A strategy for LSST to unveil a population of kilonovae without gravitational-wave triggers.

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Abstract

We propose a cadence optimization strategy for the Large Synoptic Survey Telescope (LSST) to unveil a large population of kilonovae. These transients are generated during binary neutron star and potentially neutron-star black-hole mergers and are electromagnetic counterparts to gravitational-wave signals detectable in nearby events with Advanced LIGO, Advanced Virgo, and other interferometers that will come online in the near future. Discovering a large population of kilonovae will allow us to determine how heavy element production varies with the intrinsic parameters of the merger and across cosmic time. The rate of binary neutron star mergers is still uncertain and $\lesssim 15$ events with associated kilonovae are expected to be detectable per year within the LIGO horizon. The rapid evolution ($\sim$ days) at optical/infrared wavelengths, relatively low luminosity, and the low volumetric rate of kilonovae makes their discovery difficult, especially during blind surveys of the sky. With the current LSST cadence design, $\lesssim 7.5$ poorly-sampled kilonovae are expected to be discovered in both the WFD and DDF surveys per year, under optimistic assumptions on their rate and luminosity. We propose to adopt a rolling cadence for the WFD survey in which gi observations are taken for a particular $750\,\mathrm{deg}^2$ tract of sky every night for 10 consecutive nights, with the total yearly exposure time in gi being equivalent to the 'wide-fast-deep' baseline across the survey. We expect this strategy to return ~ 272 GW170817-like kilonovae throughout the survey discovered independently from gravitational-wave triggers.

1 White Paper Information

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1. **Science Category:** Exploring the Changing Sky, The Nature of Dark Matter and Understanding Dark Energy
2. **Survey Type Category:** The main 'wide-fast-deep' survey.
3. **Observing Strategy Category:** A specific observing strategy to enable specific time domain science, that is relatively agnostic to where the telescope is pointed (e.g., a science case enabled by relatively deep precise time-resolved multi-color photometry).

2 Scientific Motivation

Binary neutron star mergers have long been predicted to be associated with short gamma-ray bursts (sGRBs) and optical/near-infrared transients called kilonovae (KN) or macronovae (see for example Goodman, 1986; Paczynski, 1986; Eichler et al., 1989). Signatures of such rapid and red transients were first found during the follow-up of sGRBs (Perley et al., 2009; Tanvir et al., 2013; Berger et al., 2013; Gao et al., 2015), but never found thereafter during blind surveys of the sky due to the low luminosity expected from KN emission (Figure 2).

On 2017 August 17 a KN was discovered to be associated with the gravitational-wave (GW) event GW170817 (Figure 1; Coulter et al., 2017; Valenti et al., 2017; Arcavi et al., 2017; Tanvir et al., 2017; Lipunov et al., 2017; Soares-Santos et al., 2017). The optical/infrared transient, hereafter referred to as the GW event GW170817, was demonstrated to be the counterpart to a binary neutron star merger, marking the beginning of a new era for GW multi-messenger astronomy (Abbott et al., 2017c). Such discovery allowed studies of great impact to be carried out. For example, the combined GW and electromagnetic information was used to measure cosmological parameters independently from any distance ladder (Abbott et al., 2017a; Hotokezaka et al., 2018). The near-infrared spectra indicated the presence of r-process nucleosynthesis (e.g., Pian et al., 2017). Well-sampled optical and infrared light curves allowed us to estimate parameters such as the ejecta mass and velocity. Moreover, the luminosity and color evolution indicated a rapid reddening of the KN, suggesting that heavy elements are synthesized, and that lanthanide-rich ejecta contribute to increasing the opacity (e.g., Smartt et al., 2017). Studies of the KN associated with GW170817 suggests that binary neutron star mergers could be among the dominant sites for r-process nucleosynthesis in the Universe.

Mergers of neutron stars with black holes are also expected to produce KNe (Kasen et al., 2017). The detection of neutron star – black hole mergers and their electromagnetic counterparts is one of the most exciting challenges for multi-messenger astronomers in the near future.

