Alert Sources**

   Rapid and reliable ToO response requires alerts to be ingested in machine-readable form. Machine readable alerts significantly reduce latency compared to manual workflows.

   Of the four experiments used for Rubin ToO triggers, LVK (GW) and IceCube (neutrino) alerts are fully supported through a kafka stream on SCiMMA. For galactic supernovae, Super-Kamiokande alerts are supported as a mirror of a GCN kafka stream with no integration to the SuperNova Early Warning System (SNEWS). As of 2025-12-29, no kafka stream for potentially hazardous asteroids is available.

   - We strongly encourage the JPL-Scout program and the forthcoming JPL-NEO Surveyor program to publish fully-machine-readable alerts to a Kafka stream, to support localization efforts from Rubin ToO followup.
   - We look forward to using the SuperNova Early Warning System version 2.0 (SNEWS 2.0) alert system with integration of Super-Kamiokande alerts.

2. **Flexible Alert Schemas for the Rubin EFD**

   The Rubin ToO program spans a wide range of astrophysical phenomena, each alert with distinct metadata. A flexible alert schema at the Rubin EFD allows the Observatory to support existing science cases with the required metadata, and new science cases without requiring disruptive changes to the core scheduling or control software.

   Schema flexibility will enable detailed probability localization information, probability-weighted distance estimation used in GW followup, or extinction priors for galactic supernovae observations. This detail will provide the necessary information for observing strategies to be precise in their execution.

3. **System Readiness Metrics**

Readiness and response must be assessed using metrics that extend beyond image-quality conditions. System availability, alert ingestion latency, scheduling response time, and interaction with telescope operators are equally critical for successful ToO execution.

Establishing standard metrics for every ToO response provides an active assessment of the Observatory's ability to respond to time-critical science and identifies bottlenecks that may not be visible in traditional observing efficiency statistics.

4. **Clear Definition of Operational Workflow and Coordination**

   One source of friction during SV ToOs was that many individuals were willing to contribute and take action for a ToO campaign, but no single person or entity had the authority to adjudicate and commit to a specific direction. While operations will benefit from a ToO advisory committee, codifying decisionmaking processes will remain a priority.

   As we transition from commissioning to operations, a clear technical workflow similar to figure 1 needs augmentation with decision nodes for relevant stakeholders, with the relevant stakeholders clearly defined. In addition to workflow definition, the appropriate authority must be granted to stakeholders at their respective decision nodes. This will establish clear responsibilities across operations, data management, and science teams.

   Formal coordination will minimize ambiguity during high-pressure events and ensure that operational decisions are consistent, auditable, and reproducible.

5. **Communications with Summit Scientists**

   Providing clear communication to summit staff is crucial for the long term success of the Rubin ToO program. Drawing on the experience from the observing campaigns during the SV program, two areas of improvement are necessary:

   - **Communication of alert receipt to summit staff:** Currently, a slack bot is the only communication mechanism visible on public communication channels. A watcher alarm would be the most direct way to immediately notify the relevant summit staff that a ToO has entered the observation queue.
   - **Simulated observing plans for received ToO alerts:** This resource will provide observers with the foreknowledge to anticipate schedule changes, including expected observation times of specific ToO observing campaigns.

   This transparency reduces operational stress and improves overall efficiency during time-critical campaigns.

6. **Defined ToO Campaign Outcomes**

   Clearly articulated success criteria for different ToO targets serve three purposes:

   - With success criteria, quantitative assessment of observing strategy can be made - did we observe too much, or too little? With this in hand, future revisions to observing strategy can be grounded in data and historical outcomes.
   - By defining the conditions where a target has been sufficiently observed by Rubin and handed off to other observatories, we can inform the decision to stop observing a ToO and return to observing other fields of the LSST.
   - These critera enable transparent reporting to the broader community about the success or otherwise of a specific ToO campaign.

   Potential success criteria could be as simple as detection in a single band, or as complex as coverage of 24 magnitude or greater in r band over the entire 90% localization region within eighteen hours of alert receipt.

   These success definitions, specific to each ToO target class and informed by the science community, will guide LSST operations through data-driven revision of observing strategies and criteria-driven decisions on observing plans.

7. **Interventional Measures to Start and Stop Observations**

   We cannot predict when exotic phenomena will occur over the ten-year LSST. As demonstrated in commissioning, a non-standard ToO (3I-ATLAS) occurred, requiring a ToO response outside of the standard operation. The ability to initiate ToO observations outside of the standard alert criteria, while bespoke, exists in the current implementation.

   Similarly, operational controls must support the intervention to terminate ToO observations once success has been achieved. This mechanism provides a safeguard against erroneous alerts and enables a flexible response to evolving science priorities.

   In addition to developing the technical capability, the workflow from the decision-making person or entity to the personnel with the technical expertise to execute on specific decisions must be defined. Whenever possible, lower barriers to system interaction will aid in minimizing the latency of decisions propagating to the system.

8. **USDF and RSP Stability During Time-Sensitive Processing**

   ToO science depends on the stability and uptime of the U.S. Data Facility and other services of the Rubin Science Platform. While responding to the S250725j trigger, some services including `Firefly` were unreliable, preventing rapid analysis of potential candidates. Additionally, bespoke image processing was delayed due to standard queue wait times for Rubin users on S3DF.

If possible, a special accounting group for time sensitive ToO reprocessing of Rubin image products would aid significantly in rapid analysis and information dissemination of specific candidates to the scientific community.

While the stability and reliability of S3DF is something the ToO program has little capacity to fix on its own, we note the direct consequence to time-sensitive analyses and potential for disruption to serendipitous discovery in the future. Infrastructure resilience directly translates into scientific outcomes.

9. **Clear Communication Channels with Other Experiments**

   ToO operations are multi-messenger - both from the science perspective, but from the operational perspective as well. Formal communications with LVK helped provide the necessary information to inform a followup decision on S250725j. Maintaining these communications with LVK will be critical as new interferometer sensitivities increase the rate of detected GW events during the LSST.

   If possible, formal communications channels with the IceCube and Super-K collaborations would benefit Rubin ToO from a decisionmaking perspective, to certify private information of specific alert qualities to best inform followup strategy. A significant portion of this expertise will come from the ToO advisory committee, however, a point-of-contact looking at the data from the external experiment can provide valuable insight that should be sustained throughout the duration of the LSST.

10. **Clear Communication and Engagement with the External Community**

   Transparent communication channels with the external community foster trust and clarify operational performance for specific ToOs. While much of the focus during the SV period was on delivering a working ToO system, engagement with the community was not an emphasis.

