Rubin Cadence Note - Saturation and Bright Objects

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Contributors

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Motivation

Unsaturated measurements of bright objects are key to maximizing the science return of the Rubin Observatory LSST, for at least three reasons:

1. Essentially all LSST fields at the program exposure length (of 2x15s or 1x30s), will include objects so bright that they heavily saturate and exhibit charge bleeding on the detector. Measurements of these objects at shorter exposure times, *with the same detector*, (and not limited to commissioning time) are essential so that the evolution of their impact on the majority-faint objects can be quantified and mitigated.
2. Unsaturated observations of very bright objects will allow LSST observations to be tied to external catalogs that primarily measure bright objects but at higher cadence than LSST.
3. For a number of science cases - particularly those observing populations within the Milky Way galaxy (e.g. tracing Galactic populations with RR Lyrae or Red Clump giants), but also including extragalactic flaring objects like blazars, or asteroids at or near opposition - the important tracer objects are usually or can become sufficiently bright that they saturate at LSST's program exposure time.

For more detailed motivation, see Gizis et al. 2018 and Chapters 10.2 (by Trilling & Jones) and particularly chapter 10.3 (by Stubbs) in the COSEP (Marshall et al. 2017).

Recommendations

1. We recommend multiple short exposures in all filters in all sight-lines. Our current recommendation is for at least 5 short exposures at 2 seconds each in all filters (Figure 2 & Figure 3), but more work is still required to determine the best combination (and how best to distribute short exposures on the sky; Figure 4). Sets of short exposures at *both* 2s and 5s would probably be best, but the impact of such a strategy requires exploration.

2. Some short exposures should be taken in non-twilight time, and substantial twilight time should be reserved for parallax measurement.
3. For the program observations, 2x15s exposures are generally preferred over 1x30s for all filters, because they increase the project sensitivity to bright, variable phenomena. See Figure 1. To mitigate the reduction of total number of observations at 2x15s as compared to 1x30s exposures, however, a hybrid strategy may be preferred in which 2x15s are used for the minisurveys and possibly for fields with the brightest known extragalactic variable objects, but 1x30s in all other regions.

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.

Not as long as time is still available for short exposures.

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.

At least some of the additional time should be spent improving the short-exposure-time coverage of regions likely to include a large population of bright foreground objects or for which the tracer population is already at or near saturation in the program exposures. The obvious candidates are the Galactic plane (the whole plane at |b| < 10 degrees or so, and not only the bulge), but also any fields away from the plane for which bright foreground objects are known. The simulated cadences that include short exposures all perform *substantially* better for bright-object coverage than do either baseline program, under the metrics indicated above: the **short_exp_?ns_?expt_v1.5_10yrs** are preferred because they offer short exposure coverage in all six filters (the **twilight_*** runs do not provide good short exposure coverage at short wavelengths).

However, there are tradeoffs against the total time allocated to mini-surveys (for example: if **short_exp_2ns_1expt_v1.5_10yrs** allocates 0.5% of the total survey time to short exposures while **short_exp_5ns_5expt_v1.5_10yrs** allocates 5% of the total, then the impact on the other minisurveys would be severe in the latter case if all that 5% were taken out of the total allocation to minisurveys). We argue that short exposures need to be taken over the entire LSST survey region to better calibrate the main survey and improve the tie to external catalogs (motivations 1 & 2 above) - and thus short exposure time should not be taken solely from the minisurvey allocation. But the tradeoffs need further exploration: at this date we are not able to make a firm recommendation about which of the short exposure strategies offers sufficient coverage of bright objects while minimizing the impact on the rest of the minisurveys.

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.

Cases in which bright transients are expected in u-band would argue *against* a change to 1x50 seconds for u-band. In the Milky Way, this would include cataclysmic variable eruptions or a Galactic supernova. Away from the mid-plane, Blazar variability is another science case for which a switch to 1x50s in u-band would not be preferred. For example, the median saturation mag of the **u_long_ms_50_v1.7_10yrs** run peaks around 14.4 mag, about 1.3 mag fainter than in the 2x15s case. Just a few blazar outbursts are expected to be brighter than 14.4 mag in u-band, but these are the most interesting ones, which can trigger follow-up observations at high and very high (TeV) energies.

