Skynet's New Observing Mode: The Campaign Manager

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Abstract

Built in 2004, the Skynet robotic telescope network originally consisted of six 0.4 m telescopes located at the Cerro-Tololo Inter-American Observatory in the Chilean Andes. The network was designed to carry out simultaneous multi-wavelength observations of gamma-ray bursts (GRBs) when they are only tens of seconds old. To date, the network has been expanded to ≈20 telescopes, including a 20 m radio telescope, that span four continents and five countries. The Campaign Manager (CM) is a new observing mode that has been developed for Skynet. Available to all Skynet observers, the CM semi-autonomously and indefinitely scales and schedules exposures on the observer's behalf while allowing for modification to scaling parameters in real time. The CM is useful for follow up to various transient phenomena including gravitational-wave events, GRB localizations, young supernovae, and eventually, sufficiently bright Argus Optical Array and Large Synoptic Survey Telescope events.

Unified Astronomy Thesaurus concepts: Astronomy software (1855); Telescopes (1689); Time domain astronomy (2109)

1. Introduction

Due to the unpredictable nature for both the location and time of transient events, using a single telescope, or even multiple telescopes at a single site, leaves the execution of an observation entirely up to happenstance. Even if the event occurs in the same hemisphere as the telescope, continuous observing will not be possible using only one telescope site. This may result in missing critical information, particularly for fast fading events such as gamma-ray burst (GRB) afterglows or kilonovae. To avoid this, a well-distributed global network of telescopes is needed to ensure that continuous monitoring of transients can occur. With near-continuous coverage of the southern hemisphere as well as built in coverage redundancy in North America, South America, and Australia, the Skynet robotic telescope network is ideal for such events.

Skynet is a sophisticated telescope control and queue scheduling software that simultaneously controls a global network of telescopes, allowing them to function individually or as an integrated whole. Furthermore, Skynet can control most commercially available telescope hardware, and provides participating institutions with easy-to-use web and API interfaces. Participating institutions are not charged, but instead contribute 10% of each of their telescopes' time for Director Discretionary science and education. Telescopes are regularly being added to the Skynet Robotic Telescope Network, which has now grown to number ≈20 telescopes, ranging in size from 14″ to 40″, with another ≈10 scheduled to join in the near future.

The Panchromatic Robotic Optical and Monitoring Polarimetry Telescopes (PROMPT) are a subset of the Skynet Robotic Telescope Network, consisting of the network's highest-quality telescopes at its highest-quality sites. Originally only at Cerro-Tololo Inter-American Observatory (CTIO), PROMPT now spans five dark sites, in Chile, Australia (for near-continuous observing in the southern hemisphere), and Canada (for full-sky coverage). Many of these are original, and identical, telescopes that have been redeployed from CTIO.

For nearly two decades, Skynet has proven successful at observing a wide variety of transients. Skynet/PROMPT was originally built to carry out simultaneous, multi-wavelength observations of GRBs when they are only tens of seconds old (to date, Skynet has observed 88 GRBs within 15–70 s (90% range) of spacecraft notification, detecting 50 optical afterglows on this timescale). In addition to being used to study GRBs (Reichart et al. 2005; Haislip et al. 2006; Dai et al. 2007; Updike et al. 2008; Nysewander et al. 2009; Cano et al. 2011; Cenko et al. 2011; Bufano et al. 2012; Jin et al. 2013; Martin-Carrillo et al. 2014; Morgan et al. 2014; Friis et al. 2015; Bardho et al. 2016; De Pasquale et al. 2016; Melandri et al. 2017), Skynet is being used to study Gravitational Wave (GW) sources, (Abbott et al. 2017a, 2017b; Valenti et al. 2017; Yang et al. 2017, 2019; Abbott et al. 2020), fast radio bursts, blazars, supernovae (SNe), supernova remnants, novae, pulsating white dwarfs and hot subdwarfs, a wide variety of variable stars, a wide variety of binary stars, exoplanetary systems, trans-Neptunian objects and

Centaurs, asteroids, and near-Earth objects. Skynet data are now published in peer-reviewed journals every ≈20 days.

