TVS Microlensing Subgroup v2.0 and v2.1 OpSim Analysis

Contributors:

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This is the TVS Microlensing Subgroup's analysis of the v2.0 and v2.1 OpSims using the microlensing metric. Typical microlensing events last between days and years and the timescale itself is referred to as the "Einstein time", t_E. In the context of the cadence analysis, we distinguish two relevant populations of interest: single lens stellar microlensing events with Einstein times t_E approximately less than 200 days (where the bulk of stellar events are between 30-70 days) and compact objects with t_E>200 days. For a meaningful statistical analysis the OGLE-IV bulge event rate serves as a standard for us which corresponds to 60 microlensing events per square degree.

There are three metrics used for this analysis: MicrolensingMetric_detect which finds the fraction of events with at least three datapoints on the rise with a 3 sigma change; MicrolensingMetric_Npts which finds the fraction of events with at least 10 datapoints within 2 t_E of peak magnification; and MicrolensingMetric_Fisher which finds the fraction of events with less than 0.1 fractional uncertainty in t_E (sigma_t_E/t_E< 0.1). The plots used to interpret these metrics are in this jupyter notebook by Lynne Jones. Note that in some cases the Npts metric should be interpreted with caution since the signal-to-noise ratio (SNR) value was accidentally ignored. The Fisher metric can overestimate the number of characterized microlensing events when the number of lensed observations are approximately equal to the number of considered parameters. In general, when we are unable to characterize more than ~20% of events, this no longer meets our subgroup's baseline expectations.

Analysis of previous OpSims by these metrics and other microlensing metrics can be found in the following cadence notes and white papers: Abrams et al. 2021, Bachelet et al. 2021, Blaineau et al. 2021, Hundertmark et al. 2021, Street et al. 2018, and Street et al. 2021

We expect to address the following caveats ***in a future report***:

- As advised, we have excluded follow-up capabilities which would enable a better characterization of Rubin-discovered stellar events with the possibility of finding exoplanets.
- We only include events with single lenses and sources, though multi lens events will likely also be discovered.
- We exclude higher-order effects such as additional constraints on the mass-distance relation by astrometric and microlensing parallax measurements. Microlensing parallax can be imperative for characterizing black hole events, so cadences which include strong aliasing should be avoided. This will be explored in a future report.

- We assume that the typical blend ratio is 1, i.e. source and neighboring stars contribute 50% of flux at baseline. A more sophisticated model would require input from crowded field photometry task-forces. This is in preparation.

New Baseline: The new baseline is a dramatic improvement over the “retro footprint” due to the inclusion of the Galactic Bulge and central part of the Galactic Plane. The v2.0 is slightly better than v2.1, since v2.1 includes the Virgo cluster which is not a traditional microlensing target.

Filter distribution (bluer_ and long_u families): The bluer and long_u families are worse by no more than 15%. This is probably because the mean magnitude of stars in the blue band in the TriLegal map is fainter, so the events are harder to detect. Having more points in bluer bands will also make the events harder to follow up.

Presto Color and third visits in a night (presto_gapXX, presto_gapXX_mix, presto_half families, and long_gaps family): In a somewhat surprising result, microlensing metrics do much worse in the presto color family. In general, microlensing events do not change sufficiently in a single night to warrant a third visit that night, and taking time away from looking at more varied points in time greatly decreases the efficacy of microlensing detection and characterization. The improvement to 1-10 day events at the large expense of the majority of events 10+ days, is not aligned with our science goals.

Twilight NEO v2.0 simulations (twilight_neo_nightpatternXX family): The SNR of observations is reduced, so the short stellar events suffer in characterizations. Some of the long events technically have more observations that overcome the SNR downsides, but the quality loss and systematic effects would make an analysis challenging despite the technically better relative assessment. (Note here that the Npts metric should not be considered since it does not have the SNR properly incorporated). This is a surprising result since we did not think the twilight observations would lead to a poorer coverage of the night-time events.

NES coverage as percentage of WFD coverage (vary_NES family): The more the survey strategy covers the NES, the less we are able to cover the Galactic Bulge and Plane which causes the microlensing metric to suffer. Around 60-75% coverage of the NES sees a significant drop in quality of microlensing characterization. (Note here that the better results in the 5-10 days in the Fisher metric is likely because the Fisher metric is very sensitive to reaching a threshold of events and the threshold happened to be reached there. You can see in the Npts metric for this family that we do *not* see a corresponding improvement).