The KAGRA and LIGO-India interferometers are expected to come online and join Advanced LIGO (AdLIGO) and Advanced Virgo (AdVirgo) at detecting GW signals after 2020 (Abbott et al., 2018). A growing network of GW observatories will provide more and better-localized GW detections and, consequently, the follow-up of GW triggers should lead to the detection of several KNe. The rates of neutron star mergers are uncertain (see a more detailed discussion in the *Technical Description*), but combining gravitational-wave (Abbott et al., 2017b) and past electromagnetic transient survey information (Kasliwal et al., 2017) we can expect $\lesssim 23$ GW events to occur every year within the AdLIGO horizon of 190 Mpc, only $\lesssim 15$ of which would be detected accounting for the AdLIGO duty cycle and only some of which may show an optical signature. Target of Opportunity (ToO) observations will serve to search for counterparts shortly after GW triggers are issued (see the white paper by Margutti et al., 2018). Limitations for KNe detection via ToO follow-up include GW detectors experiencing significant downtime, with an average duty cycle of 60 %-70 % in addition to months in which the interferometers are offline to be upgraded. When one or more interferometer is offline, the whole GW detector network decreases in sensitivity, and the source localization becomes poorer, making the discovery of possible electromagnetic counterparts more difficult. KNe may be detected by *Fermi* or *Neil Gehrels Swift Observatory* sGRB follow-up, however such events are typically detected at large distances and their relativistic emission is observable only at favorable viewing angles.

Unveiling a larger population of KNe is necessary to answer questions that cannot be properly addressed with the current LSST strategy. At present, the LSST strategy is expected to yield ∼7.5 events per year under optimistic conditions (Scolnic et al., 2018) or 4 to 15 KNe y^{-1} relying only on GW trigger follow-up (Kasliwal et al., 2017).

Determining robust rates of KNe is of primary importance because it directly constrains the rate of binary neutron star mergers. Hundreds of KN detections would allow us to understand the distribution of parameters such as ejecta mass, ejecta velocity, and opacity, along with a better understanding of the jet physics and the dependence of observed properties on the viewing angle. Moreover, a better knowledge of KN rates and properties could shed some light on the current debate on whether KNe (e.g., Kasen et al., 2017) or collapsing massive stars (Siegel et al., 2018) are the dominant sites for heavy-element nucleosynthesis in the Universe. Furthermore, searches for distant events can also allow us to understand whether the KNe rate varies with redshift. A blind survey for fast transients with well planned color measurements can help us understand the distribution of their properties in a more complete way, highlighting which different types of KNe exist and how "typical" GW170817 was.

KNe discovered with LSST should provide a large sample of host galaxies, allowing us to search for correlations between KN properties and galaxy morphology, star formation, and metallicity (e.g., Levan et al., 2017). Even if spectroscopic measurements of the active transients are not performed, large telescopes can provide high-quality observations of their hosts. The detection of KNe with LSST could also trigger reverse-searches for signatures in data acquired with GW and neutrino detectors (Acernese et al., 2007). Such an approach can be valuable especially when only one detector is online, resulting in a poorly constrained localization region (thousands of $\deg^2$), in which case a trigger is unlikely to be issued.

A cadence strategy optimized for KN discovery with LSST can aid several aspects of multi-messenger astrophysics, but can also benefit other science cases. In fact, the cadence that we describe in the following sections can lead to the discovery of other elusive fast transient phenomena, in addition to KNe. Those include for example supernova shock breakouts (e.g., Bersten et al., 2018) and GRB afterglows (Cenko et al., 2015). As for KNe, the cadence currently planned for LSST WFD is sub-optimal for fast transient detection and the rarity of most compelling cosmological events limits their detection in the DDF survey.