   This should not be the status quo, and two methods of communication exist to work with the science community as a ToO followup is happening:

   - **ObsLocTAP:** as described in DMTN-263, the Rubin observing schedule will be publicly accessible through the ObsLocTAP service. This includes target names, from which ToO observations can be inferred. While not a direct confirmation of a ToO followup, ObsLocTAP provides a live view into the visit data for Rubin observatory observations, which can be cross-matched to recent ToO's of interest by members of the community. This is an indirect method, and not ideal for communicating information to the Rubin Science Community.

- **Rubin Community posts:** This is a direct method of communication with the Science Community. When a ToO is triggered, a message on the Rubin Community Forum could notify the science community that a ToO is being triggered, details on the intended observing strategy, and where to go to access relevant data products. This is the most straightforward route to build trust from the scientific community in Rubin ToO responses.

11. **Regular Mock Alert Exercises**

Mock alert exercises are essential for validating end-to-end system behavior under realistic conditions. We learned quite a bit from testing the system on-sky, but ToO responses can be simulated without using valuable on-sky time. This is being explored for alert receipt and parsing in the Rubin ToO mock-data-challenge [RTN-107]. These exercises reveal integration gaps and uncover software inconsistencies.

Regular rehearsals ensure that both automated systems and human workflows remain operationally ready. In periods of low ToO activity (when LVK detectors are offline), a mock ToO response should occur monthly on the BTS environment, including alert receipt, observing strategy generation, and execution of simulated observations. This controlled trial of the ToO workflow will protect against bitrot, integrate new workflows and alert schemas, and validate observing strategies to drive the program forward as we begin the LSST in 2026.

12. **Tolerance for Experimentation**

The Target-of-Opportunity program will benefit from a structured tolerance for experimentation. This tolerance has been demonstrated through the SV period, enabling large improvements in our understanding of the system, and the first observations using Rubin Observatory with the express intent of searching for new discoveries in the universe.

With an appetite for observing the exotic, this experimentation should be maintained by the ToO advisory committee, and acted upon when deemed necessary.

While the authority to intervene on non-standard targets is placed in the ToO advisory committee, there must be a balance to still observe standard ToOs and remain in the 3% time allocation endorsed by the SCOC. Maintaining this will be paramount to the success of the Rubin ToO program as we progress through the ten-year LSST.

A Detailed results from validation tests

A.1 Anticipated strategies during the SV period

A.1.1 GW gold

Expected night	Resulting night	Expected visits	Resulting visits	Expected filters	Resulting filters	Expected exposure times	Resulting exposure times
0	0	3	3	gri	gri	120	120
1	1	1	1	gi	gi	180	180
2	2	1	1	gi	gi	180	180
3	3	1	1	gi	gi	180	180

TABLE 6: Results of the GW: NS gold ToO testing

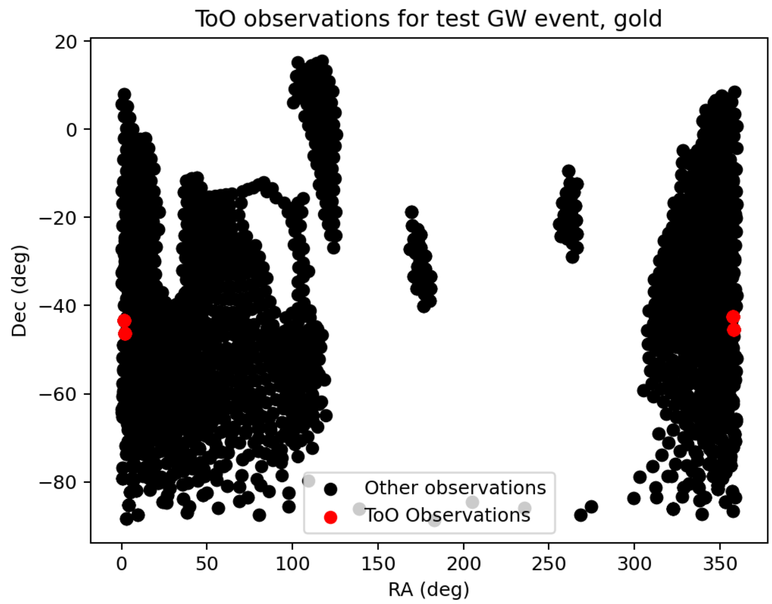

FIGURE 10: Results from GW: NS Gold ToO visits over a 5 day LSST simulation

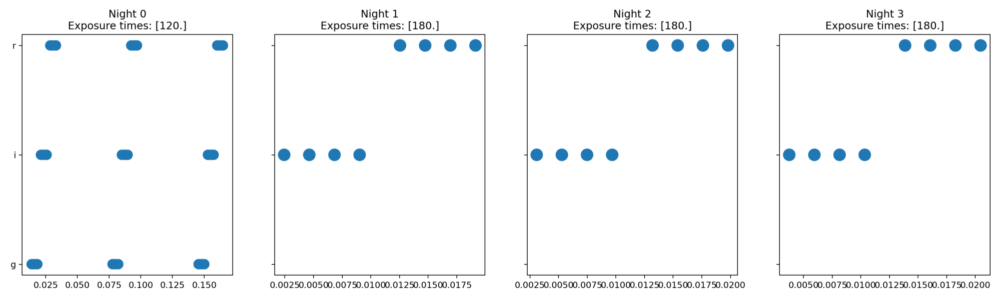

FIGURE 11: Results from GW: NS Gold ToO filter and visit distribution over a 5 day LSST simulation

A.1.2 GW Silver

Expected night	Resulting night	Expected visits	Resulting visits	Expected filters	Resulting filters	Expected exposure times	Resulting exposure times
0	0	1	1	gi	gi	30	30
1	1	1	1	gi	gi	120	120
2	2	1	1	gi	gi	120	120
3	3	1	1	gi	gi	120	120

