LSST AGN SC Cadence Note: Type-1 Quasar Variability in the Context of Photometric Redshifts

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1. EXECUTIVE SUMMARY

We have developed a metric to evaluate the effects of variability in the context of photometric redshifts for type-1 quasars as a function of OpSim run for FBS 1.5–1.7. The metric corresponds to the average number of nights between the closest observations in bands contiguous in wavelength for each slicer pixel. Considering the median value between all slicer pixels, we find that only the `baseline_samefilt_v1.5_10yrs` OpSim run underperforms consistently for all combinations of contiguous bands. The rest of the poorly ranked OpSim runs underperform only for specific band combinations, while being close to the typical OpSim run in the rest, suggesting the impact on type-1 quasar photometric redshifts will be limited. As the `baseline_samefilt_v1.5_10yrs` OpSim run does not perform particularly well in any of the metrics developed by the AGN SC, it may be advisable to not consider it as a viable survey strategy.

2. THE METRICS

AGN are intrinsically variable objects. The characteristic timescales of variability depend on wavelength and may also depend on physical factors such as $M_{\rm BH}$, luminosity and/or Eddington ratio (e.g., MacLeod et al. 2010). Furthermore, the observed variability timescales is also affected by redshift through time dilation. In the context of photometric redshifts for type-1 quasars, variability can be a source of information when combined with apparent magnitudes by constraining the luminosity and redshift. However, it can also be a source of uncertainty, as colors obtained from observations made in different epochs are not only determined by the SED shapes of the objects, but also by the possible change in brightness of said objects. In practice, longer times in between observations at different bands will result in increased color uncertainties, which will result in poorer photometric redshift uncertainties.

Generally, we rely more on colors between adjacent bands than between all color combinations, as those allow us to more easily probe specific SED features. So a simple approach to quantitatively rank the different OpSim runs will be to compare the typical time between observations in different bands. With that in mind, our metric is then simply the number of nights that pass between observations in adjacent bands. Specifically, for each healpix slicer pixel (NSIDE=64), we count the mean number of nights between observations carried out in two bands adjacent in wavelength.

A significant caveat here is that, while our metric will properly rank the OpSim runs, translating this into photometric redshift accuracy for type-1 quasars is not trivial and well beyond the scope of this cadence note. The effects of variability will be more important for lower luminosity, lower redshift quasars that are bright enough to be detected in the single exposures. Objects that only appear in the stacked images will either be host dominated, or will be at high redshift, and should be less affected by this issue. Even for those objects, however, ensuring that the combined photometry corresponds to averages taken at the same time intervals could prove useful.

3. ANALYSIS OF RESULTS

Figure 1 shows histograms of the mean number of nights between observations carried out in two pairs of adjacent LSST bands, r and i, and z and y, in slicer pixels for each of the OpSim runs. We remind the reader that longer gaps are worse for photometric redshift estimations. We rank the OpSim runs by the sum of their median number of nights for each pair of contiguous bands. We refer to this combined quantity as Ψ_N, and to the median for each pair of bands a and b as $\Psi_N^{a,b}$. Although the timescale of variability is dependent on the wavelength, this dependence is fairly weak (MacLeod et al. 2010) and does not affect our conclusions.

Using this scheme, we find that the 50$^{\rm th}$ percentile OpSim run is `filterdist_indx4_v1.5_10yrs`, with Ψ_N = 26 nights, and specific values of $\Psi_N^{u,g} = 7.7$ nights, $\Psi_N^{g,r} = 3.0$ nights, $\Psi_N^{r,i} = 4.9$ nights, $\Psi_N^{i,z} = 4.1$ nights and $\Psi_N^{z,y} = 6.3$ nights. Most of the OpSim runs that score poorly in this metric are typically due to a single band combination having an exceedingly long time in between observations (not surprisingly it is typically the u, g and z, y combinations), which suggest that while far from ideal, they would not be detrimental to our science goals. We note, however, that the OpSim run `baseline_samefilt_v1.5_10yrs` is not only the worst ranked one according to our metric, but also scores poorly in all band combinations. This OpSim run does not rank particularly well in the other metrics submitted