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.

Not as long as individual exposures do not saturate for program stars of interest, or if short exposures are available to calibrate the photometry for objects that just exceed saturation.

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.

The better bright objects are covered by short exposures (temporally and in terms of filter coverage), the better the science yield at the bright end. Two visits in a pair in different filters is likely preferred for most science at the bright end, since it allows a snapshot of the color for objects that are currently at saturation in longer exposures. Any calibration of long exposures by short exposures will also benefit from a color in the short exposures, ideally as close to simultaneous as possible. However, more exploration is required at this date as to which pairs of filters are preferred.

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.

Short exposures should be taken at least a few times every year: we recommend they be decoupled from rolling cadence so that a roughly uniform epoch distribution of short exposures throughout the 10-year main survey time baseline is maintained.

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.

Not from the perspective of bright-object coverage.

Figures of merit & Tradeoffs

We quantify our recommendations below. In addition to the standard metrics run by the project, we employ the following figures of merit:

- Saturation apparent magnitude: At each healpixel, the apparent magnitude is computed that corresponds to saturation, in each filter, for the shortest set of exposures that exist in the opsim at each sight-line. The number of sight-lines for which this saturation magnitude is fainter than a specified target magnitude is then computed, weighted by the number of stars per square arcminute in each sight-line. See Figure 1. Larger values are better.
- Saturation volume: For each healpixel, the minimum distance (in parsecs) is computed at which a typical Red Clump Giant would saturate in LSST, with the minimum taken across filters {g,i,z}, at the shortest set of exposures that exist in the opsim at each sight-line. This distance is converted into the volume within which an RCG would be saturated in any of {g,i,z}. Smaller values are better. See Figures 2 & 3.

Tradeoff between 2x15s exposures and total NVisits: For the choice of program exposure time, there is some tension between recovery of objects at the bright end and the total number of visits allocated to a given pointing (with 1x30s affording about 7% more visits to a given pointing over the survey lifetime, e.g. PSTN-051; Jones et al. 2021). If the 7% reduction is applied to all areas of the sky equally, then the impact on the mini-surveys is likely to be low (see the proper motion and NVisits columns in the table below for **baseline_nexp1** and **baseline_nexp2**). However if the 7% reduction is to be taken entirely from the minisurveys, then more work is needed to determine the thresholds for coverage for bright objects and for total allocation to the minisurveys.

This is a complicated issue and we do not yet have a detailed recommendation. One compromise might be to allocate 2x15s for regions in the sky in which a large bright foreground population is expected (such as the Plane) and to regions near the brightest known blazars (e.g. in the BZCAT5 catalog), some of which are possible neutrino sources, and to use 1x30s throughout the rest of the WFD region. (What does seem clear at present is that adoption of 1x30s program exposures would sharpen the need for short exposures.)

Tradeoff between short and program exposures: The short exposures have to come from somewhere in the total allocation, and the tradeoffs against other science metrics need exploration. We hope to explore versions of short exposure allocations during 2021: for the present, we compare two metrics that are sensitive to the total allocation at the program exposure time (2x15s) in the table below: the proper motion accuracy metric, which is sensitive to the time distribution of observations along the main survey time baseline; and the visit count (to afford sensitivity to variability).

Tradeoff with astrometry: When short exposures are taken during twilight time, a tension arises in principle between the need to provide full dynamic range for photometry via short exposures, and the need to cover as much of the parallax ellipse as possible (which requires observations of objects just rising or just setting at twilight). None of the opsims that offer short-exposure coverage seem to include a sufficient amount of twilight time for short exposures to strongly negatively impact the parallax coverage, although there is some indication the Parallax-DCR degeneracy may be worse for opsims that do include short-exposure coverage. Some example values follow.

