


The Time-Domain Extragalactic Survey Cadence Note

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ABSTRACT

The 4m Multi-Object Spectroscopic Telescope (4MOST) Time-Domain Extragalactic Survey (TiDES) is primed for the spectroscopic follow-up of LSST transients at an industrial scale. TiDES will use its 250,000 fibre-hours to conduct a comprehensive census of the time-domain sky with a focus on 3 key science areas: (i) spectroscopic observations of live transients, (ii) redshift measurements of host-galaxies for supernova photometric classification and cosmological measurements, (iii) cadenced spectra to enable the reverberation mapping of Active Galactic Nuclei out to $z=2.5$.

In this note we explore the effect of several LSST cadence simulations on the TiDES transient and AGN samples. This document is submitted in response to the solicitation for Cadence Notes^{a)}

QUESTION 1: FOOTPRINT

The current 4MOST observing strategy (Tempel et al. 2020) covers the entire southern sky between $-80 < \text{decl.} < +5$ with at least 2 observations over the 5-year survey lifetime. Extending the LSST footprint to higher declinations will result in the discovery of additional transients that TiDES will not observe. While extending to more southerly declinations — where 4MOST does observe — will certainly mitigate this, the extra area will come at the expense of fewer total visits and shallower integrated depths. In Figure 1 we show the 4MOST footprint visit-density and overlap the boundaries of two LSST cadence footprints. The `baseline_nexp2.v1.7_10yrs.db` cadence file sufficiently envelopes all observations from the 4MOST survey and would, therefore, provide better sampled light curves.

QUESTION 2: ADDITIONAL TIME ALLOCATION

The DDFs will be visited by 4MOST at least every 14 days for the TiDES AGN reverberation mapping project. This will also produce increased opportunities for the rapid spectroscopic classification of transient objects with improved light curves compared to the WFD fields. Furthermore, with repeat visits, TiDES is able to stack spectra of SN host galaxies for observations of more distant targets. The DDFs will provide a sample of transients in these higher redshift galaxies compared to WFD, this is crucial for improving the constraints on cosmological parameters. Furthermore, TiDES AGN RM will use LSST multi-band light curves to recover the intrinsic accretion disk variations that drive the broad line variations. For this, a cadence at least twice as high as the spectroscopic observations are required

^{a)} <https://docushare.lsst.org/docushare/dsweb/Get/Document-36755>

($\lesssim 7$ days) in at least g or r band. LSST single epoch depths in the DDFs are several magnitudes deeper than the limiting magnitude for 4MOST. Therefore, we prefer an observing strategy that maximises observing season in the DDFs over one that maximises single epoch depth. TiDES would advocate for any additional observing time be spent on the DDFs to improve both the SN and AGN light curve sampling, resulting in reduced systematics in the final cosmological parameters. The conclusions we draw from our analysis are the same as those presented in the DESC cadence note.

QUESTION 3: U-BAND EXPOSURE TIMES

Spectroscopic follow-up prioritisation for the the TiDES SN Ia sample is not governed by observations in the u-band because it is unlikely many supernovae would be detected to high significance in this filter. We analysed the `u_long_ms_50_v1.7_10yrs.db` cadence file and compared this to the `baseline_nexp2_v1.7_10yrs.db` in Figure 2 (along with several other cadence assumptions). As can be seen, the u-long 50s cadence shows little effect on several of our metrics.

Observations in the u-band, however, are useful for the early identification of fast-transients, such as kilonovae (KNe) or fast-blue-optical transients (FBOTs), and may help identify contaminants in SNe Ia photometric cosmology samples. 4MOST/TiDES is not the ideal survey for rapid, targeted classification of unusual transients, however, chance-encounters are likely. Additional data beyond $griz$ may well help TiDES map the diversity of the transient phase-space and train machine learning algorithms for photometric classification. Though overall, the TiDES primary science goals appear unaffected in a comparison between `baseline_nexp2_v1.7_10yrs.db` and `u_long_ms_50_v1.7_10yrs.db`, we therefore take a neutral position on the u-band exposure time discussion.

QUESTION 4: FILTER DISTRIBUTIONS

The TiDES metrics perform well with the `baseline_nexp2_v1.7_10yrs.db` cadence and we see no strong case to significantly depart from this to bias towards bluer or redder filters.