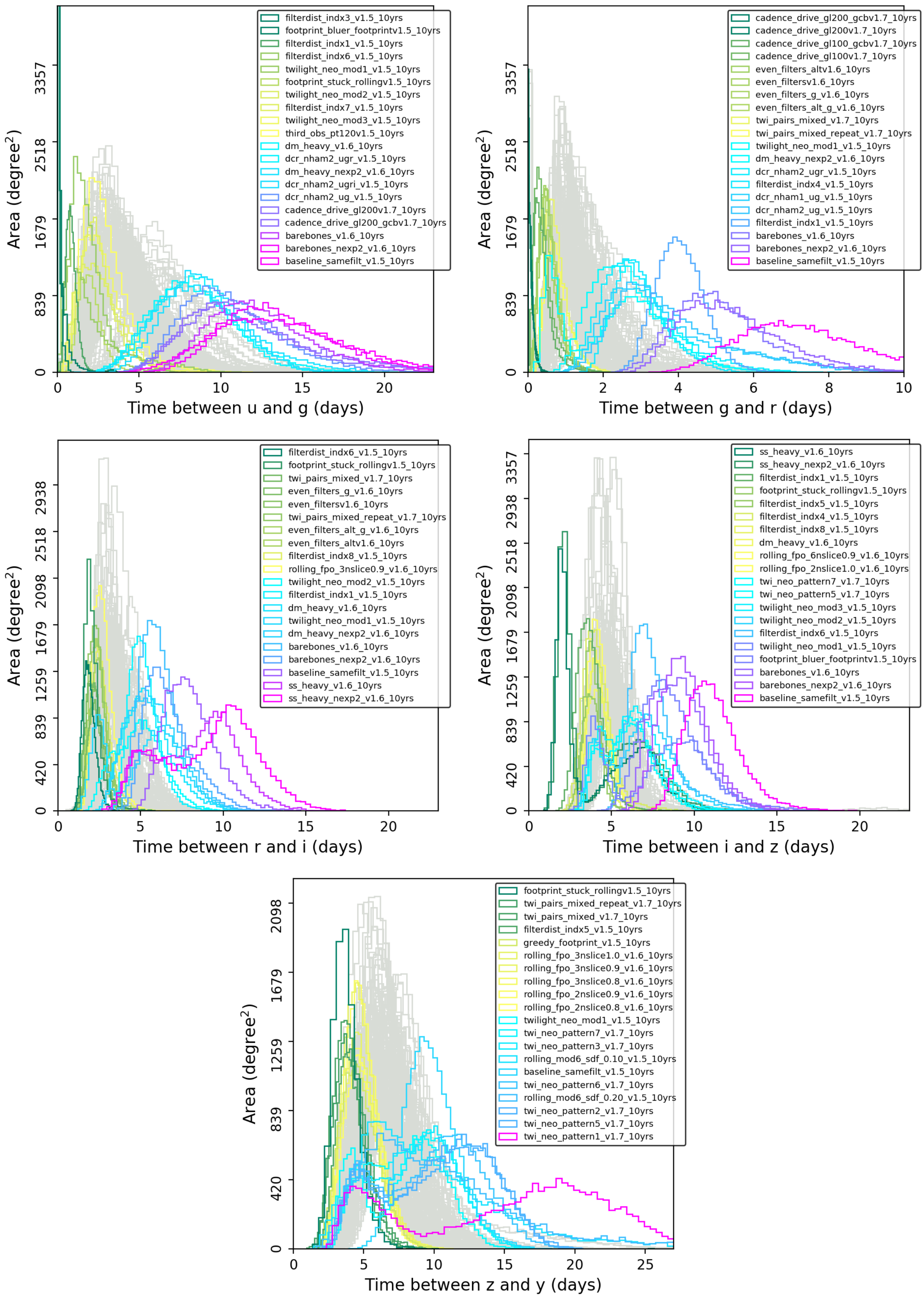

Figure 1. Expected number of nights between observations between r and i (*left*), and between z and y (*right*) expected for all 190 OpSim runs in FBS 1.5, 1.6 and 1.7. The color-coded OpSim runs correspond to the top and bottom 5% ones when ranked by their median number of nights. The rest are shown in light gray. **Shorter time gaps are better for photometric redshift estimations.**

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by the AGN SC, so it may be advisable to avoid it if possible. The best performing OpSim in our metric is nominally `footprint_stuck_rollingv1.5_10yrs`, although its low WFD areal coverage makes it a poor recommendation in a broader sense. Additionally, the `filterdist_indx5_v1.5_10yrs` and `filterdist_indx8_v1.5_10yrs` are the next best performing ones, which are actually developed with photometric redshifts in mind with respective descriptions of being "i-band heavy" and "Redder" than the baseline. We also note that the `rolling_fpo` family with 3 and 6 declination bands also score well in this metric.

4. ANSWERS TO 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.

We do not see that larger area OpSim runs ($\gtrsim$20,000 deg^2) perform systematically better than the typical OpSim run according to this metric.

> 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.

While not addressed directly by this metric, it is generally preferable from the point of view of quasar photomeric redshifts to devote the extra time to observe the DDFs. The DDFs, due to the large number of additional multi-wavelength and spectroscopic observations, are fundamental for calibrating the numerical techniques we will need to use in the WFD.

> 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.

Not in the context of variability effects over type-1 quasar photometric redshifts.

> 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 in the context of variability effects over type-1 quasar photometric redshifts.

> 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.

Our metric argues against two visits in a pair of the same filter, ranking `baseline_samefilt_v1.5_10yrs` at the bottom. With respect to visits in a pair of different filters, we do not have a strong preference, as our metric argues for obtaining pairs of filters as close in time as possible but is relatively agnostic to how this is done.

> 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.

We do not find the family of rolling cadences to consistently underperform for all contiguous band combinations in our metric.

> 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 applicable.

REFERENCES

MacLeod, C. L., Ivezić, Ž., Kochanek, C. S., et al. 2010, ApJ, 721, 1014, doi: 10.1088/0004-637X/721/2/1014