The Campaign Manager (CM) is a new observing mode that has been developed to improve Skynet's capabilities for observing transients such as GW events, GRB localizations, young SNe, and, once construction is completed, sufficiently bright Argus Optical Array (Law et al. 2021) and Large Synoptic Survey Telescope events. This new semi-autonomous observing mode designed for transients allows for auto-scheduling and auto-scaling of exposures on all Skynet telescopes. Additionally, the CM allows for real-time updates to the observing parameters so that exposure lengths can be appropriately updated as new information is learned about the target. This is a significant improvement over the existing observing method that requires observations to be canceled and rescheduled using the new parameters. The CM is available to any Skynet observer, but is most effective when coupled with target-of-opportunity (TOO) access through Skynet's Director Discretionary time.

An overview of Skynet's major components is given in Section 2. A description of the CM's front-end web-interface is given in Section 3. A review of the back-end structure of the CM is given in Section 4. A scientific application of the CM is given in Section 5 section via the Skynet research group's current use of the CM.

2. Skynet's Software Structure

The major components of Skynet include: (1) the Optical Server, (2) the Terminator client, and (3) the website. The entirety of the Skynet system, with the exception of the Terminator which is installed on each telescope's control computer, runs on servers that are located at and maintained by the University of North Carolina at Chapel Hill.

The Optical Server is responsible for monitoring the states of the telescopes as well as dispatching observations. To do this, the Optical Server sends commands to the telescope client. In turn, the Terminator monitors and handles the management of each telescope's equipment including the mount, camera, filter wheel, dome, and weather monitoring system. The Terminator is capable of detecting, and in some cases resolving, hardware issues. If the Terminator is unable to resolve an issue, an alert is sent to the Skynet team.

Skynet currently uses Web2Py which is a popular Model-View-Controller (MVC) architectural pattern for its web development framework. Access to the website (https://skynet.unc.edu) requires a Skynet account. Currently, accounts are not available to the general public, but are limited to students, researchers, and those with ownership shares on telescopes. Observers use the website to submit observations, check the status of telescopes, and retrieve their images.

3. Campaign Manager User Interface

Skynet observers have access to the campaign manager via both the Skynet web-interface and the Skynet API. All Skynet observers are provided an API key that can be found under their account settings. Additionally, ready-to-use Python scripts that interact with the API are available upon request. For observers that prefer a user interface, the CM can be used via the Skynet website. The process of using the CM involves three main the steps: (1) defining the hardware template, (2) adding an observation, and (3) updating the observing parameters as desired.

3.1. The Hardware Template

The hardware template is a pre-defined, ordered list of the desired telescopes and filters that are referenced by the CM during an observation. In the event of a rapidly fading transient, it is desirable to begin taking exposures immediately after a candidate for the event has been discovered. For this reason, the hardware template can be created at any time prior to an active event in order to shorten the time between the start of an event and the start of an observation.

The observer can add a hardware template by navigating to the "Add Campaign Template" after clicking on the "Optical Observing" under the "My Observatory" tab in the main navigation pane. The observer's first step in creating a template is selecting the desired filters for the observation. Available filters include Sloan and Johnson/Cousins as well as narrow-band, astrophotography, and special purpose filters.

Following filter selection, the observer is prompted to select the desired telescopes. In addition to the list of available telescopes, the observer is presented with an option to automatically add new telescopes as they become available. If this option is selected, the CM will add any new telescopes, along with the filters that were selected in the previous step, that the user has been granted access to that are not in the hardware template. As an example, if the observer only had access to PROMPT-1 and PROMPT-2 at the time of creating the hardware template, but was granted access to PROMPT-3 at some later time, then the CM would add PROMPT-3 to the template and schedule exposures on all three telescopes at the time of the observation.

After selecting the desired telescopes and filters, the observer is directed to a new web page containing a table that presents the telescope and filter combinations (see Figure 1). If a particular telescope/filter combination does not exist, i.e., the filter is not installed on the given telescope, then the table entry is populated with a green plus sign. This gives the observer the option to add the combination to the template even if it does not exist. If the filter is installed on the telescope at the time of the observation, then the CM will schedule exposures using the combination. If the filter is still not installed, then the CM will simply ignore the combination when scheduling exposures.

Figure 1. The displayed list of selected telescopes and filters for a hardware template. The "green plus" indicates that the given filter (column) is not installed on the given telescope (row). If clicked, the CM will schedule the particular combination once/if the filter is installed.

This option removes the need for the observer to continuously monitor which filters are installed on the Skynet telescopes.