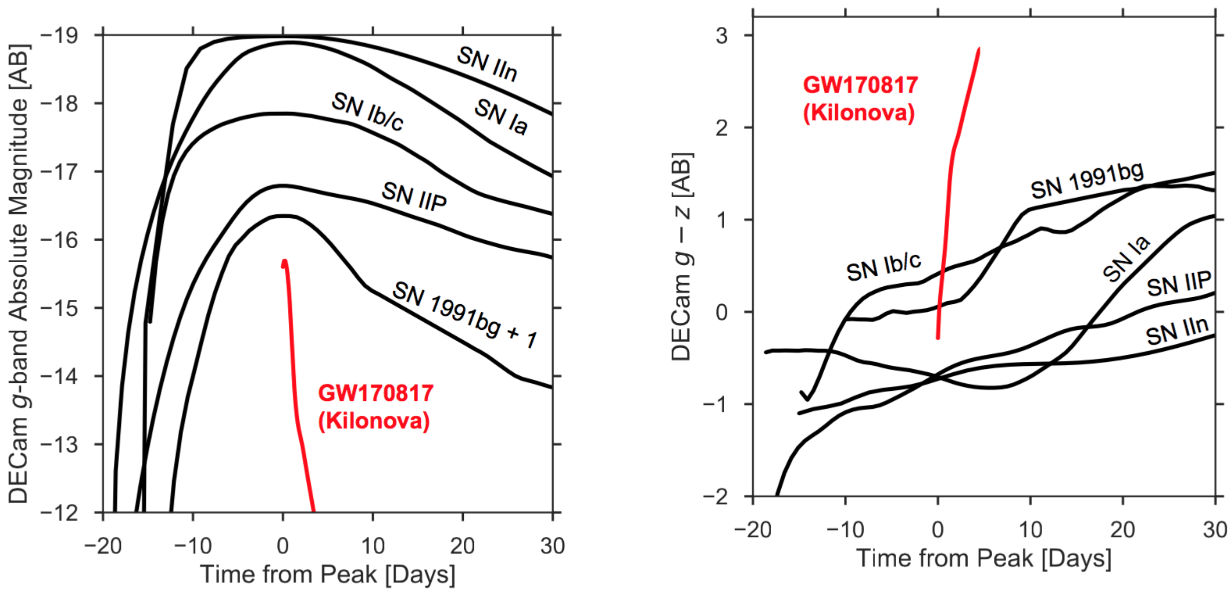

Figure 1: **Left** – g-band light curve of GW170817 compared to representative light curves of other known transients. KNe decline faster than most known or theorized optical transients. **Right** – Unique color evolution of GW170817 compared with other known transients.

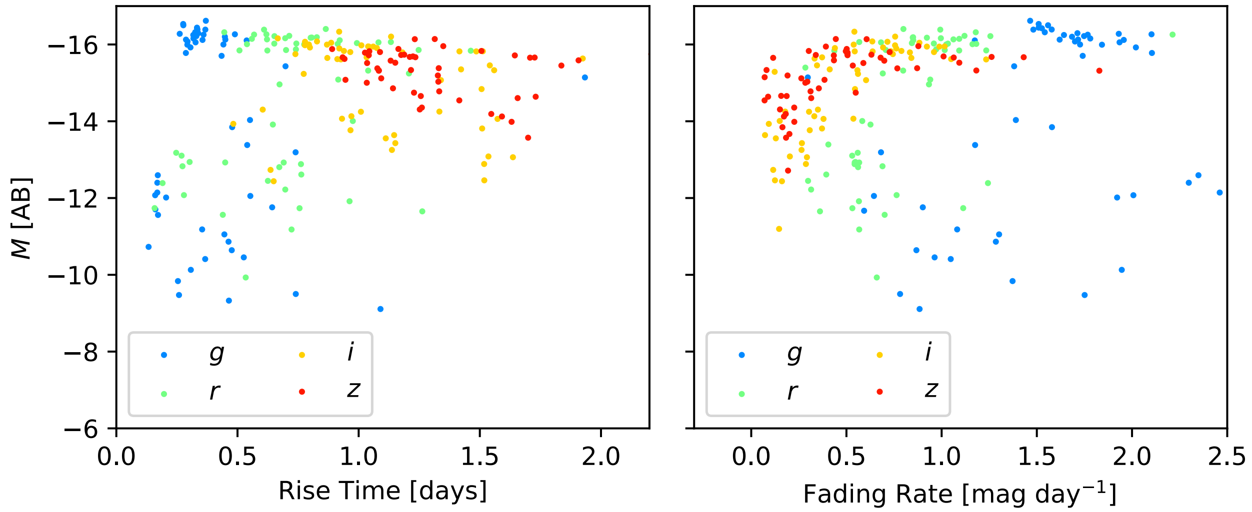

Figure 2: The peak magnitudes of a grid of KN models spanning the space of merger parameters (Kasen et al., 2017) are plotted against the rise time (*left*) and the fading rate (*right*) expected for each model in the first 3 days after the merger. Most models predict bright blue emission that evolves rapidly in g. Observations in g and i or z will yield strong measurements of colors with which to confirm and KNe and study their properties.

3 Technical Description

3.1 Proposed survey strategy modification

Currently, the cadence for LSST is based on multi-filter observations spread across the year. The average number of pointings per 10 years are, quoting the LSST Science Book (LSST Science Collaboration et al., 2009), u: 70 g: 100 r: 230 i: 230 z: 200 y: 200.

We propose a rolling cadence for the WFD survey in which, every year, *gi* observations are taken every night for 10 consecutive nights over a large area of sky. Specifically, based on values presented in LSST Science Collaboration et al. (2009):

- A) Assuming observations in the *gi* bands take place for 20 nights a month with the proposed nightly cadence, broken up into two sets of 10 consecutive nights, the sky area to be observed per set of consecutive nights is approximately $750\,\mathrm{deg}^2$ per night. After 10 nights, a different $750\,\mathrm{deg}^2$ area is observed for the next set of 10 nights. Observing for 20 days per month allows us to avoid bright time observations.

