Supernova Science Cadence Note

This Cadence Note is intended to be a qualitative assessment of the seven questions posed by the LSST Survey Scheduler team, from the perspective of supernova science. This note was assembled by representatives of the LSST Transients and Variable Stars (TVS) Science Collaboration, and is co-signed by TVS members who support these statements.

Analysis of how observing strategies enable supernova science can also be found in, e.g., the TiDES Cadence Note (Frohmaier et al.) and the DESC's observing strategy analysis paper (Lochner et al. 2021).

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Q1: WFD Footprint

Are there any science drivers that would strongly argue for, or against, increasing the WFD footprint from 18,000 sq. deg. to 20,000 sq.deg.? Note that the resulting number of visits per pointing would drop by about 10%.

For all types of SN studies to be done with the WFD, number of visits per pointing is more important than total sky area. In other words, for LSST WFD, well sampled light curves have a bigger science impact than finding more SNe. This is because well sampled light curves provide a higher statistical significance for classifying SN types and analyzing their diversity, which is required for studies involving SN rates analyses, progenitor populations, and host galaxies. Well sampled light curves also improve the filtering applied to the alerts by the brokers by increasing and improving the training samples required by the machine learning classification tools.

Based on the plots provided in the Summary Information (link to Notebook on GitHub), at first it seems that the v1.5 "big sky" footprints would be good for SN science as they both increase the unextincted area and maintain or increase the median number of visits over the "best" 18000 deg^2. However, from the "Glance" MAF plots (provided at astro-lsst-01), it is clear that the northward extension of the WFD receives far fewer visits in all filters and, in some cases, no visits in the u, i, and/or y filters. So this northern extension of the footprint would not be as useful for SN science as the original WFD footprint, but, at least in these "big sky" versions the extension appears to have no negative impact on SN science within the original WFD region. From the Summary Information plots it does not appear that any of the v1.7 footprint runs would benefit SN science, as they all result in a decrease in the number of visits.

Considerations of potential indirect benefits to SN science from the northern extension, for example via improved photo-z estimates or photometric classification training sets, from overlapping with DESI areas are beyond the scope of this cadence note.

Q2: Distribution of time to DDF / Mini-Surveys

Assuming that current system performance estimates will hold up, we plan to utilize the additional observing time (which may be as much as 10% of the survey observing time) for visits for the mini-surveys and the DDFs (with an implicit assumption that the main WFD survey meeting SRD requirements will always be the first priority). What is the best scientific use of this time?

The DDF represent crucial opportunities for transient science that require either a higher cadence than the current WFD baseline, longer observation periods, or deeper observations. For all types of SNe, spending this additional observing time to extend the season length of the DDF observations will both increase the number of SNe detected, and provide longer term monitoring of SN light curves. Extending light curve coverage is especially useful for, e.g., the high-redshift time-dilated events such as Superluminous SNe in the early universe; lensed systems in which a reappearance is expected; or SNe with CSM interaction which can lead to long, slow light curve declines and unpredictable re-brightening phases. This time could also be used to increase the number of filters observed per night, which would allow for a region of the survey that could be more conducive to studies and obtaining follow-up of rapidly evolving events (e.g. infant supernovae with early-time features and fast evolving transients), events which are also well suited to the increased DDF cadence in general, as well as provide a ‘gold sample’ for lightcurve classifiers and archival datasets.

Of the proposed DDF cadence strategies proposed in PTSN-051, we suspect that the ‘daily’ cadence would be preferred due to the similar overall depth as the deep baseline cadence and reduced probability of long gaps between observations. These gaps tend to make prompt follow-up observations more difficult, and lower the quality of archival lightcurve samples. As the survey strategy document discusses, we want to highlight that currently "...we are also missing metrics; metrics reflecting classification confusion and detection requirements for transients." (PTSN-051 S.6.2) which are important for the DDF cadence evaluations, and also highlight that an end-to-end test of survey-cadence to transient event classification would be a useful exercise.

While the candidate mini-surveys extend the coverage of the survey, none of them have sufficient cadence or cover preferred regions of the sky to an extent that said mini-survey would enhance SNe science more than an extension to the DDF.

Q3: Exposure Times for u-Band

Are there any science drivers that would strongly argue for, or against, the proposal to change the u band exposure from 2x15 sec to 1x50 sec?

Obtaining individual u-band images that are ~0.5 mag deeper would increase the number of SNe with u-band detections, which would also increase the likelihood of detecting some rare phenomena in low-redshift SN light curves. For example, low-z Type Ia SNe with early blue excess from a non-degenerate binary companion star, or early shock breakout in low-z core collapse SNe. However, since the WFD number of u-band visits is about a third that in the griz bands (i.e., u-band has a low cadence), the overall science impact is not likely to be significant enough to overcome the detrimental loss of 5 to 10% of the number of visits in the griz filters, which will degrade the light curve sampling. For high-z objects (e.g. Cooke et al 2012 & Moriya et al 2019) there will be no u-band detections of the SN itself due to Ly-alpha absorption.

The resulting deeper coadded u-band limits could provide improved photometric redshifts (photo-z) for host galaxies -- and in particular limit the number of catastrophic failures in the photo-z estimates which are one of the largest sources of misclassification for current SNe lightcurve classification algorithms -- but this is unlikely to overcome the negative impact in the number of griz visits.

Q4: Observing Time Allocation Per Band

Are there any science drivers that would strongly argue for, or against, further changes in observing time allocation per band (e.g., skewed much more towards the blue or the red side of the spectrum)?