QUESTION 5: VISIT PAIRS

Intra-night visit pairing in the same filter has a strong detrimental effect on transient science from TiDES. To test this we analysed a TiDES-cosmology sample using the `baseline_samefilt_v1.5_10yrs.db` cadence simulation. This is by-far the worst performing cadence of our simulation set. The performance of `baseline_samefilt_v1.5_10yrs.db` is shown in Figure 2 where there is an almost 10% increase in the uncertainty on the distance modulus to the SN Ia sample — which is crucial for cosmology — and on the date of maximum brightness. We, therefore, strongly endorse observing strategies that make intra-night observations in different filters. Our case for different intra-night filters is strongly supported by the findings in the DESC cadence note.

TiDES will also use its vast spectroscopic sample to train machine-learning algorithms for photometric classification of transients (Carrick et al. 2020). Colour information on a single epoch can help the rapid and early photometric classification of transients.

Two randomly chosen SNe Ia are shown in Figure 3, with observed light curves generated under several cadence assumptions. The light curves observed under the `baseline_samefilt_v1.5_10yrs.db` cadence file are clearly inferior to other strategies; they lack multi-band observations that are critical for constraining colour evolution. No significant temporal evolution is expected between the same-filter-same-night re-visits, with little new information gained about the transient other than an improved signal-to-noise. This is further supported by Figure 2 where we count the unique epochs and filters as single pre- and post-peak detections to show that there are 30% fewer light curve points from `baseline_samefilt_v1.5_10yrs.db` compared to `baseline_nexp2_v1.7_10yrs.db`.

QUESTION 6: ROLLING CADENCE

In principle, rolling cadence strategies should have a clear benefit to transient science, chiefly, that light curves are better sampled. Not only would this allow for better studies of individual objects, but would also improve the photometric classification of transients and hence the purity of any resulting SN Ia cosmology samples. We do not, however, see this improvement in any of our metrics presented in Figure 2. It may seem surprising that our simulations using the `rolling_scale0.2_nslice2_v1.7_10yrs.db` and `rolling_scale1.0_nslice2_v1.7_10yrs.db` cadence files do not show a substantial improvement over `baseline_nexp2_v1.7_10yrs.db` — with only a small percentage increase in the number of pre- and post-peak detections in Figure 2 — but we believe this is due to a rolling cadence being

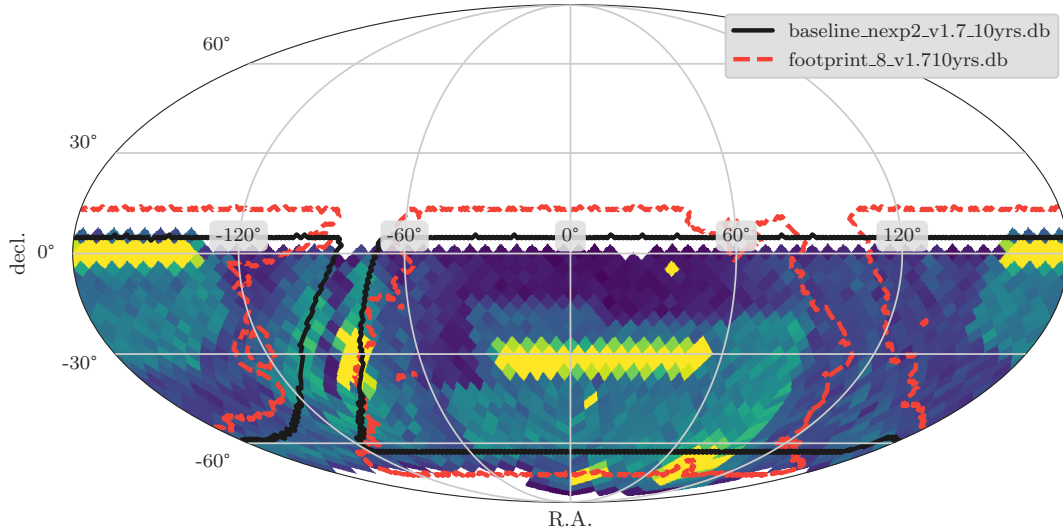


Figure 1. The 4MOST sky coverage is shown by the heatmap with the scale determined by the number of repeat visits. The 4MOST footprint will be observed at least twice (purple on the colorscale) with the LSST DDFs more frequently observed (at least every 14 days; yellow on the colorscale). Other areas of the sky, such as the WAVES fields (Driver et al. 2019) or LMC/SMC observations (Cioni et al. 2019), are observed more frequently to meet the science requirements of the other 4MOST consortium surveys. The red dashed line shows the boundary of the `footprint_8.v1.710yrs.db` cadence simulation and the solid black line represents the `baseline_nexp2.v1.7_10yrs.db` boundary.