- B) Assuming observations taking place 360 days per year, the sky area to be observed every set of 10 consecutive nights is $500\,\mathrm{deg}^2$ per night. After 10 nights, a different $500\,\mathrm{deg}^2$ area is observed for the following set of 10 nights. This strategy is is less effective than A) because it includes bright time observations.

Dark and grey time should be used for these observations to enable the detection of fainter and/or more distant sources with strategy A). The specific month at which each sky area is covered can differ every year, in order to enable the imaging of the planned $18000\,\mathrm{deg}^2$ every year.

Observations in the remaining *urzy* filters (and additional 130 *i*-band pointings) are not constrained by this proposal and may be obtained with whatever alternative cadence that will best fulfill the broad LSST science objectives. These observations will also serve to provide longer baseline for the *gi* observations, allowing us to further reject supernovae and monitor the long-term behaviour of the discovered transients.

3.2 High-level description

Describe or illustrate your ideal sequence of observations.

We propose to modify the WFD survey strategy performing *gi* observations each night for 10 consecutive nights. It is crucial that observations in both filters are performed on the same night in order to provide reliable color information at each phase of the discovered transients. The time spacing between visits in the 2 chosen filters should be minimized, ideally < 3hr given the rapid evolution of KNe. A time spacing of > 30 minutes would allow the rejection of moving objects in order to consider those candidate events detected in both *gi* filters on one night and not detected the nights before and after as newly discovered KNe.

The choice of observing for 10 consecutive nights is dictated by several factors:

- KN models (Kasen et al., 2017) are expected to fully evolve in $\lesssim$10 days, so high cadence is necessary for their discovery. A blue component generated from lanthanide-poor disk winds can be present and is expected to be visible for only 3-4 days. A compilation of light curves estimated for a range of ejecta masses and velocities are presented in Figure 3.
- Ten consecutive nights of observations would allow us to obtain well-sampled light curves. At least 2-3 data points per band combined with upper limits before and/or after the detection can help uniquely identify KNe, reducing the number of contaminant sources. Hundreds of such light curves are expected to yield distributions of KN ejecta masses, velocities, and opacity measurements.
- The median number of 100 g-band visits for the area explored with the WFD survey suggests to consider 10 epochs per year for the proposed cadence. The larger number of i-band observations will allow more temporally spaced visits in addition to the 10 consecutive nights of gi observations.
- A sequence of 10 consecutive nights allows observations to be performed in dark and grey time to maximize the number of discoveries.

Main objective of the proposed strategy: Increase the observing cadence for a large region of sky (450 times larger than DDF in total, ~12.5 times larger than DDF per night) in 2 filters to provide a large number of KN and fast-transient detection.

Why not relying solely on the DDF survey for KN detection? Only a small number ($<1\,\mathrm{y}^{-1}$) of such rare faint transients will be detectable in DDF because of the limited sky area explored (Scolnic et al., 2018).

Why 2 filters? Detections in multiple filters on the same night allows us to A) measure temperature and infer properties of KN, and B) reject most contaminant sources such as supernovae (Cowperthwaite et al., 2018). In addition, visits separated by > 30 minutes allow moving objects to be easily flagged.

3.3 Footprint – pointings, regions and/or constraints

Describe the specific pointings or general region (RA/Dec, Galactic longitude/latitude or Ecliptic longitude/latitude) for the observations. Please describe any additional requirements, especially if there are no specific constraints on the pointings (e.g. stellar density, galactic dust extinction).

3.4 Image quality

Constraints on the image quality (seeing).