Q3 partially covered the potential benefits and drawbacks to low-z SN science of spending more time in the bluer band. Generally, more light curve points in the bluer bands provide a better chance of identifying low-z SNe that are young or peculiar, which are more valuable objects for follow-up (triggers for e.g., Swift UV, optical spectroscopy). Conversely, more light curve points in the redder bands would benefit higher redshift SNe, but due to time dilation, larger volume, and fainter apparent magnitudes, this would not have an appreciable impact on SN science.

Q5: Same-Night Visit Pairs (or Triplets)

Are there any science drivers that would strongly argue for, or against, obtained two visits in a pair in the same (or different) filter? Or the benefits or drawbacks of dedicating a portion of each night to obtaining a third (triplet) visit?

Many kinds of rapidly evolving (hour to day) transients will require immediate follow-up to leverage the Rubin LSST photometry towards a better physical understanding.
For example, rare subtypes of “fast and furious” explosive transients such as kilonovae or GRB optical afterglows, and fast-evolving, short-duration phenomena exhibited by otherwise normal supernovae such as shock breakout or signatures of ejecta interacting with a binary companion or circumstellar material.

Bianco et al. (2018) describes the “Presto-Color” strategy, and demonstrates how at least three observations per night are required in order to quickly identify such phenomena and trigger the necessary follow-up. Two observations in different filters obtained with a short time gap to provide a color, and one observation in one of those filters obtained with a gap of several hours (before or after) to provide the slope in magnitude (i.e., the rate of change in brightness). Scientifically valuable transients can be identified by their location in the color-slope parameter space.

Bianco et al. (2018) proposed metrics that evaluated OpSim runs based on the number of triplets of observations in two filters which satisfied the “Presto-Color” strategy. An evaluation of a family of third-observation OpSim runs that produce three observations in two filters within a night has been done, and is informative. However, these strategies did not constrain which of the three filters were done in pairs (for the color) or as the single (for the slope); always made the single-filter observation after the pair (resulting in high airmass observations which are generally less useful for everyone), and did not enforce the maximum and minimum time gaps.

Three observations within a night does not necessarily lead directly to a scientific gain for rapid transients unless the time gap constraints are enforced, and the griz filters are used (colors and slopes based on u and y photometry do not identify valuable targets as well). Bianco et al. (2018) propose a time gap of <30 minutes for the different-filter pair (for color) and at least 2 hours for the single-filter observation (for brightness change), and more recent studies suggest that a single-filter time gap of 4 hours is much more effective. Obtaining different-filter pairs with a >30 minute time gap does not provide true color information for fast-evolving transients, and obtaining the single-filter observation within 2 hours does not allow sufficient time for a change in brightness to be detected. Of course there are exceptions to every rule: for some types of fast transients a same-filter gap of <2 hours would reveal a brightness change.

As described in the survey strategy cadence choices document (ls.st/pstn-051; Section 6.2), a metric which performs end-to-end transient detection and classification and simulates the fidelity of identifying rapid transients for follow-up is needed in order to further discussion about "Presto-Color" strategies. Towards this end, the LSST TVS-SC is generating larger simulations of transients, both normal and rapid, to populate the color-magnitude phase-space and evaluate the time gap constraints. This will set the stage for end-to-end transient classification tests and a true transient metric which can evaluate the effectiveness of OpSim runs with third observations. However, this will not be ready for the Cadence Notes deadline (expected completion Fall 2021).

Q6: Rolling Cadence

Are there any science drivers that would strongly argue for, or against, the rolling cadence scenario? Or for or against varying the season length? Or for or against the AltSched N/S nightly pattern of visits?

A crucial ingredient to obtaining robust SN occurrence rates and the analysis of SN type demography is the accuracy of the photometric classifications, based on the LSST light-curves alone. In particular, high-cadence light curve sampling is imperative to obtain an accurate transient classification. We performed some simulations adopting as a metric the fraction of SNe with a correct photometric classification, and compared the values obtained for the baseline cadence and AltSched rolling cadence scenarios. The photometric classification drastically improves in a rolling search scenario for all SN types by reducing the contamination between different SN types with similar light-curves. For Type Ia SNe subtypes, the fraction improves from about 70% to 90%, up to redshift z=0.4, when a rolling cadence is adopted.

Monitoring a smaller area in a rolling cadence scenario could impact the discovery of rare events (i.e. the number of rare events with a single detection), however, these events without a well sampled light curve or spectroscopic classification cannot be properly identified anyway. Extending the season length helps us to discriminate the long-term variability of active galactic nuclei (AGN) from nuclear transients such as SNe or tidal disruption events (TDEs). Nuclear SNe are valuable signatures of bulge stellar populations and TDEs provide rare and valuable insight regarding supermassive black holes.

Q7: Dither Patterns

Are there any science drivers pushing for or against particular dithering patterns (either rotational dithers or translational dithers?).

There are no strong SN-related science cases that argue for or against particular dither patterns or rotations. However, the overlap regions in the tiling pattern are not insignificant; with a default hexagonal tiling pattern, the circular FOV led to ~16% overlap regions. This can be useful for either increasing depth, if adjacent tiles are observed close together in time, or increasing cadence, if there is a sufficient time difference in the observations of adjacent tiles allowing sources to measurably vary. Dither patterns add another layer to this. For SN studies, use of a rolling cadence strategy is the preferred method to increase cadence.