TABLE 7: Results of the GW: NS silver ToO testing

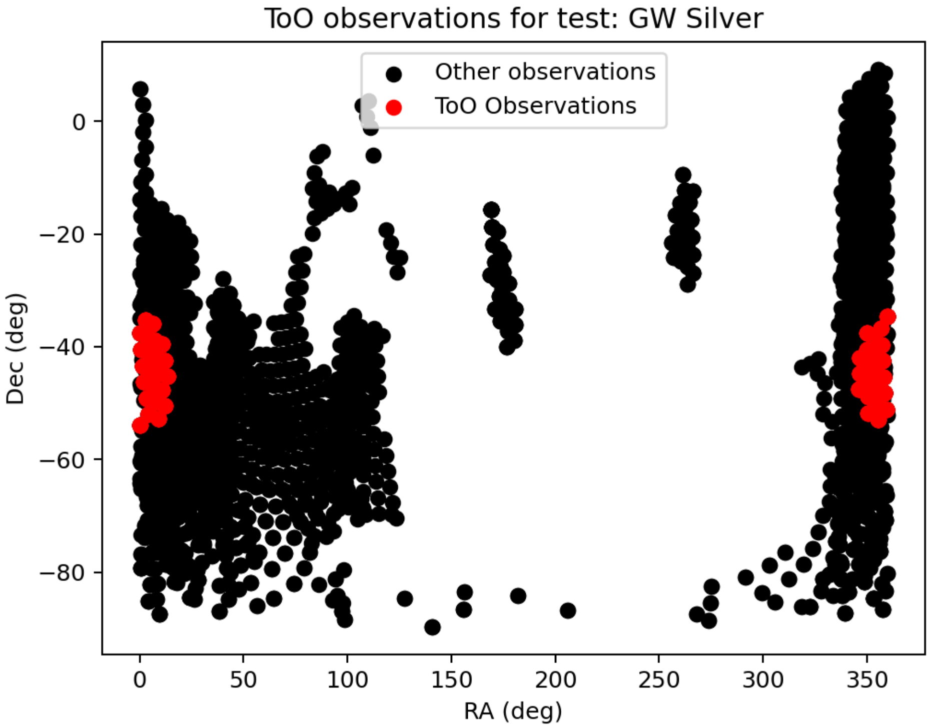

FIGURE 12: Results from GW: NS Silver ToO visits over a 5 day LSST simulation

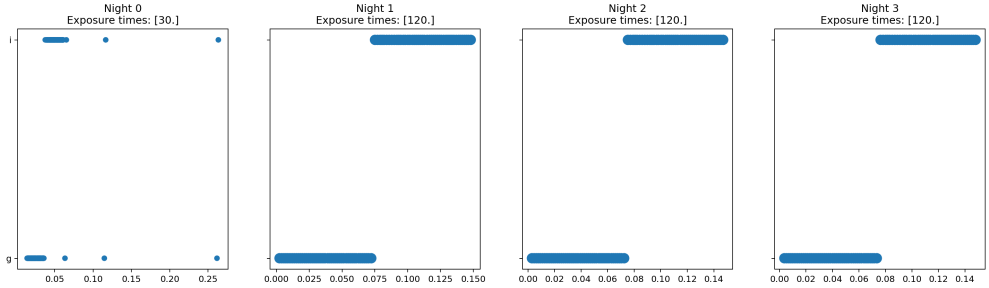

FIGURE 13: Results from GW: NS Silver ToO filter and visit distribution over a 5 day LSST simulation

A.1.3 GW BBH

A.1.3.1 Dark time, distant event BBH

Expected night	Resulting night	Expected visits	Resulting visits	Expected filters	Resulting filters	Expected exposure times	Resulting exposure times
0	0	1	1	gri	gri	30	30
2	2	1	1	gri	gri	30	30
7	7	1	1	gri	gri	30	30
9	9	1	1	gri	gri	30	30
39	39	1	1	gri	gri	30	30

TABLE 8: Results of the GW: BBH, dark time, distant event ToO testing

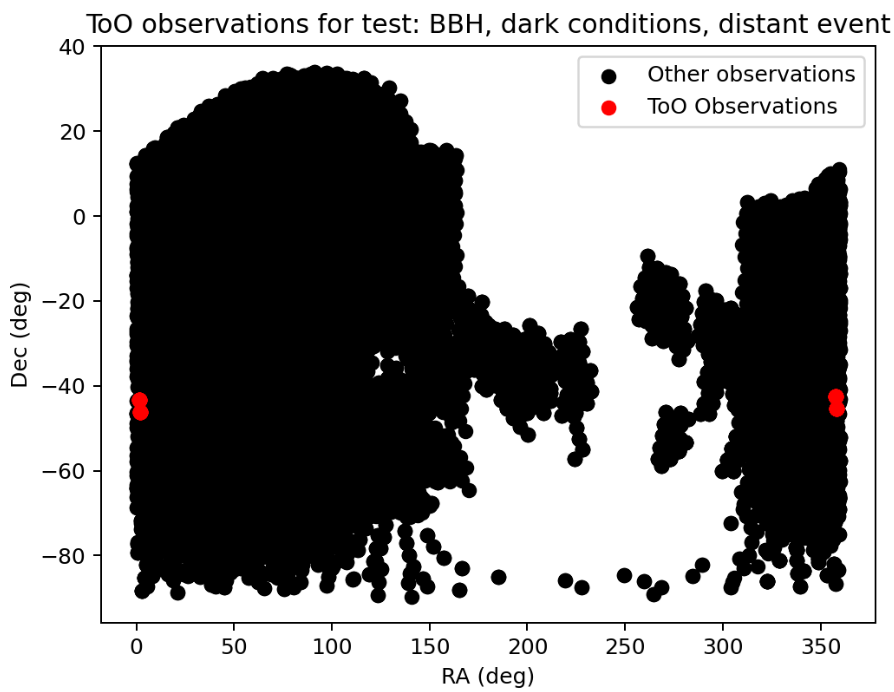

FIGURE 14: Results from GW: BBH, dark conditions, distant event ToO visits over a 5 day LSST simulation

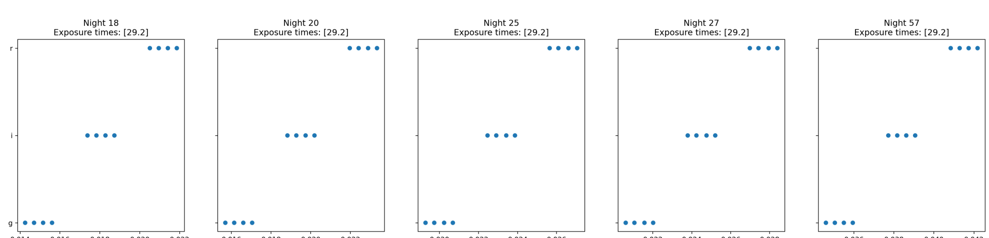

FIGURE 15: Results from GW: BBH, dark conditions, distant event ToO filter and visit distribution over a 5 day LSST simulation