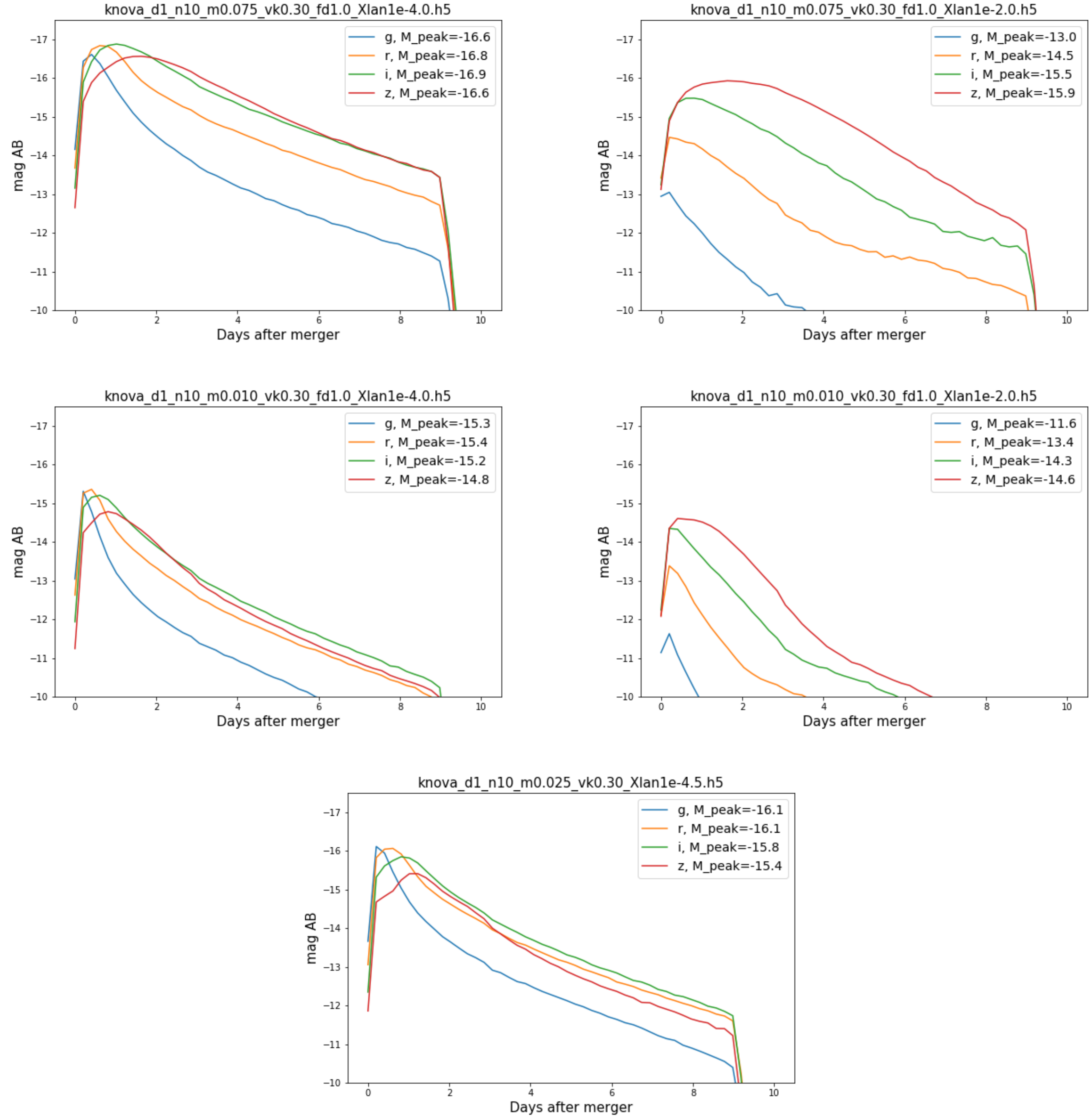

Figure 3: KN models from Kasen et al. (2017). The two plots at the top show KNe with high ejecta mass ($0.075M_\odot$) and the two central panels show KNe with low ejecta mass ($0.01M_\odot$). The plots of the left are created assuming low lanthanide mass fraction (Xlan=10^{-4}) and those of the right assuming high lanthanide mass fraction (Xlan=10^{-2}). The bottom plot shows model light curves built with parameters that best fit the KN counterpart to GW170817 ($0.025M_\odot$, Xlan=$10^{-4.5}$; Arcavi, 2018).

No constraint on image quality is required.

3.5 Individual image depth and/or sky brightness

Constraints on the sky brightness in each image and/or individual image depth for point sources. Please differentiate between motivation for a desired sky brightness or individual image depth (as calculated for point sources). Please provide sky brightness or image depth constraints per filter. With a proposed strategy based on 2 sets of 10 observing nights per month (i.e., 20 nights per month in total), dark and grey time are preferred. Avoiding bright time allows us to maximize the depth of nightly-stacked images, and therefore the sky volume explored.

3.6 Co-added image depth and/or total number of visits

Constraints on the total co-added depth and/or total number of visits. Please differentiate between motivations for a given co-added depth and total number of visits. Please provide desired co-added depth and/or total number of visits per filter, if relevant.

The proposed strategy relies on high inter-night cadence. Co-added images for each night observations in all filters will provide deep images optimal for KN detection. Co-addition of images acquired on different nights is not required.

3.7 Number of visits within a night

Constraints on the number of exposures (or visits) in a night, especially if considering sequences of visits.

Multiple visits using the same filter on the same night are not required. In this proposal we do not aim at rapid detection and spectroscopy (see for example the white papers by Bianco et al.), as the main goal is to collect large number of faint and distant events. Moving objects will be flagged out by requiring sources to be detected on multiple nights or with g+i observations spaced $>$ 30 minutes on the same night.

