LSST Cadence Note for Accreting Binaries

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1 Introduction

Cataclysmic Variables (CVs) entail such a wide range of variability (outbursts on non-periodic timescales of days to decades, orbital periods of tens of minutes to hours, high and low states from days to months or years, amplitudes of variation from 15 magnitudes (novae) down to 2-9 mags for dwarf novae and 2-5 mags for eclipses and high-low accretion state variations) that it is virtually impossible to designate one cadence that will fit all science objectives.

Low Mass X-ray Binaries (LMXBs), with a black hole or neutron star compact primary, share some characteristics with CVs, particularly when it comes to the nature of the companion stars (typically K-M dwarfs) and the orbital periods, though the LMXB distribution generally extends to longer periods. Accretion driven outbursts are also typically much rarer than CVs and also generally higher in amplitude. Their spatial distribution in the Galaxy is similar to CVs, with a concentration towards the Galactic plane, though their space densities are much less than CVs. The compact object masses have been confirmed in only about 30 systems, based upon dynamical measurements, though their true census is thought to number several orders of magnitude higher (Corral-Santana et al. 2016 A&A 587 61).

Understanding the physical characteristics and the growth processes of these accretion-driven binary systems is key for many areas of astrophysics from star-formation, energy feedback, to gravitational wave astronomy. This cadence note will focus on two primary science objectives for both CVs and LMXBs: 1) to optimize the discovery and characterisation of all types of CVs and LMXBs to gain a better understanding of their population in our Galaxy, 2) to optimize the discovery of unusual systems, such as those containing highly magnetic white dwarfs, novae and systems entering low states so that followup observations can be obtained while the system remains in the unusual state.

The population study will require increased observations in the galactic plane over that involved with WFD. The plan put forward by the LSST Survey Footprint in the Galactic Plane and Magellanic Clouds Cadence Note (Street et al.) will serve much of our purpose.

To this end, we have run simulations that aim to determine the fraction of accreting sources in outburst that can be detected over the course of the 10 year survey. We also performed a simulation to determine the number of accurate $u-g$ and $g-r$ color calculations that can be made across the 10 year survey footprint, since the color information measured during outbursts are important for characterising SEDs of accreting sources and too few color measurements will have a detrimental effect on the science that can be performed.

2 Methodology of the Study

For our simulations we created a typical CV outburst light curve as exhibited by a Dwarf Nova. This was partly informed from our study of newly discovered CVs from the Catalina Real Time Survey (CRTS). The parameters for these light curves include the amplitude of the outburst and the outburst length, which were in the range $2 < \Delta m_g < 8$ and $7 < t < 20$ days respectively. In addition we assumed a typical thermal SED characterised by a blackbody spectrum with a temperature between $6000 < T < 8000$ K and quiescent magnitude between $16 < m_g < 23$. While this is a simplification, particularly for highly obscured regions of the Galactic plane, we believe it suffices for the MAF analysis from the perspective of simple detection.

Two metrics were considered for this Cadence Note. The first, which is a detection metric, uses simulated light curves with intrinsic variability and a single random outburst on random coordinates in the survey footprint, and tries to detect at least 4 consecutive data points or 2 consecutive data points in at least 2 filters above 3σ of the quiescent light curve's standard deviation.

The second metric, determines if 2 user-specified filters are observed close enough in time, throughout the survey period, to calculate an accurate color. This metric is useful to determine if the color space can be sufficiently sampled, which is especially useful for sources with rapidly evolving SEDs. These two metrics were run on 3 cadence sets released in OpSims 1.7 and the additional OpSims 1.7.1 that work best for our science goals. These 3 cadence sets are `new_rolling/full_disk_v1.7_10yrs`, `baseline_nexp2_v1.7_10yrs` and `rolling_scale0.9_nslice3_v1.7_10yrs`. Figure 1 displays the output of these 2 metrics, both run on the `new_rolling/full_disk_v1.7_10yrs` cadence set, run as part of the new OpSim 1.7.1 that aims to explore denser coverage in the galactic plane. These 2 metrics are still under development and will be submitted to the external mafContrib metric repository, hosted on `https://github.com/LSST-nonproject/sims_maf_contrib`.