In the same table, the observer has the option to specify the order that the CM schedules the filtered exposures for each telescope. Although Skynet is a heterogeneous network of robotic telescopes, there are subsets, e.g., PROMPT, that have identical equipment. Allowing the observer to specify the order prevents identical telescopes from taking identical exposures at the same time. This prevents the collection of redundant information and maximizes the efficiency of using the Skynet network of telescopes.

3.2. Adding an Observation

For Skynet to begin scheduling and dispatching exposures, an observation must be submitted. The observer can add an observation by navigating to the "Add New Observation" after clicking on the "Optical Observing" under the "My Observatory" tab in the main navigation pane.

When selecting the targets coordinates, the observer has the option to use the target lookup feature that uses local catalogs and SIMBAD (Wenger et al. 2000) to auto-populate the right ascension (R.A.) and declination (decl.) of the target. However, since the CM is designed to be used for transient targets, it is unlikely that the target will be cataloged. As an alternative, the observer can manually enter the sky coordinates.

In addition to the coordinates, event-specific parameters are required to auto-scale exposure lengths. These include: (1) a desired signal-to-noise ratio (S/N) per exposure; (2) an assumed brightness in an observer-selected filter at an observer-selected time, post-event; (3) an assumed temporal index (both power-law and exponential options are available); (4) an assumed spectral index; and (5) a maximum acceptable exposure duration.[1]

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[1] If an exposure would exceed a telescope's recommended maximum tracking duration, a block of exposures is scheduled instead.

The TOO option must also be specified before submitting the observation. Though the CM is available without TOO, it is most effective when paired with it. Enabling this option gives the observer exclusive access to the specified telescopes for the duration of the observation. If multiple TOO observations from different observers are active on the same telescopes, Skynet's load balancer is capable of handling such scenarios.

Finally, a configurable option to delay filter sequences is also available before submitting the observation. Adding a delay between filter sequences is useful for transients that vary slowly with time. The observer may choose from a fixed delay length or a delay length that scales based on the time since the event. With these parameters defined, the observation can be submitted and exposures will be immediately dispatched to the selected telescopes using the selected filters.

3.2.1. Monitoring the Observation

After the observation has been submitted, the CM automatically runs through all filter lists on all telescopes in the hardware template, automatically scaling exposure or exposure-block durations from scope to scope, from filter to filter, and as a function of time, given each telescope/filter combination's typical limiting magnitude and the assumed temporal and spectral indices, to achieve similar S/N per exposure or exposure block.

To monitor the exposures being scheduled, a "Live Update" web-page has been developed specifically for use with the CM. A link to the "Live Update" page is accessed by clicking the link under the observation info pane on the observation page. The "Live Update" page (see Figure 2) displays a table similar to that of the hardware page. However, the table cells now display, along with the order, a progress bar that shows not only the exposure length, but the current progression of that exposure for each telescope/filter combination. Each table cell also allows the observer to modify the order of the filter

Telescope	☑ B	☑ V	☑ R	☑ I
☑ MDRS-14	⊙⊙ Order: 0 ☑ 199s/217s	⊙⊙ Order: 1 ☑ last: 217s	⊙⊙ Order: 2 ☑ last: 165s	⊙⊙ Order: 3 ☑ last: 199s
☑ GORT	⊙⊙ Order: 0 ☑ 199s/217s	⊙⊙ Order: 1 ☑ last: 217s	⊙⊙ Order: 2 ☑ last: 165s	⊙⊙ Order: 3 ☑ last: 199s
☑ NSO-17-CDK	⊙⊙ Order: 0 ☑ last: 149s	⊙⊙ Order: 1 ☑ 50s/149s	⊙⊙ Order: 2 ☑ last: 113s	⊙⊙ Order: 3 ☑ last: 137s
☑ DSO-14	⊙⊙ Order: 0 ☑ last: 253s	⊙⊙ Order: 1 ☑ last: 253s	⊙⊙ Order: 2 ☑ last: 192s	⊙⊙ Order: 3 ☑ 79s/253s
☑ Morehead			⊙⊙ Order: 0 ☑ 48s/170s	
☑ PROMPT-AUGOII-1	⊙⊙ Order: 0 ☑ 197s/236s	⊙⊙ Order: 1 ☑ last: 236s	⊙⊙ Order: 2 ☑ last: 179s	⊙⊙ Order: 3 ☑ last: 216s
☑ DSO-17	⊙⊙ Order: 0 ☑ 187s/356s	⊙⊙ Order: 1 ☑ last: 356s	⊙⊙ Order: 2 ☑ last: 270s	
☑ Prompt3	⊙⊙ Order: 0 ☑ last: 250s	⊙⊙ Order: 1 ☑ last: 250s	⊙⊙ Order: 2 ☑ 36s/190s	⊙⊙ Order: 3 ☑ last: 224s
☑ SOS-14	⊙⊙ Order: 0 ☑ 80s/217s	⊙⊙ Order: 1 ☑ last: 217s	⊙⊙ Order: 2 ☑ last: 165s	
☑ Prompt5	⊙⊙ Order: 0 ☑ last: 210s	⊙⊙ Order: 1 ☑ last: 210s	⊙⊙ Order: 2 ☑ 36s/159s	⊙⊙ Order: 3 ☑ last: 188s
☑ Prompt4	⊙⊙ Order: 0 ☑ last: 217s	⊙⊙ Order: 1 ☑ last: 217s	⊙⊙ Order: 2 ☑ 30s/165s	⊙⊙ Order: 3 ☑ last: 195s
☑ Prompt6	⊙⊙ Order: 0 ☑ last: 167s	⊙⊙ Order: 1 ☑ last: 167s	⊙⊙ Order: 2 ☑ last: 127s	⊙⊙ Order: 3 ☑ 3s/150s
☑ Prompt8	⊙⊙ Order: 0 ☑ last: 210s	⊙⊙ Order: 1 ☑ last: 210s	⊙⊙ Order: 2 ☑ 44s/159s	⊙⊙ Order: 3 ☑ last: 188s
☑ Yerkes-41	⊙⊙ Order: 0 ☑ 260s/296s			