A.1.3.2 Dark time, nearby event BBH

Expected night	Resulting night	Expected visits	Resulting visits	Expected filters	Resulting filters	Expected exposure times	Resulting exposure times
0	0	1	1	ugi	ugi	30	30
2	2	1	1	ugi	ugi	30	30
7	7	1	1	ugi	ugi	30	30
9	9	1	1	ugi	ugi	30	30
39	39	1	1	ugi	ugi	30	30

TABLE 9: Results of the GW: BBH, dark time, nearby event ToO testing

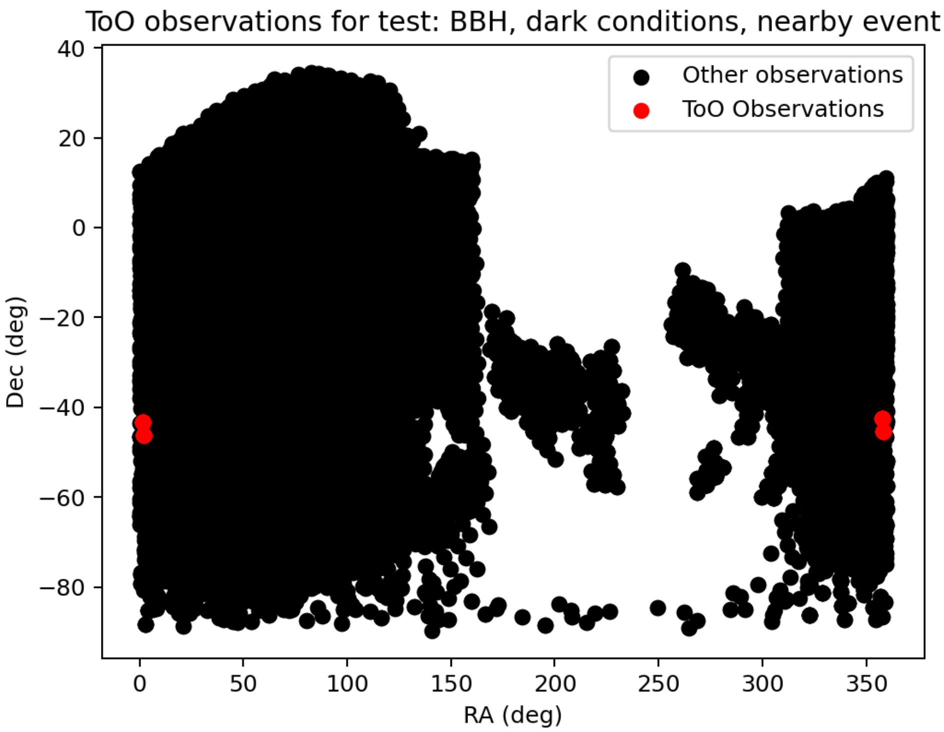

FIGURE 16: Results from GW: BBH, dark conditions, nearby event ToO visits over a 45 day LSST simulation

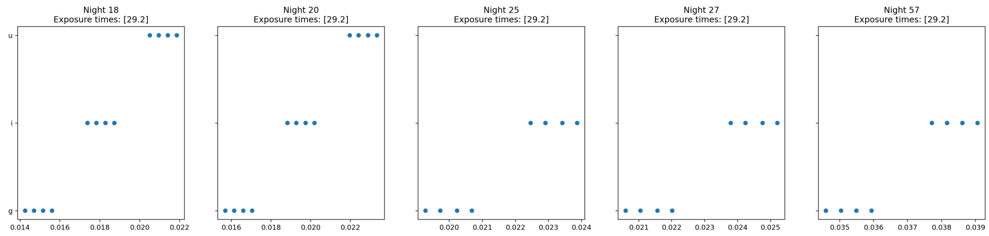

FIGURE 17: Results from GW: BBH, dark conditions, nearby event ToO filter and visit distribution over a 45 day LSST simulation

A.1.3.3 Bright time BBH

Expected night	Resulting night	Expected visits	Resulting visits	Expected filters	Resulting filters	Expected exposure times	Resulting exposure times
0	0	1	1	riz	riz	30	30
2	2	1	1	riz	riz	30	30
7	7	1	1	riz	riz	30	30
9	9	1	1	riz	riz	30	30
39	39	1	1	riz	riz	30	30

TABLE 10: Results from GW: BBH, bright conditions ToO filter and visit distribution over a 45 day LSST simulation

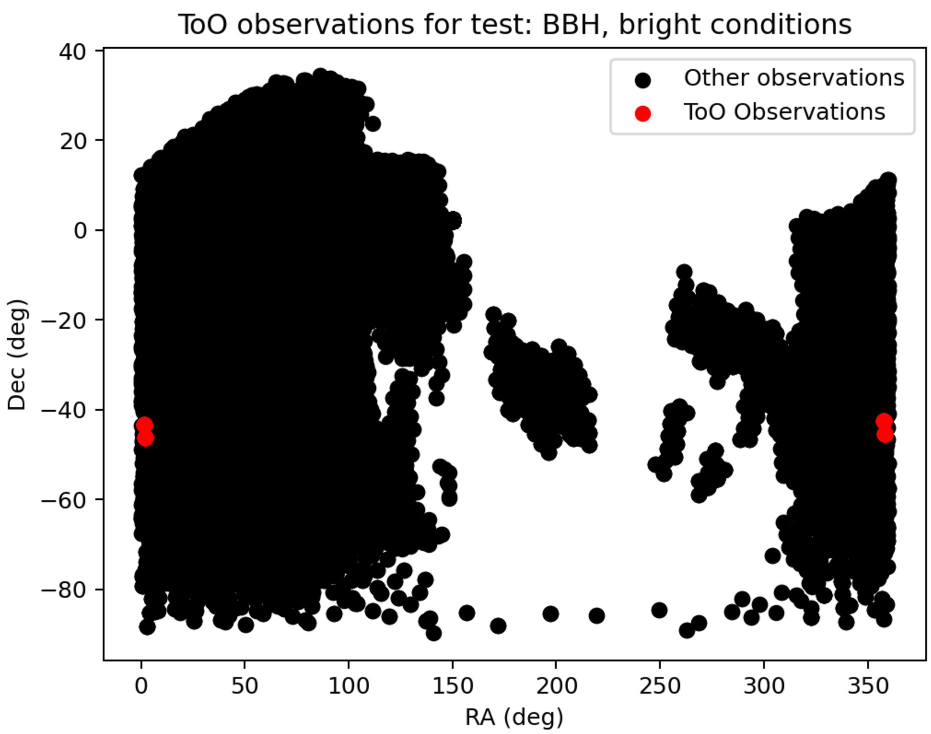

FIGURE 18: Results from GW: BBH, dark conditions, nearby event ToO visits over a 45 day LSST simulation