Galactic Plane (GP) coverage as a percentage of WFD coverage (vary_GP family): We see similarly to the NES metric that technically if we cover the Galactic Plane more, that we get fewer microlensing events overall, since many of the microlensing events are concentrated towards the Bulge. However, it is interesting to be able to probe microlensing events throughout the Galactic Plane. To be able to characterize the event rate to the similar degree as the 4th run of the Optical Gravitational Lensing Experiment (OGLE-IV), we would need at least ~15 events per degree squared in the Plane (Sajadian and Poleski 2019; for retro OpSims).

Galactic Plane Footprint without pencil beams (plane_priority_priorityX.X_pbf_): We find that there is a drop in efficiency for the long duration events in the plane priority map when it covers those of ~0.4 or lower. This matches what is found by the general Galactic Plane metrics.

Galactic Plane Footprint with pencil beams (plane_priority_priorityX.X_pbt_): We find similar results to without pencil beams since we get a similar number of events. However, the pencil beam fields were picked specifically to optimize our ability to probe Galactic structure (along with other goals) throughout the Plane. Decades of microlensing surveys have looked at the Galactic Bulge, but Rubin will enable us to look much deeper across the Galactic Plane, so looking in strategic spots is helpful.

Pencil beam sizes (pencil_): The size of the pencil beams does not appear to affect the microlensing results. So we should optimize for slew time/other metrics.

Good seeing metrics (good_seeing_): As the good seeing metric is prioritized more of our science case gets worse since it appears as though the footprint decreases and we end up with fewer events. (As a side remark, better template images for DIA could improve alerts and photometric accuracy but there is insufficient data to assess a suitable trade-off).

DDF Observing Strategies (ddf_frac_): Since the DDFs do not cover the Galactic Plane, the more they are covered the worse our science case gets. At the current level of the DDFs in the OpSims, it hurts short event characterization at the 10-15% level, but besides that it does not appear to significantly hurt the microlensing science case.

Microsurveys (virgo_cluster, carina_,smc_movie, roman, local_gal, too_rare, short_exp, north_stripe, mutli_short):

- Virgo cluster - like the NES, since virgo is not a microlensing target, too much coverage reduces the microlensing output.
- Carina_ - like the NES, since carina is not a microlensing target, too much coverage reduces the microlensing output.
- Smc_movie - though shorter duration events are negatively impacted, the SMC has traditionally been a good microlensing target to explore halo microlensing. So even if there are fewer events in the Plane by a few percent, this is an acceptable trade off.
- Roman - Covering the Roman field both during Roman's window and also filling in the gaps between its observations are incredibly helpful. It could potentially be more useful, during Roman's observing windows, to concentrate more of the Galactic Bulge observations on the Roman field (some sort of weak rolling). Not so much that the rest of the Bulge is compromised, but perhaps ~0.5 rolling since that did not seem to significantly negatively impact detection and characterization of events > 30 days (see Rolling Cadence). Work is in progress to quantify this further.
- Local_gal - This seems to negatively impact microlensing but is still below our defined threshold.

- Too_rare - it seems like to the extent implemented in the opsim this does not affect us unless there are microlensing ToOs. Some short durations appear to be improved by this metric, but this is likely due to a coincident field.
- Short_exp - see the twilight family analysis. Likely this is decreasing the SNR which causes the shorter events to be less effectively detected and characterized, and technically for the longer ones to get better because there are more observations, but the decrease in SNR is probably not worth it.
- North_stripe - like the NES, since the north stripe is not a microlensing target, too much coverage reduces the microlensing output.
- Multi_short - stellar event characterization rate drops below our threshold in the multi_short_v2.0. See vary_expt.

Rolling Cadence (rolling, roll_, _six_rolling): In general the rolling cadence does better for short events, especially rolling bulge, but this is *not* the priority. We did not expect the Rubin observatory to be able to completely characterize short duration events, rather to alert on them. So increasing the efficiency in 1-10 day events (the minority of events) at the expense of longer ones (most events) does not meet our science goals. Note that we have not included microlensing parallax here, but parallax is important to characterize events, particularly candidate black holes and may suffer from aliasing in rolling cadences. Normal parallax metrics can be used as a rough proxy for microlensing parallax. It may be beneficial to take time away from the low priority plane to look at the Roman bulge when Roman isn't already looking at it (though not extensively before Roman launches) so that we can better characterize Roman events, since they will have large gaps. This is subject to ongoing work which will be explored in an upcoming report.

Varying exposure time (vary_expt and shave_): In general the shave series shows that longer exposure times are more effective for detecting microlensing events. This makes sense since as the SNR increases, we can more effectively characterize the events. Note that this metric does not take into account variable blending. So longer exposures may lead to more blending which would lead to worse microlensing characterization.