Figure 2. The "Live Update" display for a large-scale campaign using Johnson/Cousins filters. Progress bars with orange indicate an ongoing exposure. Radio buttons with check marks indicate that the particular telescope/filter combination has not been paused by the observer. Unchecking the radio button will cause the CM to cease scheduling exposures for that particular combination until rechecked.

sequence in real time, if desired. Monitoring the observation can also be done via the Skynet API, if desired.

In addition to the telescope/filter table, there is a web-form positioned above the table that displays all of the event-specific parameters as well as their corresponding values. As new information is learned about the target, such as its brightness at a certain time in a certain filter, or its temporal and spectral indices, these parameters can be modified and the CM will immediately update upcoming exposure lengths and display the changes in the table.

Finally, the observer can discontinue use of particular telescopes, particular filters, or combinations thereof (or add them back in) in real time. Otherwise, each telescope/filter combination automatically discontinues once the maximum acceptable exposure or exposure-block duration is exceeded.

4. The Campaign Manager

The CM is built into the existing Skynet source code and is almost exclusively contained within the MVC structure. That

is, the data-related logic is handled in the model, the data manipulation and processing are handled in the controller, and the user interface (UI) logic is handled in the views. The only CM code not contained in the MVC is the calling routine. The calling routine is contained in a script named the "client monitor." An instance of the client monitor is created for each live telescope connected to Skynet and is responsible for handling the telescope's exposure queue and sending the appropriate commands to the Terminator. Hence, the CM is called on a per-telescope basis and is only responsible for handling exposures from the telescope associated with the given client monitor instance.

4.1. Objectives

The CM algorithm has four main objectives: (1) generate a list of exposures that should be scheduled based on the observer's selected telescopes/filters, (2) calculate the exposure length for each exposure using the observer's event-specific parameters, (3) compare the list of currently scheduled exposures to the list of exposures in (1), and (4) add/cancel/ update exposures as appropriate according to (3). (see Figure 3) for a visualization of objectives (3) and (4).

4.2. Activation

The CM does not start up and run indefinitely once a telescope connects to Skynet. Instead, the main loop in the client monitor, which runs until the telescope is disconnected, continuously checks if there are any active observations and if the observer has specified that the observation should be handled by the CM. The observer can flag an observation for the CM via either the Skynet web interface or the API when adding the observation.

Once activated, the CM schedules four minutes of exposures based on the observers inputted parameters. Since the CM does not run indefinitely as a standalone script, it must be repeatedly called in order to update the existing exposure (if there is an update to the parameters by the observer) or to schedule new exposures beyond the initial four minute schedule. By default, the CM is called every 60 s to perform the four objectives listed in Section 4.1. Additionally, the CM is called immediately after an observer updates any of the input observation parameters. The 60 s timer is reset after an update to the parameters is detected.

