Rubin Cadence Notes - SMWLV+TVS synthesis

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Contributors

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Summary & Perspective

This document provides a synthesis to the SCOC of the cadence notes' recommendations from the point of view of SMWLV and TVS science. The overlap between SMWLV and TVS science is so substantial that both SMWLV and TVS submissions are considered here, for 24 cadence notes in total (extragalactic TVS science interests are indicated throughout). More detail can be found in the answers to the 7 SCOC questions below, here follow a few indications.

Sky coverage: A majority of these cadence notes argue for substantial coverage of the Milky Way (including the Magellanic Clouds (MC) and South Celestial Cap (SCP)), though differences are apparent in how best to accomplish this (whether to extend WFD or via minisurveys). Surveys that extend WFD down to the plane (in some cases without varying depth by extinction) tend to score better on Galactic structure and population metrics, but there are exceptions. As expected, science cases that trace the stellar populations in the Milky Way - at least half the cadence notes considered here - prefer that LSST points where most of the stars are found. It is important to point out that, for Milky Way science, "The Galactic Plane" does NOT just mean the *inner* Galactic plane: almost the same number of science cases emphasize the broader galactic plane as focus on the bulge. We note that the *negative* longitude region in the inner Galactic plane (at high declination) *is* among the priority areas for Galactic science (see the Street et al. Galactic footprint cadence note). A handful of cadence notes emphasize special regions of the sky, in some cases one or two LSST fields, or an additional DDF in the inner Plane.

Short exposures: Short exposure coverage to fill in the bright-end of LSST's dynamic range (e.g. COSEP 10.2, 10.3, Gizis 2018 cadence whitepaper), remains an additional orthogonal dimension that has received relatively little cadence exploration to-date, and SMWV/TVS science cases are among those for which short exposures may be the most important (but SSSC also likely has a strong interest here; e.g. COSEP Section 10.2). It is important to extend LSST's dynamic range by including shorter exposures in all filters and in all fields, though from where this time should be taken is unclear at present - using all the twilight time for short exposures would compromise parallax measurement and is not preferred.

Continuing work: A number of important areas of the LSST strategy still require further work for SMWLV/TVS science. These include (but are not limited to): the NEO/parallax tradeoff for twilight time; determining how many exposures and under what conditions is "good enough" for LSST provide a legacy survey in crowded regions; what metric output ranges are appropriate for globular and open cluster science. Some indication of these areas is provided in a separate section below.

Running the new metrics: One important outcome of the cadence notes process has been the development of new science metrics and new capabilities within the community to evaluate simulated strategies for Galactic science (such as the validation of spatial confusion metrics, and including 3D extinction). Now that the community has run these new metrics on a representative sample of opsims, it is important that the new metrics be run on all the opsims, centrally, so that the simulations can be compared on a uniform basis.

Additional strategy exploration: In several areas, the process of assessing survey strategies has uncovered areas in which additional opsims are required (short exposures being an obvious example, but by no means the only one). We plan to work with the OpSims team to specify additional opsims that will allow us to determine the various minima for the different strategies (including the special regions like star forming regions and the Roman overlap fields). We emphasize in particular that the metrics and figures of merit from the other science collaborations must also be run on the additional strategies, so that their impact on the key science cases for the project can be determined.

Responses to SCOC Questions

Q1: 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%. If available, please mention specific simulated cadences, and specific metrics, that support your answer.

Many Galactic science cases are improved by an extension of the WFD area, but it matters which areas are covered in the extension. Metrics tend to perform better for opsims that extend WFD to the regions of importance for Galactic science. The SMWLV/TVS collaborations attempted to quantify this by translating the set of 2018 cadence whitepapers into footprints of the highest-priority regions for Galactic science (Street et al. cadence note). Seven of the 24 cadence notes emphasize science in the bulge and five require the wider galactic plane. We recognize the efforts of the MAF team to include the Galactic bulge in several simulations but we highlight the importance of covering the Plane to many areas of science, as well as just the Bulge. Five notes focus on the Magellanic Clouds, highlighting the diverse science return from tracing the important stellar populations in the Milky Way. Additionally, important Galactic structure science drivers require covering as much of the Galaxy as possible, including the SCP.