3.8 Distribution of visits over time

Constraints on the timing of visits — within a night, between nights, between seasons or between years (which could be relevant for rolling cadence choices in the WideFastDeep. Please describe optimum visit timing as well as acceptable limits on visit timing, and options in case of missed visits (due to weather, etc.). If this timing should include particular sequences of filters, please describe.

The rolling cadence that we propose requires the same 750 deg^2 of sky be observed in the gi filters for 10 consecutive nights. For coverage of the WFD footprint we require two such consecutive 'runs' of gi imaging on two different 750 deg^2 tracts of sky for a total of 1500 deg^2 observed per month in gi.

Every set of 10 consecutive observing nights is independent from each other, so every year the time at which a certain sky area is images can be optimized for other science cases, as long as it is imaged for 10 consecutive nights every year.

3.9 Filter choice

Please describe any filter constraints not included above.

We propose to perform nightly-cadenced observation is g and i filters. We leave ~ 100 i and all $ugry$ observations unspecified so that they may be optimally distributed for other science cases. Observations of our high-cadence fields in other filters are not required but add information to any discovered transient.

3.10 Exposure constraints

Describe any constraints on the minimum or maximum exposure time per visit required (or alternatively, saturation limits). Please comment on any constraints on the number of exposures in a visit.

No exposure time constraint is required.

3.11 Other constraints

Any other constraints.

We require no additional constraint.

3.12 Estimated time requirement

Approximate total time requested for these observations, using the guidelines available at `https://github.com/lsst-pst/survey_strategy_wp`*.*

As our proposal only modifies the cadence of the original LSST strategy, **it should not add any significant overheads in time**.

The approximate total amount of time required for our main proposed strategy is given by tiling $750\,\text{deg}^2$ per night for 10 consecutive nights, using g and i filters, for 20 nights every month. Assuming 2 visits (one in g and one in i) with 30s exposure time, the required observing time per night is:

2 visits × [(30s exposure) + (120s slew) + (5s settle and readout)] × (750 deg^2) / (10 deg^2 FoV) = $6.46\,\text{hr}$

Therefore the annual time necessary to perform such observations is ~ 1550 hours per year, already planned to be allocated for gi observations.

3.13 Technical trades

To aid in attempts to combine this proposed survey modification with others, please address the following questions:

1. *What is the effect of a trade-off between your requested survey footprint (area) and requested co-added depth or number of visits?*

Properties	Importance
Image quality	3
Sky brightness	2
Individual image depth	3
Co-added image depth	1
Number of exposures in a visit	3
Number of visits (in a night)	3
Total number of visits	1
Time between visits (in a night)	3
Time between visits (between nights)	1
Long-term gaps between visits	3
Other (please add other constraints as needed)	

Table 1: **Constraint Rankings:** Summary of the relative importance of various survey strategy constraints. Please rank the importance of each of these considerations, from 1=very important, 2=somewhat important, 3=not important. If a given constraint depends on other parameters in the table, but these other parameters are not important in themselves, please only mark the final constraint as important. For example, individual image depth depends on image quality, sky brightness, and number of exposures in a visit; if your science depends on the individual image depth but not directly on the other parameters, individual image depth would be '1' and the other parameters could be marked as '3', giving us the most flexibility when determining the composition of a visit, for example.

2. *If not requesting a specific timing of visits, what is the effect of a trade-off between the uniformity of observations and the frequency of observations in time? e.g. a 'rolling cadence' increases the frequency of visits during a short time period at the cost of fewer visits the rest of the time, making the overall sampling less uniform.*
3. *What is the effect of a trade-off on the exposure time and number of visits (e.g. increasing the individual image depth but decreasing the overall number of visits)?*
4. *What is the effect of a trade-off between uniformity in number of visits and co-added depth? Is there any benefit to real-time exposure time optimization to obtain nearly constant single-visit limiting depth?*
5. *Are there any other potential trade-offs to consider when attempting to balance this proposal with others which may have similar but slightly different requests?*

Because our goal is to collect a statistically significant sample of KN events beyond the GW detection horizon, the strategy we propose does not require multiple visits using the same filter on the same night. Thus we need not consider the trade-off between exposure time and number of visits for a given filter. For the same reason, we need not consider the trade-off between number of visits in a single filter and co-added depth, though there would be benefit to real-time exposure-time optimization so as to achieve comparable depth in all of the fields we intend to image in a given night. Reducing the total number of visits per night (i.e. imaging in only one filter) would be highly disruptive to our science case.