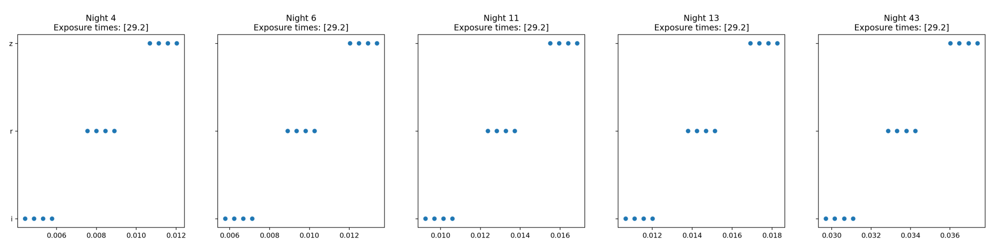

FIGURE 19: Results from GW: BBH, dark conditions, nearby event ToO filter and visit distribution over a 45 day LSST simulation

A.2 High energy neutrino

Expected night	Resulting night	Expected visits	Resulting visits	Expected filters	Resulting filters	Expected exposure times	Resulting exposure times
0	0	1	1	g,rz	g,rz	120,30	120,30
1	1	1	1	g,r	g,r	120,30	120,30
7	7	1	1	g,rz	g,rz	120,30	120,30
Any	18	1	1	u	u	30	30

TABLE 11: Results from a neutrino ToO, filter and visit distribution over a 20 day LSST simulation

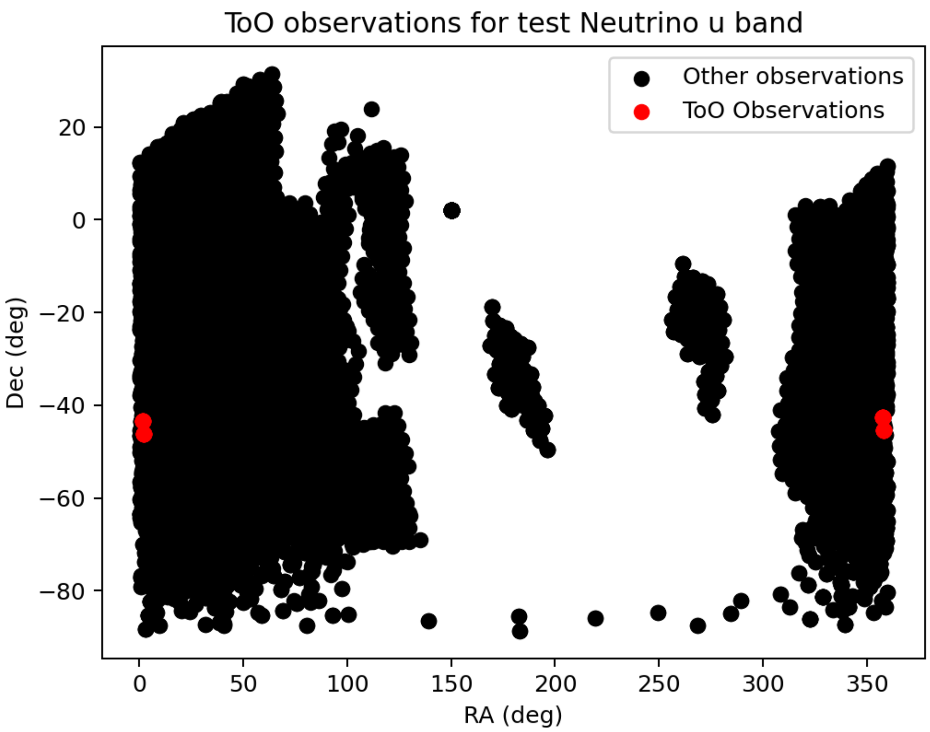

FIGURE 20: Results from a neutrino ToO visits over a 20 day LSST simulation

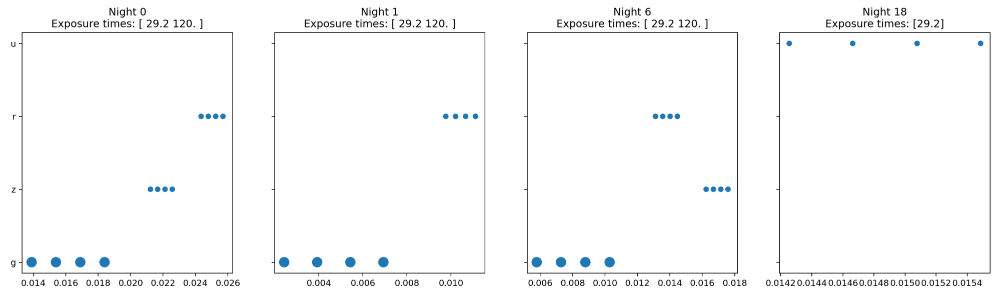

FIGURE 21: Results from a neutrino ToO filter and visit distribution over a 20 day LSST simulation

A.3 Potentially hazardous asteroid

A.3.0.1 Twilight PHA

Expected night	Resulting night	Expected visits	Resulting visits	Expected filters	Resulting filters	Expected exposure times	Resulting exposure times
0	0	1	1	z	z	15	15

TABLE 12: Results from a potentially hazardous asteroid, twilight conditions ToO, filter and visit distribution over a 20 day LSST simulation