4.3. Exposure Lists

To semi-autonomously schedule exposures, the CM's first task is to create a list of exposures corresponding to the ordered filters that the observer specified in their hardware template. If the CM continuously ran as a background script, then this would be as simple as checking a list that gets appended each time an exposure is scheduled. However, since the CM is called
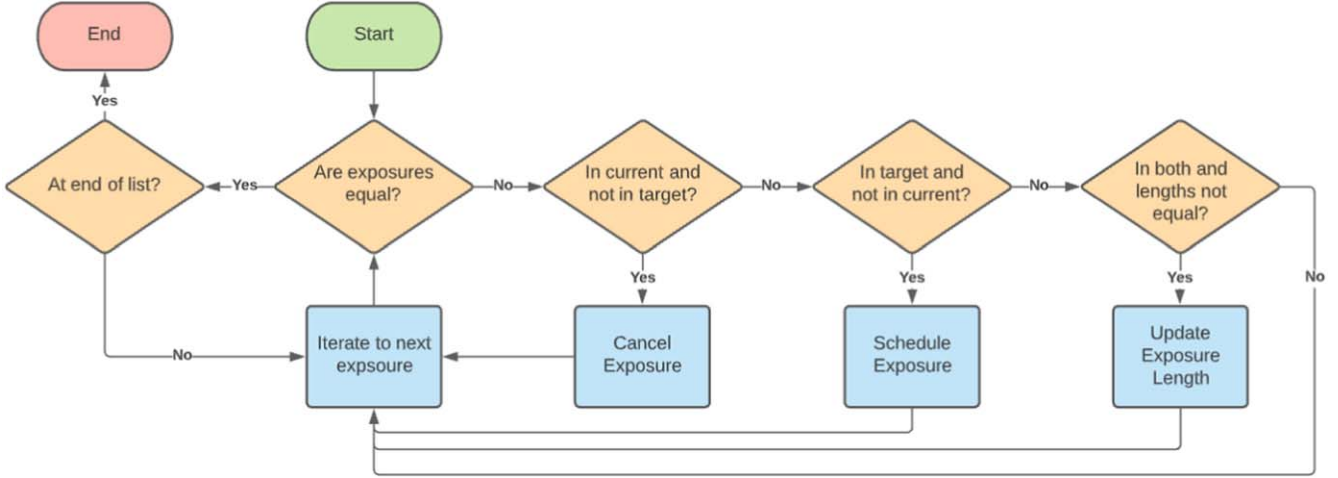
Figure 3. The matching algorithm comprising of the CM's third and forth main objectives as described in Section 4.1. Following the generation of the current list, i.e., the list of currently scheduled exposures, and the target list, i.e., the list of exposures that should be scheduled based on any recent user-inputted changes, the CM iterates through both lists, compares their properties, and modifies the current list to match the target list.

periodically, it must first determine which exposures have already been scheduled and are waiting to be executed such that the observer's specified order can be preserved.

The process of determining which exposures have already been scheduled is further complicated since the CM is repeatedly scheduling the same sequence of filters. When calculating the exposure lengths (Section 4.4) it is crucial to know how many times the filtered exposure has been scheduled due to the time dependency of the scaling equation. To remove this degeneracy, a unique identifier called the "iteration ID" is defined. The iteration ID is incremented each time that a full sequence of exposures is scheduled. For example, if the observer requested the filters *B*, *V*, and *R*, then each exposure in that sequence would have the same iteration ID. However, the iteration ID would be incremented the next time they are scheduled.

The CM will schedule ordered exposures until at least two exposures and at least four minutes are scheduled. Though the time limit of four minutes is semi-arbitrary, both conditions are necessary in ensuring that the observation is executed without interruption (see Figure 4). The client monitor is constantly checking for exposures that need to be executed on a given telescope. If the CM were to schedule a single exposure with an exposure length of 15 s, then there would be a 45 s gap in which there are no exposures scheduled for the observation. To prevent an idle telescope, the client monitor would begin executing exposures for another observation even if the observer had specified TOO. The telescope would then slew to the new target only to have slew back once the CM scheduled another exposure. Requiring at least two exposures and a minimum time buffer of at least 60 s prevents this.