Opsim	**ParallaxCoverage Metric at r = 22.4 (median)**	**Parallax - DCR degeneracy at r = 22.4 (median)**	**Proper motion precision at r = 20.5 (mas/yr)**		**Number of visits at >= 15 seconds (in r-band)**	
			WFD	**GP**	**WFD**	**GP**
baseline_nexp2_v1.7	0.49	0.18	0.18	0.35	194	42
baseline_nexp1_v1.7	0.50	0.20	0.18	0.35	211	43
short_exp_5ns_5expt_v1.5_10yrs	0.53	0.36	0.18	0.40	213	29
twi_neo_pattern1_v1.7_10yrs	0.45	0.27	0.20	0.38	167	39

Figures

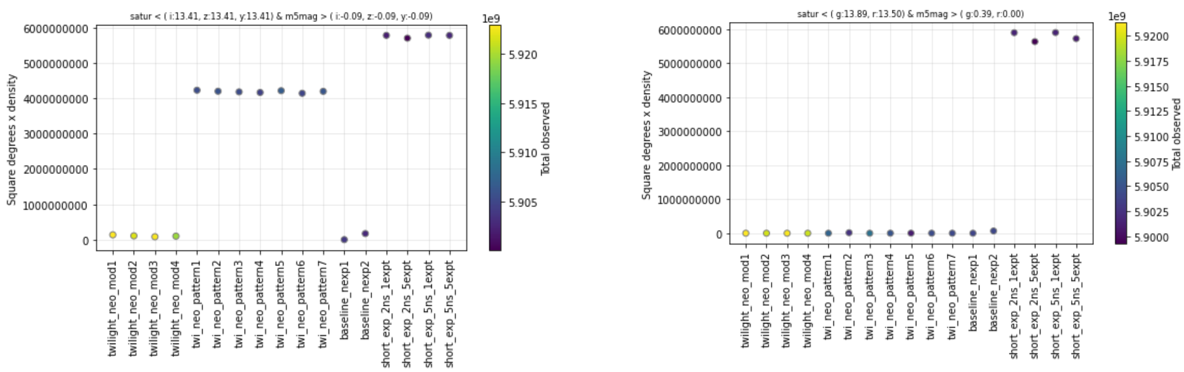


Figure 1: “non-parametric” saturation figure of merit, showing the number of objects observed in regions at which the saturation level (at median seeing) is brighter than the apparent magnitude of a G-type star seen at r = 13.5. Calculated using a version of this notebook. **Left panel:** condition must be met in {i & z & y} filters. **Right panel:** condition must be met in {g & r} filters. _Both baseline simulations offer essentially no coverage in this brightness regime_, and the performance of the opsims including short exposures is somewhat mixed: as might be expected, the **v1.7/twilight_neo** family of opsims does not offer short exposure coverage in g-band, and most of the difference in figure of merit at {i,z,y} for nonzero coverage, is due to differences in coverage at large negative declination. Only the **v1.5/short_exp_?ns_?expt** family of opsims meets the criteria in all of {g,r,i,z,y}. Larger FoM value is better.

