On the observational synergies between all-sky surveys for the characterization of microlensing events.

Etienne Bachelet, Rachel Street, Las Cumbres Observatory
Somayeh Khakpash, University of Delaware
Natasha S. Abrams, R. Di Stefano, Harvard University.
Yiannis Tsapras, University of Heidelberg,
TVS Microlensing Group

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1 Introduction

The Rubin Observatory will deliver an unprecedented survey that will, by itself, transform many fields in astrophysics. But it will not exist in isolation. A number of other major new space-based wide-field survey facilities will be operating contemporaneously that will offer complementary capabilities, such as near infrared (NIR) wavelength imaging. It is valuable to consider whether coordinating the survey strategies between these great observatories can enhance the scientific return for all concerned.

In this Cadence Note, we focus particularly on the Roman Galactic Exoplanet Survey (RGES) region in the Galactic Bulge as this is most closely aligned with our science interests, but we note that the scientific potential of coordinated observations extends to other key Rubin science drivers and to other Missions, so we advocate for broad discussions between Rubin and other survey facilities, including both galactic as well as extra-galactic science.

The Roman Space Telescope will conduct intensive ($\sim$20 min cadence) photometric monitoring of $i \sim$19–25 mag stars in the RGES 0.281 deg^2 field in NIR passbands. Due to spacecraft pointing constrains, it will observe the Bulge for a total of $\sim$432 d spread over 6 'seasons' of $\sim$72 d each, spaced out by gaps of several months. The goal of the survey is to discover bound and free-floating exoplanets via their microlensing signatures [1, 2]. In [3] we proposed an observing strategy where Rubin would deliver highly valuable complementary data, by monitoring the RGES field in the same timeframe as Roman. There were two elements to this strategy:

- Simultaneous observations: Rubin observes the RGES footprint every 30 min for $\sim$2–4 hrs/night during Roman survey seasons to measure the microlensing parallax for free-floating planet events, a critical parameter to enable the mass of the lenses to be determined. We proposed that these observations use an "alternating-i" strategy, interspacing i-band images with g, r, z observations to provide color and stellar variability information
- Off-season observations: Rubin observes the RGES footprint with a $\sim$3-day, WFD-like strategy, again cycling through a limited filterset (g, r, i, z). Many microlensing events will exceed the RGES seasons with timescales up to $\sim$300 d. The RGES lightcurves for these events will be incomplete, missing valuable information and reducing the number of planets that can be discovered from anomalies in the lightcurves. Rubin can fill these gaps.

Street et al. [3] emphasized that the resulting combined dataset would be revolutionary not just for exoplanet science but also for many other aspects of stellar astrophysics. The optical LSST passbands combined with the NIR Roman imaging can be combined to deliver excellent characterization of all objects within the survey field. This is ideal to understand the interstellar extinction of the fields, and to properly measure the source properties and determine the degree to which the source is blended with nearby objects (potentially including the lens). We note that the Science Advisory Committee (SAC) report highlighted synergistic observations with other surveys as a capability that needed to be added to OpSim [4].

2 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.

The RGES field lies outside the region that the WFD covers at regular ($\sim$3 day) cadence, and receives a lower number of visits that the average for the main survey region in the baseline_v1.5_10yrs simulation, with much larger values of the Median Inter-Night Gap metric. Comparing this with the bulges_bulge_wfd_v1.5_10yrs simulation, including the Bulge in the WFD survey dramatically improves the Median Inter-Night Gap and total number of observations.

However, we note that further optimizations are possible. Firstly, simply applying the WFD filterset and cadence to the Galactic Bulge places greater emphasis on bluer filters than required for galactic science (g, r, i, z are preferred). So we advocate for regular monitoring in a reduced filterset, with less frequent observations in u, y. It is unclear to the authors whether it would be simpler in practise to implement this as a modification of the WFD strategy or as a distinct survey, so we leave that decision to the MAF team.

Secondly, while observations of the Bulge are always valuable, they would be *most* valuable if they were concentrated in years when RGES is also operating.

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.

We propose that Rubin monitor the RGES survey field with a $\sim$1-3 d cadence in g, r, i, z throughout the years when Roman will also be observing the field. A minimal survey that serves most of our science goals would include a **single Rubin pointing towards the RGES field**.

Serving the remainder of our science goals would involve including high cadence observations (every 30 min) in i-band alone for the $\sim$1–4 hr windows on the limited number of nights when the field is visible to both Rubin and Roman.

As outlined in [3], we recommend the metrics (available from the TVS public Github repository) optimize-bulgeddffootprint.py[1] to select the footprint for this survey, and we developed the following metrics to help to evaluate the coordination between the survey strategies: numObsInSurveyTimeOverlap, CadenceOverVisibilityWindow. We recommend minimizing the IntervalsBetweenObs metric. We note that normalizing the output of the numObsInSurveyTimeOverlap and IntervalsBetweenObs metrics will required further analysis to determine the minimum sampling required to both measure parallaxes and detect anomalies and we anticipate completing this analysis by the end of Q2, 2021.

However, we acknowledge that Rubin alone cannot coordinate its observations with another survey – that requires Project-management level discussions involving both Rubin and Roman, and more concrete details of exactly when the RGES will take place. **We cannot properly evaluate whether any of the observing strategy experiments conducted so far would benefit our science until such discussions take place**. Bearing in mind the time pressure for Rubin to determine its strategy, and the support for coordination expressed by Roman Senior Project Scientist, we take this opportunity to encourage such discussions to take place at the earliest opportunity.

3 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.

[1] https://github.com/LSST-TVSSC/software$_tools/blob/master/optimize_bulge_ddf_footprint.py$

The extinction towards the Galactic Bulge makes the stars very faint in the u-band. Therefore, it would be beneficial to change the u-band exposure from 2x15s to 1x50s.

4 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.

At minimum, our science requires r- or i-band timeseries imaging. Multi-band imaging in g, r, i, z, with a strong emphasis on i is most beneficial as the timeseries color information can be used to measure the blending of microlensing source stars in the crowded fields, as well as providing a wealth of additional astrophysical data which would serve other galactic science goals, as described in [3].

5 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.

We advocate for the "alternating-i" strategy outlined above, but sequential visits in i-band are also highly useful to our science. Additional visits per night are always beneficial, as this will improve the cadence on the field and better constrain key lightcurve features.

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.

In general, the rolling cadence scenarios are beneficial for characterizing exoplanetary and stellar-mass lenses *provided* that the RGES field is surveyed at periods that complement the Roman survey periods. We do note that lensing by black holes typically lasts longer, ∼100-300 d, and in some cases would exceed the rolling cadence observing season. Our investigations so far (described in the cadence note Abrams et al.) suggest that some rolling cadences cause a decline in discovery rates for this class of events.

We developed the numObsInSurveyTimeOverlap metric to assist with evaluating different OpSims, as soon as the RGES survey period are known.

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.

There are no strong scientific arguments for or against dithering, provided the pointing is not offset so much that coverage of the RGES field is reduced. We include Figure 1 to illustrate how the RGES field is smaller that that of Rubin, and fits within a single pointing. We do note that the Rubin pointing for this field could be optimized to include the regions of relatively low extinction and maximize the number of stars observed. This would not only provide additional discoveries of microlensing events detected by Rubin alone, but also a range of stellar astrophysics.