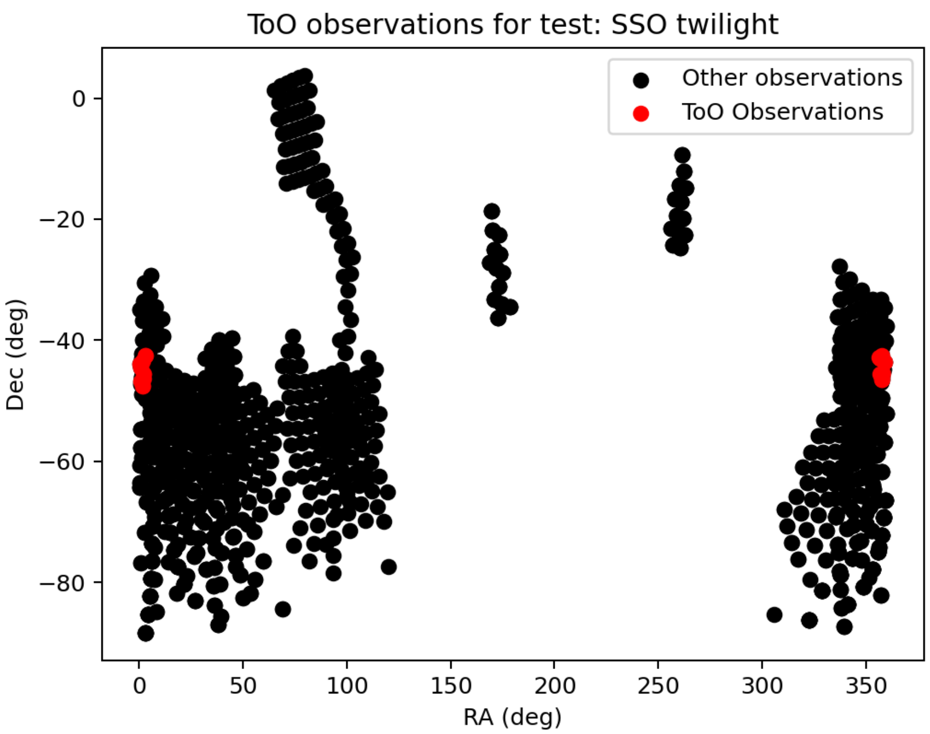

FIGURE 22: Results from a potentially hazardous asteroid, twilight conditions ToO, visits over a 2 day LSST simulation

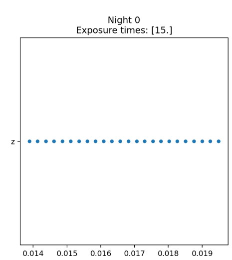

FIGURE 23: Results from a potentially hazardous asteroid, twilight conditions ToO, filter and visit distribution over a 2 day LSST simulation

A.3.0.2 Night PHA

Expected night	Resulting night	Expected visits	Resulting visits	Expected filters	Resulting filters	Expected exposure times	Resulting exposure times
0	0	1	1	r	r	15	15

TABLE 13: Results from a potentially hazardous asteroid, night conditions ToO, filter and visit distribution over a 2 day LSST simulation

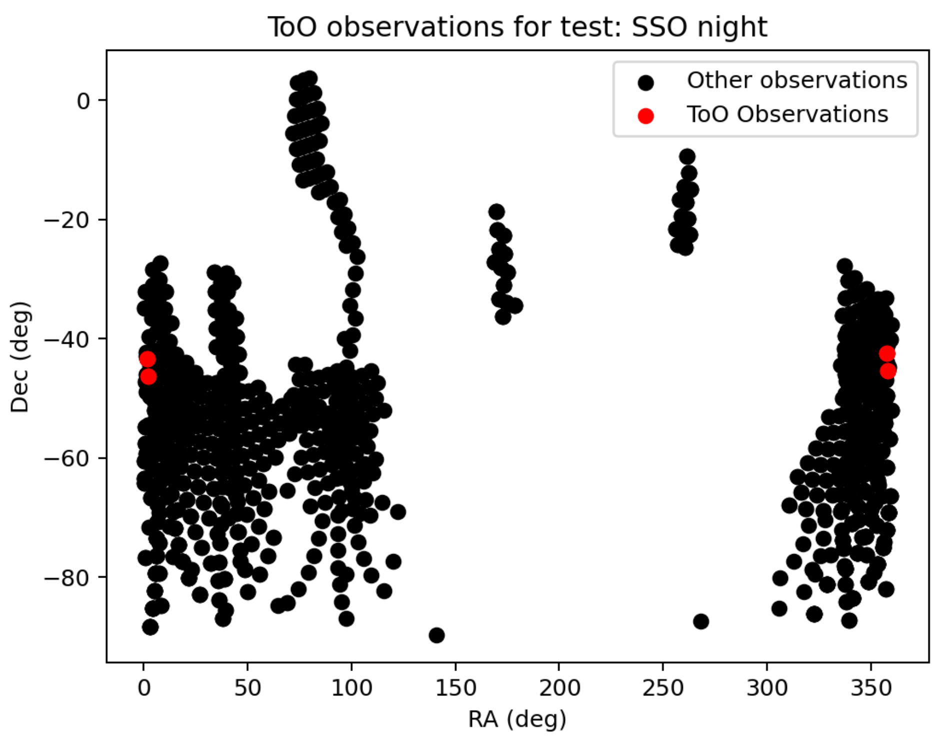

FIGURE 24: Results from a potentially hazardous asteroid, night conditions ToO, visits over a 2 day LSST simulation

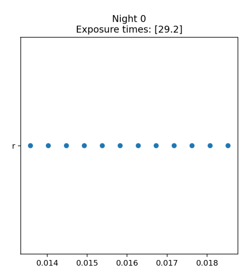

FIGURE 25: Results from a potentially hazardous asteroid, night conditions ToO, filter and visit distribution over a 2 day LSST simulation

A.4 Additional ToO strategies during the SV period

A.4.1 Galactic SN

Expected night	Resulting night	Expected visits	Resulting visits	Expected filters	Resulting filters	Expected exposure times	Resulting exposure times
0	0	4	4	i	i	1,15	1,15

TABLE 14: Results from a galactic SN ToO, filter and visit distribution over a 2 day LSST simulation