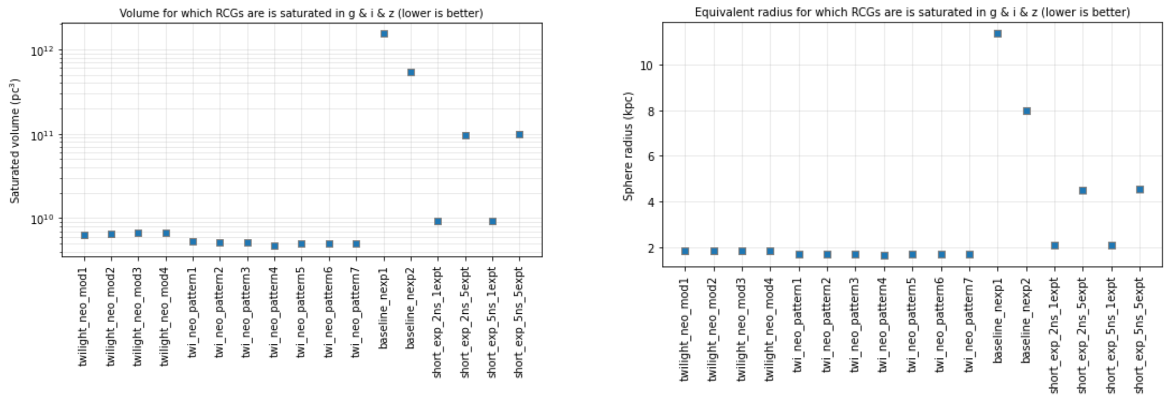


Figure 2: Volume within which a Red Clump Giant (RCG) would be saturated in any of {g,i,z}. Smaller values are better. This is expressed as a volume (left panel, log scale) and as the radius (in kpc) of a sphere with the same volume (right panel, linear scale). For indications of the spatial dependence of the saturation distances, see Figure 3.

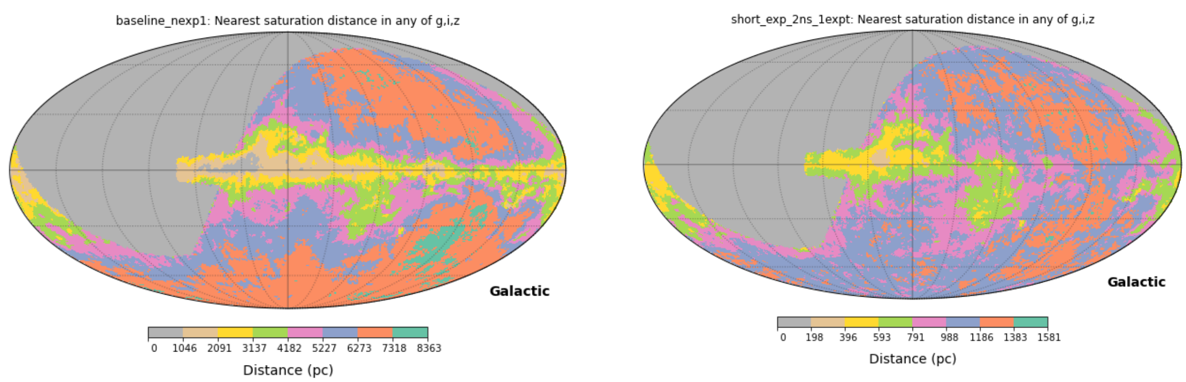
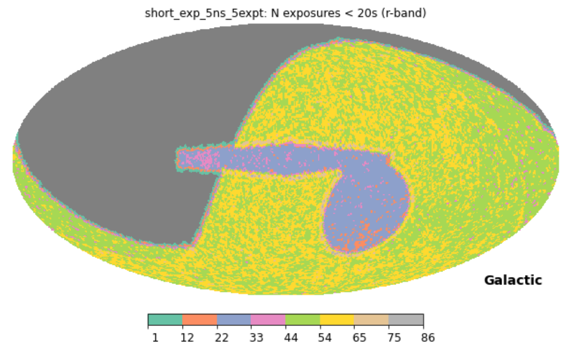


Figure 3: Spatial dependence of the distance-to-saturation for Red Clump Giants (RCGs; absolute magnitude M_r = +0.55; Ruiz-Dern et al. 2018), accounting for variable extinction along the line of sight at each pointing. The closest distance to saturation in any of the filters {g,i,z} is shown: lower numbers are "better." These figures were produced using a version of this notebook. *Left panel:* the v1.7 baseline strategy but with 1x30s exposures. *Right panel***:** an example strategy that includes short exposures in each filter (here, v1.5/short_exp_2ns_1expt). For the "long" exposures, the 2x15s is preferred over the 1x30s strategy since it opens up more of the Galactic disk to monitoring with the majority of the exposures. In addition, inclusion of short exposures allows RGCs to be observed much closer to the observer, in all sight-lines.

Figure 4: Counts of exposures shorter than 20s in each healpixel, for opsim **short_exp_5ns_5expt**. Areas of the sky with a likely higher count of saturated objects are covered roughly a factor two *less* well by short exposures. Further work is required to quantify the scientific impact of the distribution of the short exposures on the sky.



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