4.4. The Scaling Equation

Skynet employs a credit-based currency system that observers use to schedule their observations. However, since Skynet is a heterogenous network, one credit cannot be easily mapped to a fixed unit of observing time. For example, to achieve a S/R for a given target, a 1.0 m telescope in CTIO would need to expose for a shorter duration than the 40 yr old, 24 inch Morehead telescope located in downtown Chapel Hill. For this reason, mapping one credit to one observing second, or any other fixed unit of time, does not make sense.

Instead, Skynet charges one credit for a one-second exposure on Skynet's PROMPT-5 telescope and scales based on the observer's selected telescope's efficiency relative to PROMPT-5. To achieve this, Skynet uses a cron job to calculate the efficiencies of each telescope once per week using the most recent, open filtered exposures. These efficiencies, ε_t, are defined as the inverse of the exposure time, t_{exp}, needed to achieve a limiting magnitude, *m*, of 20 at a S/N of 5:

$$\varepsilon_t = \frac{[(\text{S/N})/5]^2 \cdot \log_{10}[(m - 20)/2.5]}{t_{\text{exp}}}. \qquad (1)$$

Here, the assumption is made that the source of interest is sufficiently bright enough that the noise is purely Poisson. Thus, the S/R factor in Equation (1) must be squared. Outlier rejection is performed using Robust Chauvenet Rejection (Maples et al. 2018) to eliminate anomalous data points due to weather, hardware issues, or any other source of contamination. Equation (1) is used as the starting point for scaling exposure lengths.

However, since the CM is interested in calculating exposure lengths, not efficiencies, we start by taking the inverse of
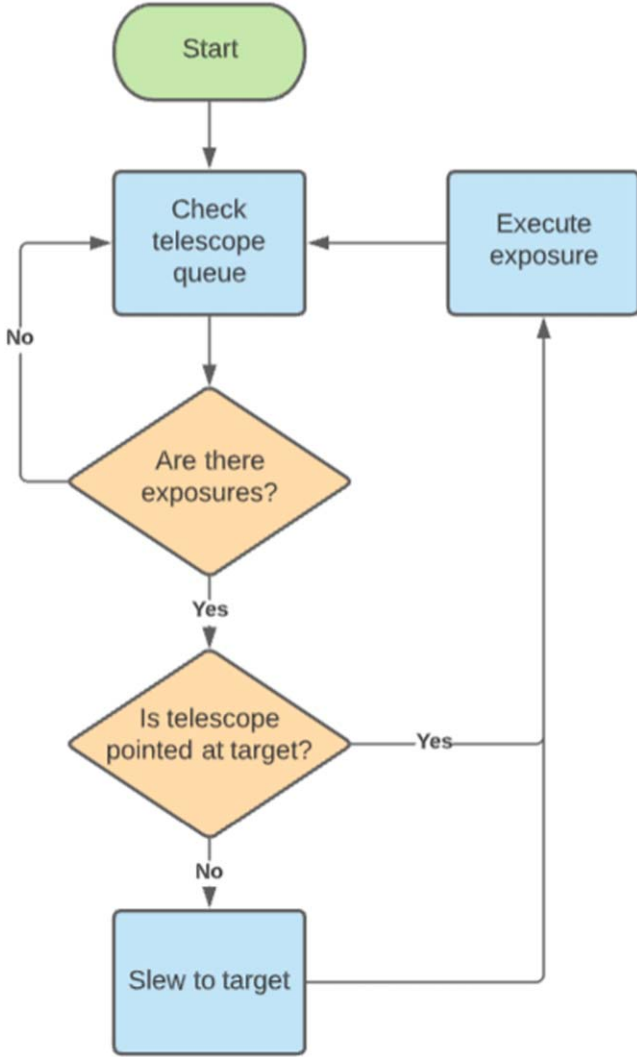
Figure 4. A greatly simplified client monitor algorithm emphasizing the importance of the CM scheduling exposures into the future. If the CM did not schedule at least two exposures with a minimum 60 s time buffer, then the telescope would repeatedly slew to other targets wasting valuable observing time.