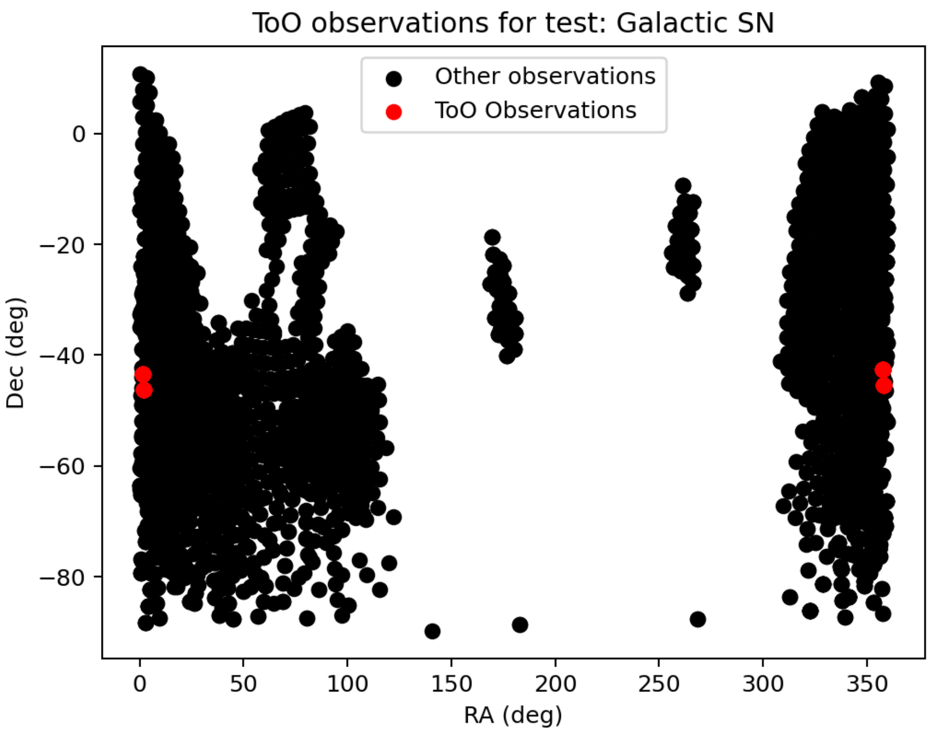

FIGURE 26: Results from a galactic SN ToO, visits over a 2 day LSST simulation

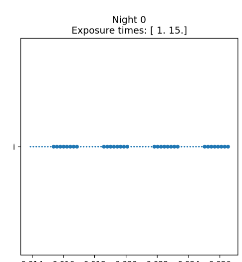

FIGURE 27: Results from a galactic SN ToO, filter and visit distribution over a 2 day LSST simulation

A.4.2 Lensed BNS

A.4.2.1 Large skymap lensed BNS

Expected night	Resulting night	Expected visits	Resulting visits	Expected filters	Resulting filters	Expected exposure times	Resulting exposure times
0	0,1	1,3	1,3	g,r	g,r	30,30	30,30
1	1,2,3	1,3	1,3	g,r	g,r	30,30	30,30
2	3,4	1,3	1,3	g,r	g,r	30,30	30,30

TABLE 15: Results from a lensed BNS large skymap ToO, filter and visit distribution over a 5 day LSST simulation

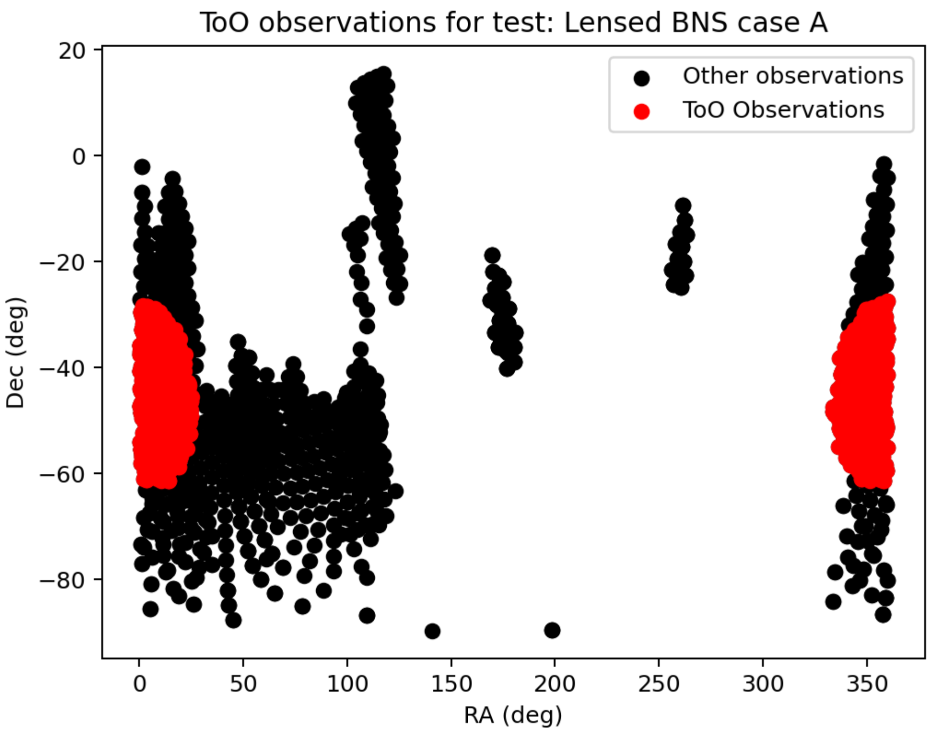

FIGURE 28: Results from a lensed BNS large skymap ToO, visits over a 5 day LSST simulation

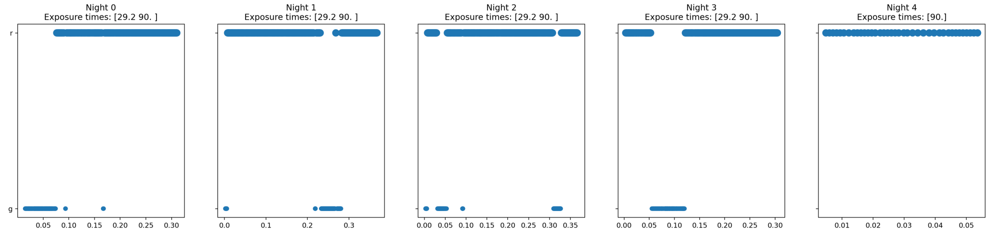

FIGURE 29: Results from a lensed BNS large skymap ToO, filter and visit distribution over a 5 day LSST simulation

A.4.2.2 **Small skymap** lensed BNS

Expected night	Resulting night	Expected visits	Resulting visits	Expected filters	Resulting filters	Expected exposure times	Resulting exposure times
0	0,1	1	1	g,r	g,r	180	180
1	1,2	1	1	g,r	g,r	180	180
2	2,3	1	1	g,r	g,r	180	180

TABLE 16: Results from a lensed BNS large skymap ToO, filter and visit distribution over a 5 day LSST simulation