The collaboration has not yet determined a minimum viable coverage to inform the tradeoffs regarding coverage of important Galactic regions (e.g. the extension of WFD over the entire Southern sky as per the gp_smooth opsim, is likely best for Galactic science but we recognize that tradeoffs are likely, as this particularly strategy currently violates SRD - further exploration is needed, including those opsims already generated to extend WFD to the Southern sky in an SRD-compliant way). We note that several of the Cadence Notes do offer alternative strategies to optimize the survey in the Galactic Plane if trade-offs are necessary.

<u>On average</u> (and there are exceptions), though, strategies that allocate more exposures to the regions containing more stars tend to perform better.

This is not unanimous - some science cases (particularly the extragalactic cases) do prefer to increase the area covered by the WFD regions, often pushing to regions of lower extinction than favored by

Galactic Plane science. Conversely, two science cases - TDEs and supernova detection - prefer to increase time coverage of the existing WFD region rather than expanding the area covered.

Q2: 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? If available, please mention specific simulated cadences, and specific metrics, that support your answer.

Based on the submitted cadence notes, it is crucial to ensure coverage of the bulge, and the wider plane, and the Magellanic clouds, *and* the SCP. It is more important that these areas be sufficiently covered than that they be identified with WFD or a mini-survey. (There may be an advantage in implementing these regions as mini-surveys due to increased flexibility to address the various tradeoffs - such as an altered filter balance - but this is probably an operational issue.)

We point out that coverage of the bulge at negative Galactic longitudes *is* valued by the science collaborations, enabling a variety of constraints on the relatively little-studied far-side of the bulge and inner plane, and we recommend that this region NOT be dropped from LSST's coverage if possible. (See, e.g. the Galactic footprint cadence note by Street et al. (which itself synthesizes recommendations from more than a dozen of the 2018 Cadence whitepapers that focus on Galactic science). In addition to scientific merit, the overlap with Northern-hemisphere surveys such as PanSTARRS will be beneficial for time baseline extension and cross-calibration (as was the case for DECam investigations of the inner bulge).

The collaborations have not yet settled on minimum coverage for the Galactic regions of interest - it probably depends on location. The coverage of the inner plane achieved in the current baseline simulation is not sufficient for most science cases that probe variable or transient populations (e.g. Buckley et al. accreting binaries cadence note).

Short-timescale variability science cases also require enhanced coverage. Rolling cadence can provide this for some of the science cases, but some minimum of observations must be reserved to ensure each field retains some coverage each year throughout the 10-year main survey interval. For several important science cases, special regions of enhanced coverage are required (e.g. star formation in Carina and other regions; e.g. synergy with the Roman space telescope for microlensing in the inner Plane) or even additional DDFs. If implemented, microsurveys of special regions would also enable alternate cadences that are tuned to the primary science of these regions (e.g. special cadence and epoch coverage to match Roman coverage; or early completion of high-frequency monitoring of star forming regions).

We note that alternative mini-surveys are also proposed in some notes, such as additional blue coverage for WFD for TDEs, surveying of selected blazars, or surveying the northern sky to Dec=+30, extending the sample of RR Lyrae and increasing extragalactic sample size.

Coverage of bright objects remains an important unresolved issue, and there is a likely minimum required coverage at 1s (or even 5s), in all filters, for every field observed by LSST. This coverage is required both to calibrate main-survey data, and to open up the bright end of the dynamic range of LSST for science. (It is likely that at least SSSC also has a strong scientific requirement for short exposures, e.g. Chapters 10.2 and 10.3 of the COSEP). It is not clear whether short exposure time should be taken from the WFD or from the minisurveys (or from engineering time or regular calibration observations if taken); it seems unlikely that twilight time alone will be sufficient.

Q3: 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? If available, please mention specific simulated cadences, and specific metrics, that support your answer.

Saturation - even in the u-band - is a concern for some science cases (e.g. Blazar variability; e.g. phenomenon-agnostic science cases such as anomaly detection). While the majority of science cases that address this issue prefer greater depth per exposure in u, we do recommend that a fraction of program exposures in u-band be kept at 2x15s to increase the dynamic range of the main-program exposures: particularly for the minisurveys, the same region could be observed with both sets of observing times. The best fraction of these 2x15s u-band exposures probably depends on latitude.

Concerns were raised that increasing the u-band exposure times would restrict the time available for observations in both this and other filters, and hence impact the cadence achieved.