4 Performance Evaluation

Please describe how to evaluate the performance of a given survey in achieving your desired science goals, ideally as a heuristic tied directly to the observing strategy (e.g. number of visits obtained within a window of time with a specified set of filters) with a clear link to the resulting effect on science. More complex metrics which more directly evaluate science output (e.g. number of eclipsing binaries successfully identified as a result of a given survey) are also encouraged, preferably as a secondary metric. If possible, provide threshold values for these metrics at which point your proposed science would be unsuccessful and where it reaches an ideal goal, or explain why this is not possible to quantify. While not necessary, if you have already transformed this into a MAF metric, please add a link to the code (or a PR to sims_maf_contrib) in addition to the text description. (Limit: 2 pages).

Table 2: We explore the detectability of a set of KNe modelled with different ejecta mass and lanthanide mass fraction. First compute the expected number of KN recovered with at least one detection in both g and i filters (gi) assuming that we can . The "Raw potential" represents the number of KN that could be detected during LSST WFD survey (at least one data point in at least one filter). We compute the number of KNe that we expect to recover in the survey with at least 2 detections in the same filter with nightly cadence (C1), 2-night cadence (C2), and 3-night cadence (C3). Numbers are computed considering a KN rate of $1000\,\mathrm{Gpc}^{-3}\mathrm{y}^{-1}$.

KN model	gi (C1)	Filter	Raw potential	C1	C2	C3
GW170817	272	g	782	131	42	19
		i	199	82	37	16
		z	21	9	3	1
Low ej. mass, low Xlan	96	g	315	49	15	6
		i	87	37	14	6
		z	10	4	1	1
Low ej. mass, high Xlan	1	g	3	0	0	0
		i	27	11	4	2
		z	8	4	1	0
High ej. mass, low Xlan	460	g	1367	237	77	36
		i	640	276	120	55
		z	96	45	16	6
High ej. mass, high Xlan	5.9	g	19	3	1	0
		i	121	50	20	9
		z	40	20	5	3

The aim of this project is to unveil a large population of KNe that are expected to evolve rapidly, fading away in less than 10 days at optical wavelengths. The current WFD design is largely sub-optimal to discover KNe. The tests that we performed using Sims-MAF (Figure 4) show low recovery efficiency for GW17817-like KNe, with about 10 events possibly discovered during the survey. Scolnic et al. (2018) estimate that ~ 69 of such events, however this number is optimistic in that large time windows are considered to constrain the duration of the transient ($\geq$20 days), which may not be effective to remove high-redshift supernova background. Cadences in the order of 1 or $\sim$few days are necessary to better constrain KNe in the optical. Moreover, neutron star merger rates are highly uncertain (rate=1540^{+3200}_{-1200} Gpc^{-3} yr^{-1} according to Abbott et al., 2017b, see Appendix for more details).

We estimate the number of KN that could be detected in different scenarios, considering several cadence options (1, 2, and 3 night cadence) and diverse KN models. The luminosity and duration of KNe strongly depend on the ejecta mass, kinetic velocity, and electron fraction among other parameters. Details on the numerical radioactive-decay-powered models that we explore are described in Kasen et al. (2017). We consider in particular 5 models: one that well fits the light curve of GW170817, the other four build with combinations of low/high ejecta mass (m=0.010/0.075 $M_\odot$) with low/high lanthanide mass fraction (Xlan=$10^{-4}/10^{-2}$). All the considered models assume kinetic velocity v_k=0.3 c, and density profile exponents d=1 (inner) and n=10 (outer). Figure 3 shows the *griz* light curves corresponding to the chosen models.

Results of our calculations are presented in Table 2, using detection limits of g=24.8, i=23.8, and z=22.5 (LSST Science Collaboration et al., 2009). We focus on g,i,z observations in order to identify which combination of filters and cadence allows us to discover most KNe. Given the dramatic colors and color evolution of KNe (Figure 2-1), combined combined *gz* observations would be preferred, but results in Table 2 suggest higher chances of discovering KNe by pairing g with i filter.

Calculations show that LSST has the potential to detect a large number of KNe (see the “Raw Potential” column in Table 2), however individual detections cannot be labelled as “discoveries” in this context. This can be achieved requiring, for example, at least two detection in one filter on one night, or multiple detections with one filter over multiple nights.

The larger number of discovered KNe is achieved requiring at least one detection in both g and i filter, assuming a nightly cadence (C1) that allows to cover the peak time of KNe in both filters and well constrains the duration of the transient. As the cadence moves from nightly to 2 and 3 nights, the number of discovered KNe decreases by one order of magnitude for every type of KN model.

We conclude that with the proposed *gi* nightly-cadence strategy hundreds of KNe can be unveiled, adding $\sim$ 1 order of magnitude of events to the number of KNe that may be recovered with the current WFD strategy. This result would be independent from the functioning of GW detectors and from the success of follow-up campaigns of GW triggers.