difficult to simulate within the LSST scheduler. Balancing the needs of other science cases that require uniform sky coverage or increased season length is especially challenging for a rolling cadence. TiDES would advocate for continual efforts in producing simulations of rolling cadence strategies in line with the requests of the DESC cadence note. If such a cadence proved successful, TiDES would have a powerful case for 4MOST to adopt a rolling strategy that followed LSST. This would certainly increase the number of young transients that TiDES could classify, allowing the community to follow-up the most interesting candidates.

For TiDES RM, we require continuous light curves in each available observing season of the DDFs. Therefore, for reverberation mapping, a non-rolling cadence of the DDFs is strongly preferred for at least the first 5 years of LSST.

QUESTION 7: DITHERING

Dithering is an essential part of survey operations to mitigate the effects of non-uniform response over the image plane. For 4MOST follow-up, TiDES would strongly argue for a dither strategy that retains an overlap of the central 4.2 deg^2 (the 4MOST field-of-view) of the LSST field for each visit to the DDFs. The TiDES requirements for dithering are shared with DESC and we refer to the findings in their cadence note.

REFERENCES

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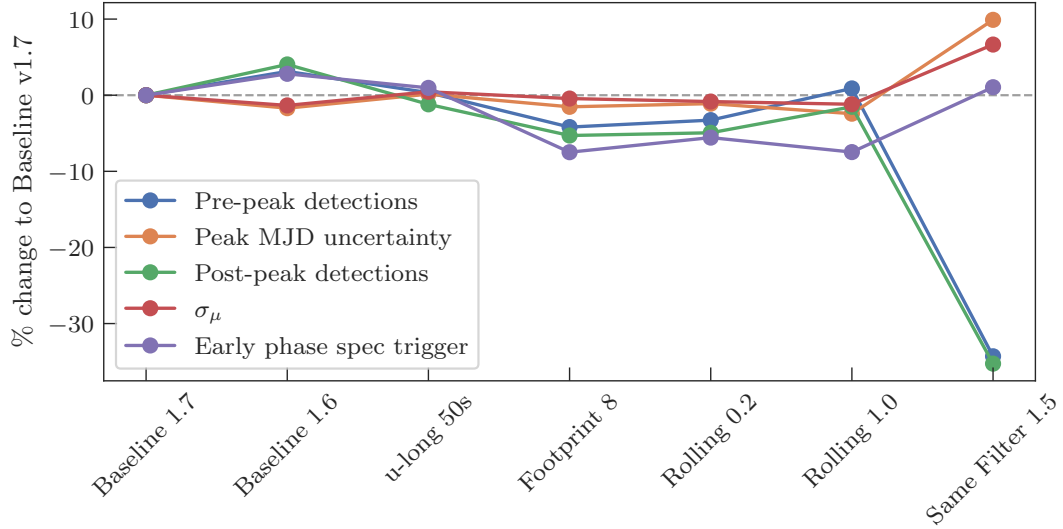


Figure 2. A comparison of several metrics that contribute to the success of the 4MOST/TiDES survey. The metrics shown are evaluated just for the type Ia supernova sample, however, the performance for other SN sub-types is considered in the arguments presented in this document. We show the percentage change from the `baseline_nexp2_v1.7_10yrs.db` cadence simulation. The number of pre-peak detections ($> 5\sigma$ in any filter) is represented by the blue circles. Here, peak is defined as the date of maximum brightness in the B-band. The number of post-peak detections is shown by the green points. We fit the SALT2 model to the light curve to determine the uncertainty on our date of peak. Equivalently, we use the SALT2 model to compute the distance modulus, μ , for each SN Ia and present the uncertainty on this with the red circles. Finally, the light curve phase we trigger the object into the 4MOST queue is shown by the purple points (positive values indicate earlier triggering).