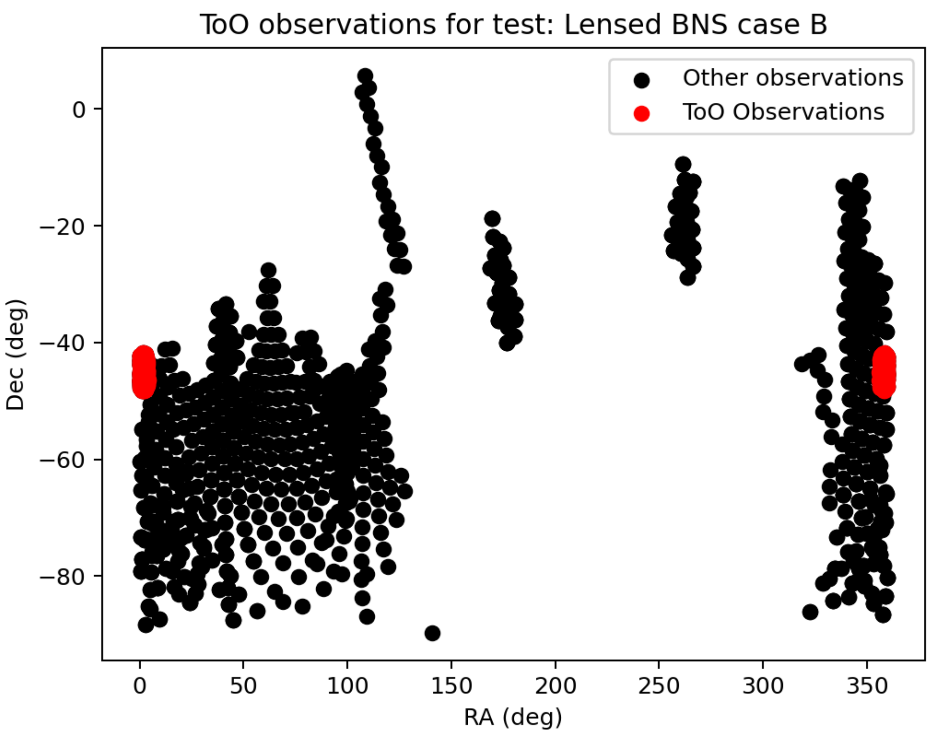

FIGURE 30: Results from a lensed BNS large skymap ToO, visits over a 5 day LSST simulation

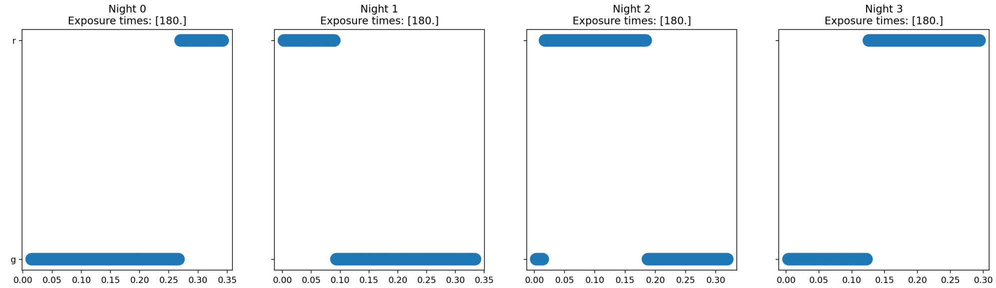

FIGURE 31: Results from a lensed BNS large skymap ToO, filter and visit distribution over a 5 day LSST simulation

B Alert Packet Schema

B.1 EFD alert schema

The EFD alert schema. Note that the `reward_map` field is iterated as `reward_map0`, `reward_map1`, ... `reward_map12287`, where each entry is one pixel in a flattened Healpix skymap of `nside` $= 32$ and `RING` ordering.


```
        {"namespace": "lsst.scimma",
         "type": "record",
         "name": "ToO_alert",
         "fields": [
                 {
    "type": "record",
    "name": "AutoRecord",
    "fields": [
        {    "name": "alert_type",
             "type": "string"
        },
        {    "name": "time_created",
             "type": "string"
        },
        {    "name": "is_test",
             "type": "boolean"
        },
        {    "name": "is_update",
             "type": "boolean"
        },
        {    "name": "superevent_id",
             "type": "string"
        },
        {    "name": "timestamp",
             "type": "long"
        },
        {    "name": "reward_map",
             "type": {"type": "array",
```

```
                    "items": "int"
                }
            },
            {   "name": "instrument",
                "type": {"type": "array",
                    "items": "string"
                }
            }
        ]
}
]
}
```

C References

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D Acronyms

Acronym	Description
ATLAS	A Toroidal LHC Apparatus
BBH	Binary black-hole
BNS	Binary Neutron Star
BTS	Base (La Serena) Test Stand
CSC	Commandable SAL Component
DEC	Declination
DECam	Dark Energy Camera
DELVE	DECam Local Volume Exploration Survey
DES	Dark Energy Survey
DIA	Difference Image Analysis
DMTN	DM Technical Note
DOI	Digital Object Identifier
DR2	Data Release 2
EFD	Engineering and Facility Database
FBS	Feature-Based Scheduler
FCS	Filter Changer System
FOV	field of view
GCN	General Coordinates Network
GRB	Gamma-Ray Burst
GW	Gravitational Wave
JPL	Jet Propulsion Laboratory (DE ephemerides)
KAGRA	Kamioka Gravitational Wave Detector
LIGO	Laser Interferometer Gravitational-Wave Observatory
LSST	Legacy Survey of Space and Time (formerly Large Synoptic Survey Telescope)
LSSTCam	LSST Science Camera
LVK	LIGO-Virgo-KAGRA
NASA	National Aeronautics and Space Administration
NEO	Near-Earth Object
NS	Neutron star
ObsLocTAP	Observation Locator Table Access Protocol (IVOA standard)
PHA	potentially hazardous asteroids

PP	Post processing
PSTN	Project Science Technical Note
RA	Rapid Analysis
RSP	Rubin Science Platform
RTN	Rubin Technical Note
S3DF	SLAC Shared Scientific Data Facility
SAL	Service Abstraction Layer
SCOC	Survey Cadence Optimization Committee
SCiMMA	Scalable Cyberinfrastructure to support Multi-Messenger Astrophysics
SN	SuperNovae
SNEWS	SuperNova Early Warning System
SNR	Signal to Noise Ratio
SSO	Solar System Object
SV	Science Validation
TMA	Telescope Mount Assembly
TSTN	Telescope and Site Tech Note
TVS	Transients and Variable Stars Science Collaboration
ToO	Target of Opportunity
USDF	United States Data Facility
UTC	Coordinated Universal Time
WCS	World Coordinate System