Equation (1). Since telescope efficiencies are calculated using open filters only, a factor must be added to account for the efficiencies of the observer's selected filter. This accounts for the remaining hardware dependencies, but if left as is, the scaling equation still fails to account for event-specific parameters. To account for these, a time-dependent factor, as well as a frequency-dependent factor are added, yielding:

$$
\begin{aligned}
t_{\exp} = {} & [(S/N)/5]^2 \cdot \log_{10}[(m-20)/2.5] \\
& \times \left(\frac{\varepsilon_t}{\varepsilon_f}\right)\left(\frac{t_{\exp} - t_{\text{event}}}{t_{\text{ref}}}\right)^{-\alpha}\left(\frac{\nu_f}{\nu_{f,\text{ref}}}\right)^{-\beta}.
\end{aligned} \tag{2}
$$

The filter efficiency, ε_f, is calculated and stored as a value between 0 and 1 in the Skynet database. On the other hand, the telescope efficiency is stored as an inverse and can achieve a value higher than 1 as a result. The time-dependent factor normalizes the time between the execution of the exposure, t_{exec}, and the start of the transient event, t_{event}, and then scales it according to the assumed temporal index of the source, α. The frequency-dependent factor normalizes the center frequency of selected filter, ν_f, to the center frequency of the reference filter, $\nu_{f,\text{ref}}$, and then scales it according to the assumed spectral index of the source, β.

Similarly, an exponential scaling function that makes use of the same parameters is also available

$$
\begin{aligned}
t_{\exp} = {} & [(S/N)/5]^2 \cdot \log_{10}[(m-20)/2.5] \\
& \times \left(\frac{\varepsilon_t}{\varepsilon_f}\right)\left(\exp\left[-\alpha\frac{t_{\text{exec}} - t_{\text{event}}}{t_{\text{ref}}}\right]\right)\left(\frac{\nu_f}{\nu_{f,\text{ref}}}\right)^{-\beta}.
\end{aligned} \tag{3}
$$

The observer has the option to specify either a power or exponential function while adding the observation.

4.5. Stopping the Campaign Manager

There are four independent stopping conditions for the CM to cease scheduling exposures and cancel the observation. The stopping conditions include: (1) an observer expends all of their available credits, (2) all of the telescope/filter combinations have been masked, (3) the observer selected cancel-after date has been reached, or (4) the observer manually cancels the observation.

Masking available telescope/filter combinations can be done manually by the observer, or automatically by the CM if exposure lengths exceed the observer-inputted maximum allowable length. In most cases, the observer will manually end the observation once they have collected their data. The cancel-after date is intended as a fail-safe, cut-off date to prevent the observer from accidentally expending all of their credits.

5. Discussions and Conclusions

The recent emergence of multi-messenger astronomy has resulted in multiple large-scale observing campaigns in an attempt to better understand some of the most violent processes in the universe. Following a successful discovery of the electromagnetic counterpart to GW170817 (e.g., Abbott et al. 2017a), Skynet sought to improve its follow-up observing capabilities. Thus, development began on the campaign manager in 2018 with the goal expanding Skynet's existing capabilities to observe transients to better image optical counterparts to compact binary coalescences.

Before the CM can be utilized for follow-up observations, candidates to such events must first be discovered. Currently,

Skynet has two internal methods, and one external method, for candidate detection. If a candidate is detected via an internal method, a detection alert will be distributed to the greater astronomy community through the Gamma-ray Coordinates Network and the CM will be immediately and automatically triggered via the API. In the case of an external detection by another research group, the CM will be triggered manually using the candidate's sky coordinates.

The first internal discovery method utilizes Distance Less Than Forty (DLT40), which is a young, less than 100 Mpc (previously 40 Mpc) supernova search that uses Skynet's identical PROMPT telescopes at our Chilean, Western Australian, and Canadian sites to observe ≈400–600 galaxies per night per site. DLT40's narrow-field, targeted search approach was proven successful with their co-discovery of the GW170817 optical counterpart (Valenti et al. 2017).

The other internal discovery method utilizes the Evryscopes (Law et al. 2015), two large arrays of small telescopes, in Chile and California, that cover the entire visible sky in a single exposure, repeatedly imaging the sky every two minutes and stacking images to achieve depth. The two Evryscopes, designed, built, deployed and operated by Law's group at the University of North Carolina at Chapel Hill, use mass-produced compact CCD cameras, mass-produced compact camera lenses, and a novel camera mounting scheme to make robotic telescopes with a total of 1.3 gigapixels covering the sky. The Evryscopes were not utilized in the 2017 kilonova discovery. As such, their images of 16,000 square degrees in each exposure may greatly reduce the time between the LIGO detection and the activation of the CM if there is a sufficiently bright, early counterpart.

Although designed with LIGO/Virgo/KAGRA events in mind, the CM is well equipped to handle observations of various other transient phenomena. Skynet will be using the CM to observe GRBs between GW events.

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