New OpSim simulations of our proposed strategy would help us compute even more reliable numbers for expected KN discoveries. We plan on using the transientAsciiMetric[1] to generate light curves and measure the recovery efficiency for KN models and observed events.

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[1] `https://github.com/fedhere/sims_maf_contrib/blob/master/mafContrib/transientAsciiMetric.py`

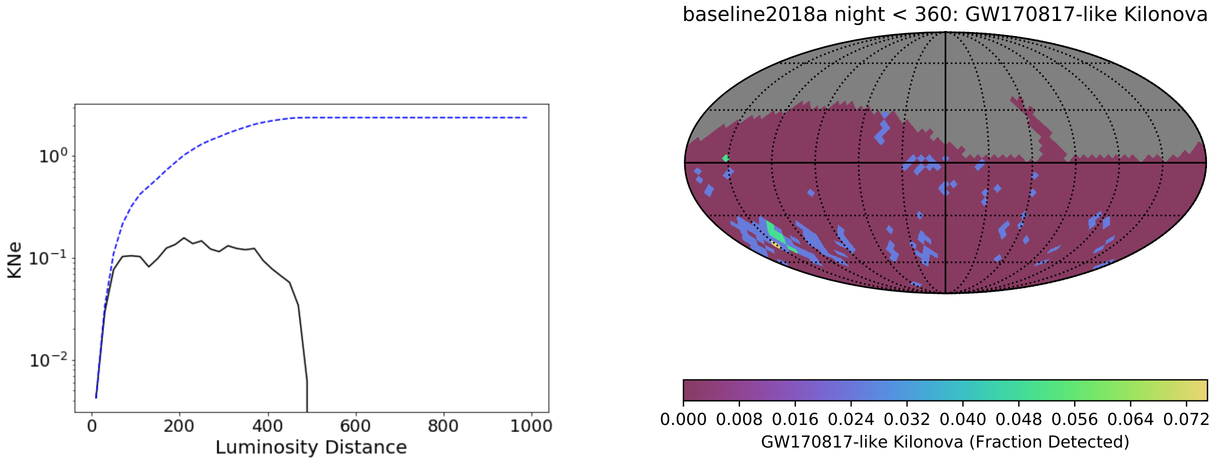

Figure 4: *Left* – Expected number of GW170817-like KNe observable during the 10-year survey in at least 2 filters with the current WFD design. The number of events are plotted survey as a function of luminosity distance in bins of 20Mpc. The black solid line represents the number of KN detections per bin, the blue dashed line represents their cumulative number, assuming a KN rate of R=800 $\mathrm{Gpc}^{-3}\mathrm{y}^{-1}$ (Kasliwal et al., 2017). *Right* – SkyMap representing the detection efficiency for KNe at a luminosity distance of 200 Mpc for 1 year of survey, under the same conditions described for the *left* panel.

5 Special Data Processing

Describe any data processing requirements beyond the standard LSST Data Management pipelines and how these will be achieved.

Each night's visits in each band should be stacked to increase depth.

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6 Appendix

Rates

Rates of binary neutron star mergers are still highly uncertain. Abbott et al. (2017b) estimate a binary neutron star merger rate R=1540^{+3200}_{-1200} Gpc^{-3} yr^{-1} based solely on GW searches. However, the lack of KN detection in past optical surveys constrains this rate toward its lower limit, placing 3σ upper limits to R $< 800\,\mathrm{Gpc}^{-3}\mathrm{yr}^{-1}$ for GW170817-like events and a more conservative value of $< 1600\,\mathrm{Gpc}^{-3}\mathrm{yr}^{-1}$ assuming that the typical KN is 50% as luminous as the GW170817 KN (Kasliwal et al., 2017). Assuming a upper limit R $< 800\,\mathrm{Gpc}^{-3}\mathrm{yr}^{-1}$, a total number of $\lesssim 23\,\mathrm{y}^{-1}$ binary neutron star mergers can be expected to occur within the LIGO horizon of 190 Mpc, only $\lesssim 15$ of which will be detectable due to the non-homogeneous antenna pattern of GW detectors and their duty cycle. Moreover, only a fraction of those will have a detectable electromagnetic counterpart, as some could be located too close to the Sun to observe with optical telescopes, or generate faint transients beyond the detection limit of available telescopes. In light of these limitations, the expected binary neutron star detection rate of 4-80 yr^{-1} events detected by the LIGO-Virgo-KAGRA network after 2020 based only on GW searches (Abbott et al., 2018) is likely going to provide only a few tens of events throughout the entire duration of LSST.