If the project can guarantee recovery of point-source photometry brighter than saturation, the preferences might change. This issue probably requires additional iteration with the project, and may have to wait until commissioning observations have established how well objects above saturation will be recovered.

We note that several cadence notes assume that individual 15s u-band measurements will be made available to the community. It would be good to determine in what mode (and how often) these measurements will be made available.

Q4: 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)? If available, please mention specific simulated cadences, and specific metrics, that support your answer.

The default WFD filter-set enables the greatest range of science cases; SMWLV and TVS science cases cover the entire wavelength range LSST will probe. Opsims that sacrifice either end of the spectrum will disadvantage some science cases, and there is a likely minimum of coverage in {u,y}. A number of Notes advocated for higher cadence observations in {g, r, i, z}, particularly in regions of higher extinction; g-band observations are almost universally emphasized. That said, the scientific value of u-band observations was highlighted, including in the Galactic Plane to enable metallicity measurements. Higher cadence observations in blue bands {u,g} were considered to be essential for the characterization of TDEs as well as young stars. This is somewhat in tension with the needs of brown dwarf science, which requires {r,i,z,y} filters.

Q5: 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? If available, please mention specific simulated cadences, and specific metrics, that support your answer.

Pairs: Most cadence notes that address the issue tend to prefer pairs in different filters than pairs in the same filter (RR Lyrae tracers being an exception). There is some tension between the cases as to which filters are preferred, with the optimum for SMWLV/TVS science likely depending on location; for example, for fields including star forming regions, {g,r,i} filters seem to be preferred, but for high-energy phenomena like accreting binaries, {u,g,r} is preferred. Further work is required to test opsims that implement fractional allocations to these two filter-sets, for the different science cases. A logarithmic distribution of time gaps is probably preferred for many science cases, particularly in opening up the minutes-hours window for variability, as advocated by at least two cadence notes.

Triplets: most notes did not express a strong preference for triplets over pairs - in most cases where this was mentioned, it was in the negative (in that allocating a triplet in a given field could reduce the total area covered at rapid cadence in a given night).

Other: some science cases expressed a need for higher-cadence monitoring. These mostly fall into the category of special spatial regions (e.g. higher-cadence monitoring of star-forming regions).

For about half the cadence notes, no preference was expressed regarding the distribution of visits within a night.

Q6: 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? If available, please mention specific simulated cadences, and specific metrics, that support your answer.

Rolling cadence: Notes focusing on Galactic science pointed out that, while the rolling cadence is in general beneficial for characterizing time domain phenomena, the length of the rolling cadence season can impose critical constraints on the phenomena to be studied. For example, seasons shorter than 1yr will strongly impact the detection of microlensing by black holes, and the characterization of long-term variables (like Miras) and transients (like Soft X-ray transients and dwarf novae). Galactic structure research is primarily concerned with the total number of visits rather than their distribution (assuming certain conspicuous tracers like RR Lyrae are well-measured: several cadence notes develop this further), but the value of obtaining short exposures for all pointings annually was also emphasized. It is probably necessary to reserve a fraction of the exposures in each filter to maintain quasi-uniform monitoring over the entire ten-year time baseline of the survey. Further work is required to determine what fraction to reserve (and what filter balance to apply to rolling cadence; {g,r,i} seems most likely, but we do not yet have quantitative constraints on this).

For some science cases, rolling cadence offers the best opportunity to measure phenomena at short timescales, or at timescales currently missing from most planned strategies (e.g. Andreoni, Bellm cadence notes).

Where tested, AltSched implementations tend to perform worse than baseline for many cadence notes, but this requires further exploration at present.

Q7: Are there any science drivers pushing for or against particular dithering patterns (either rotational dithers or translational dithers?) If available, please mention specific simulated cadences, and specific metrics, that support your answer.

For astrometry, dithers need to be statistically uncorrelated with parallax factor and DCR.

Most cadence notes did not express a strong preference for or against dithering; those that did, generally indicate that rotational or large translational dithers tend to improve the science. There is a possible tension between science cases towards the Magellanic clouds (e.g. the MC periphery studies prefer large and/or rotational dithers, while the search for interstellar scintillation towards the MCs seems to prefer dithers of a few pixels).