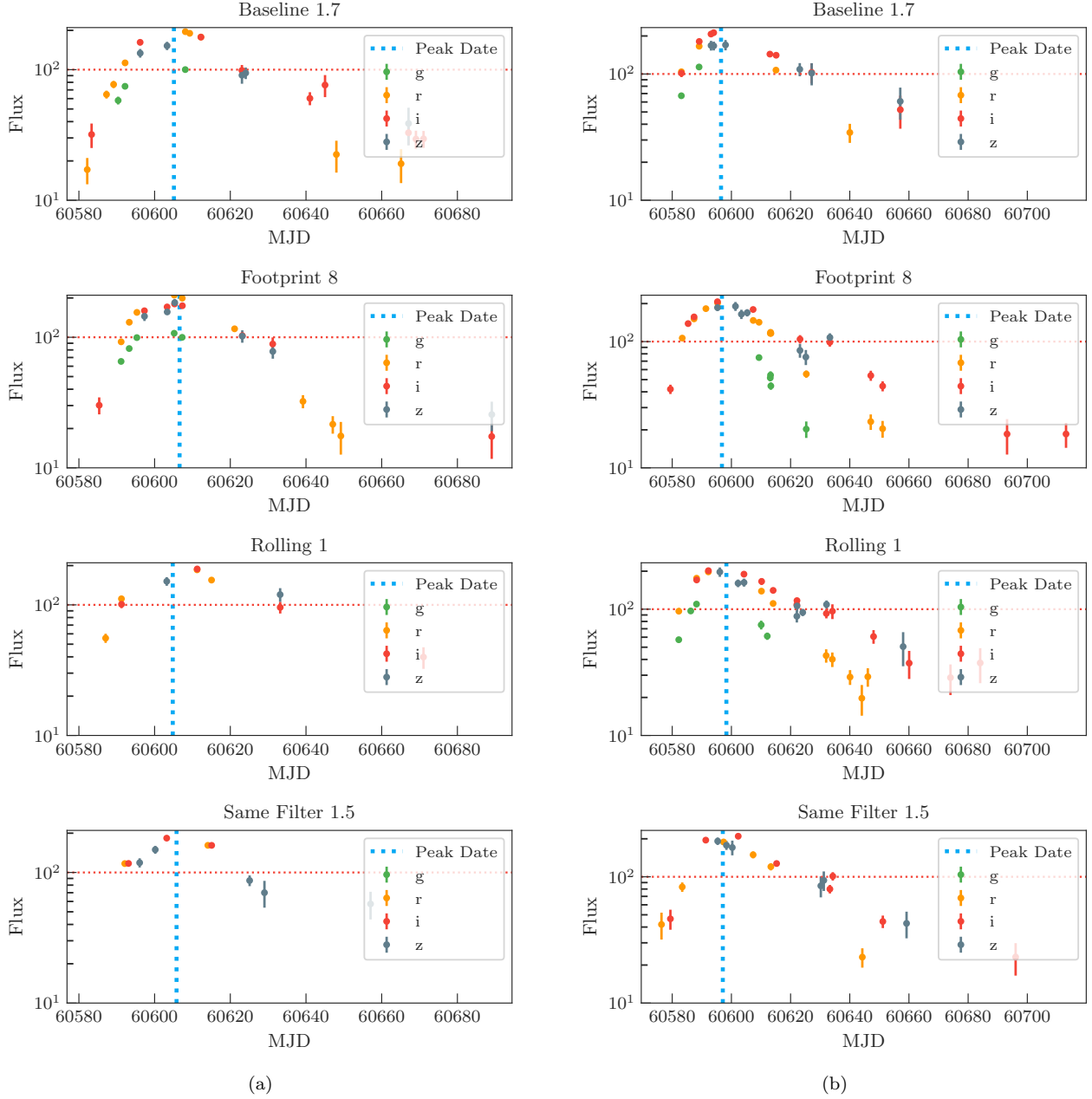


Figure 3. Two different type Ia supernovae are observed in our simulations under different cadence assumptions. Each 5σ observation in the **griz** filters is shown and the date of maximum brightness is marked by the blue dashed line. The horizontal orange dotted line shows the typical limiting depth of a 1 hour spectrum taken by 4MOST. Early light curve triggering allows a greater opportunity for a live classification spectrum to be taken at phases above this flux limit. Once a supernova has faded below this, the host-galaxy will be targeted to measure the redshift of the target. We will be able to reach greater depths as multiple epochs of galaxy spectra can be stacked to improve signal-to-noise .