3 Survey Footprint

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 speci c simulated cadences, and speci c metrics, that support your answer.

Our science is best served by using the current WFD and adding in smaller surveys of the plane and the Magellanic Clouds.WFD is good for picking up all CVs, with the galactic plane (e.g. the microlensing areas) good for increased numbers to get correct population statistics, simulated with the `baseline_nexp2_v1.7_10yrs` cadence set. Rolling cadence is good for picking up fast novae and other shorter timescale variations, simulated with the `new_rolling/full_disk_v1.7_10yrs` cadence set.

Increasing the footprint would allow discovery of more systems. A non-negligible fraction of LMXBs are known to lie at relatively high Galactic latitudes, possibly spatially scattered by natal kicks imparted during supernova explosions. Sampling outside the plane would discover more of these rarer systems.

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 rst priority). What is the best scienti c use of this time? If available, please mention speci c simulated cadences, and speci c metrics, that support your answer.

The minisurvey of the Magellanic Clouds will be important for picking up novae and related super soft X-ray sources, which are also a class of accreting White Dwarfs which undergo outbursts. Most CVs will be too faint for detection, however.

4 Exposure time per visit

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 speci c simulated cadences, and speci c metrics, that support your answer.

Exposures of 1x50 are good for sources with high extinction in the galactic plane, while 2x15 can extend to brighter mags, so ideally the choice would depend on the Galactic latitude. Also, the best value of u would come from more measurements that are spread over different outburst states than the value from coadded depth.

5 Allocation of observing time per band

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 speci c simulated cadences, and speci c metrics, that support your answer.

Notwithstanding reddening, most outbursting CVs are intrinsically blue, due to a hot WD and accretion disk, so an ideal color would be $u - g$. However, with restricted availability of the u filter, the best alternative would be $g - r$. u band could be useful in higher Galactic latitude fields which are less extincted. Use of u also has an advantage for the saturation limit. Higher cadence in g, r, is optimal over z and i.

6 Time sampling and revisit offsets

Q5: Are there any science drivers that would strongly argue for, or against, obtained two visits in a pair in the same (or di erent) lter? Or the bene ts or drawbacks of dedicating a portion of each night to obtaining a third (triplet) visit? If available, please mention speci c simulated cadences, and speci c metrics, that support your answer.

Colors ($u - g$ or $g - r$) will be very useful for differentiating CVs from other types of variables. A triplet visit observation is less useful. With the current cadences available, there are very few observation windows over the 10 year survey period where a reliable $u - g$ can be measured, and is especially true when measuring $u - g$ colors for rapidly changing systems, see Fig: 1

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 speci c simulated cadences, and speci c metrics, that support your answer.

The WFD is better to pick up all CVs and LMXBs for population studies, while a rolling cadence is better for discovering novae and fast changes in high-low states for immediate followup by ground and space observatories.

Since the most numerous CVs (and many LMXBs) only outburst on decade timescales, a minimum cadence is needed throughout the 10 yrs to maximize the discoveries.

Maintaining long-term (approximately) uniform sampling of the Galaxy will substantially enhance binary orbital period characterisation capabilities. Johnson et al. (2019 MNRAS 484 19) have shown through dedicated simulations that cadencing strategies where the Galactic plane coverage is maintained over the lifetime of the survey can boost measurements of binary periods from light curves by factors of several. This holds for a very wide range of parameter space (quiescent r mag ranging from 16–23, and orbital periods ranging over 0.01–100 days). The simulations of Johnson et al. were carried out for LMXBs, but the period characterisation is expected to be similar for CVs. Only about 30% of known and candidate LMXBs currently have measured orbital periods. Period measurement is a crucial step in dynamical mass confirmation, so long-term Galaxy coverage will substantially enhance the completeness of compact object mass measurements in Galactic binaries.

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

No