Most of the science cases in SMWLV/TVS cadence notes are concerned with point-source photometry, so a dither pattern that mitigates the impact of bad pixels is assumed. Commissioning observations are likely to be crucial for understanding how best to dither LSST to support point-source flux recovery.

Rotational dithers are probably preferred for fields containing bright foreground objects (so that the bleed can be rotated within the image stack and thus averaged through). Whether this is needed, and how well this works in practice, probably requires commissioning observations to address.

Continuing cadence work

In some cases, the investigations were not sufficiently complete by the 2021 April 15th deadline to be submitted as a cadence note. A sample of these areas, mostly identified from the cadence notes, is provided below. This is unlikely to be a comprehensive list: these active investigations may uncover future directions and opportunities for increased observing efficiency, that we have not yet considered. The intention is for these investigations to reach a point at which the SCOC can be furnished with updated constraints, during (Northern hemisphere) Summer 2021.

Topic	**Comments**
Confusion-limited legacy survey: determine the minimum exposure set required at which LSST hits the confusion limit for good seeing.	A new metric for the confusion limit for color has been developed (by KO) and now needs integrating into sims_maf and running on simulated strategies.
Parallax-DCR degeneracy and the best usage of twilight time	The Gizis et al. brown dwarfs cadence note addresses the tradeoffs for twilight time usage somewhat. It is already clear that using all the twilight time for NEOs would be very bad for parallaxes.
Distance indicators for Magellanic clouds (and other) structure from variable star lightcurves.	More detailed conclusions are expected by the end of Q2, 2021.
Globular cluster and open cluster science	It is likely that metrics already developed can address this, but the thresholds need to be determined.
Reducing aliasing in period recovery for variable objects	Upgrades to figures of merit for variables, in addition to proposals for new opsims to address aliasing.
Which pairs of filters are most valuable for color measurements from paired visits	The TVS and SMWLV stellar variability sub-groups are well-placed to address this question.
Verify assumptions about the ability to remove the contaminating foreground star and background galaxy population with the matched filter approach; simulate survey performance at a variety of spatial scales and shapes; evaluate recovery of variable stars; determine optimal filterset for detection and characterization of dwarf galaxies	Basic results are expected during summer 2021, but more detailed work may continue into commissioning.

Cadence notes considered here

	SMWLV-led		TVS-led
1	Carlin et al: A resolved census of dwarf satellites around Local Volume galaxies	7	Abrams et al: Microlensing Discovery and Characterization Efficiency at Different Timescales
2	Clarkson et al: Saturation and Bright Objects	8	Andreoni et al: Maximizing Serendipitous Kilonova and Fast Transient Discovery
3	Clarkson et al.: Bulge stellar populations with LSST	9	Bachelet et al: On the observational synergies between all-sky surveys for the characterization of microlensing events.
4	Gizis: Brown Dwarf Astrometry	10	Blaineau et al: Microlensing towards the Magellanic Clouds: searching for long events
5	Olsen et al: A census of dwarf satellites and substructure around the Magellanic Clouds	11	Bellm et al.: Give me a few hours: Missing Timescales in Rubin Cadence Simulations
6	Prisinzano et al: Maximizing volume and uniformity coverage of star forming regions in the Galactic Plane	12	Bonito et al.: Young stars and their variability with Rubin Observatory LSST
		13	Buckley et al: Accreting Binaries
		14	Graham et al: Supernova Science
		15	Hernitschek & Stassun: Cadence impacts on reliable classification of standard-candle variable stars, including detection of amplitude, period, phase modulation effects (e.g. Blazhko effect)
		16	Hundertmark et al.: Alerting transient phenomena in the Galactic Plane in time to coordinate follow-up
		17	Li et al: Anomaly detection
		18	Moniez et al: Detection of interstellar scintillation by high frequency imaging of the LMC or SMC
		19	Musella et al: Classical variable stars in different Galactic environments: pulsation behaviour recovery.
		20	Raiteri et al: Blazar Variability
		21	Street et al: LSST Survey Footprint in the Galactic Plane and Magellanic Clouds
	AGN-led	22	Tisanic & Palaversa: Simulations of multiband Lomb-Scargle-derived variable star periods
24	Kovacevic et al: Two metrics on AGN variability observables	23	Van Velzen et al: Tidal Disruption Events