LSST AGN SC Cadence Note: Quasar Counts

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1. EXECUTIVE SUMMARY

We have developed a metric to estimate the number of quasars that will be detected in the 10 year coadded i-band observations as a function of OpSim run in FBS 1.5–1.7. We find that the main difference between the number expected for different OpSim runs is driven more strongly by the area covered rather than by differences in depth, implying that in most OpSims we are typically detecting objects fainter than the knee of the QLF. As such, in terms of overall statistics (which factor into most AGN-related LSST goals in one way or another), there is a preference, albeit not a very strong one, for strategies that would provide wider WFD footprints.

2. THE METRICS

We estimate the number of QSOs that will be detected in i-band at the co-added 10 year depth of LSST observations. We choose i-band because it will be one of the deepest bands in the WFD and serves as a good comparison to other surveys such as SDSS. Furthermore, the LSST Science Book, in section 10, has already provided an expected number of quasars detected in this band. Note that a modestly larger number of objects are expected to be detected in y-band, however many of them, due to obscuration and/or redshift, will not be detected in any other band and hence will be harder to characterize.

To estimate the number of detected quasars we use the model "A" bolometric QSO luminosity function of Shen et al. (2020). We start from that parametric form provided by Shen et al. (2020), and follow all the steps detailed by the authors to relate the bolometric luminosity function with the observed luminosity function at a wavelength $\lambda = \lambda_{\rm eff}^{i-{\rm band}}/(1+z)$. In short, we start with the functional form of the bolometric luminosity function and transform it into the intrinsic luminosity function (i.e., reddening corrected) at wavelength λ considering both the bolometric correction at wavelength λ and the dispersion of this correction. We only consider objects with intrinsic absolute magnitudes $M_i < -20$ mag, as less luminous objects are likely to be dominated by their host galaxy emission at the relevant wavelengths[1]. We then convolve this intrinsic luminosity function with the same obscuration distribution considered by Shen et al. (2020) to obtain the observed luminosity function. Finally, we estimate the number of QSOs detected in a given slicer pixel as the integral of $\phi_{\lambda}^{\rm Obs}$ between $z = 0.3$ and $z = 6.7$ and between 15.8 mag, the saturation magnitude of LSST in i-band, and the 5σ magnitude limit of the pixel. The magnitude limit is estimated using the `ExgalM5` MAF metric, limited to only areas with foreground reddening $E(B-V) < 1.0$ mag to avoid regions of high obscuration near the Galactic Plane and Galactic Center. The redshift limits were chosen to match those of Table 10.2 in the LSST Science Book.

3. ANALYSIS OF RESULTS

Figure 1 shows a histogram of the expected number of quasars to be detected by each OpSim run in FBS 1.5–1.7 in the coadded 10-year i-band observations, both for the WFD alone as well as for the WFD in combination with the non-DDF mini surveys (i.e., GP, NES and SCP). We do not include the DDFs since they will be much deeper than any of the other mini surveys, although including them is unlikely to affect these numbers due to their small areas. The great majority of the OpSim runs return a very similar total number of expected quasar detections of around 11 million in the WFD alone, and approximately 15 million when including the mini surveys. The three OpSim runs that predict less than 10 million quasars detected in the WFD correspond to `footprint_stuck_rollingv1.5_10yrs`, `twi_neo_pattern1_v1.7_10yrs` and `twilight_neo_mod1_v1.5_10yrs`, with respective WFD surface areas of 9,753, 13,612 and 15,649 deg^2. Those with more than 13 million quasars correspond to `wfd_depth_scale0.70_noddf_v1.5_10yrs`, `wfd_depth_scale0.65_noddf_v1.5_10yrs` and `footprint_big_wfdv1.5_10yrs`, with respective WFD surface areas of 21,480, 21,502 and 22,224 deg^2. We note that all of these numbers are considerably smaller than the ~17 million expected for 20,000 deg^2 according to Table

[1] Note that such faint AGN are crucial to the success of AGN science in LSST but are beyond the scope of this metric as the QSO luminosity function only applies to bona fide quasars.

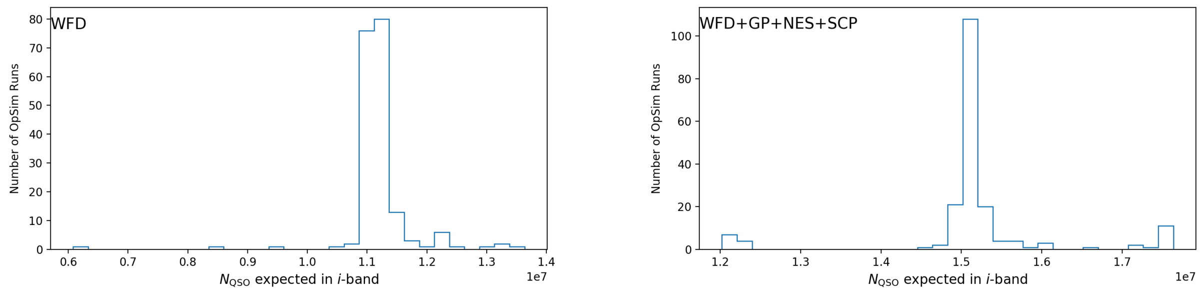

Figure 1. Histogram of the number of quasars expected to be detected by each of the OpSim runs in the coadded 10-yr observations of LSST. The left panel shows the numbers expected in the WFD alone, while the right panel shows those expected in the WFD plus all the non-DDF mini surveys (i.e., GP, NES and SCP).

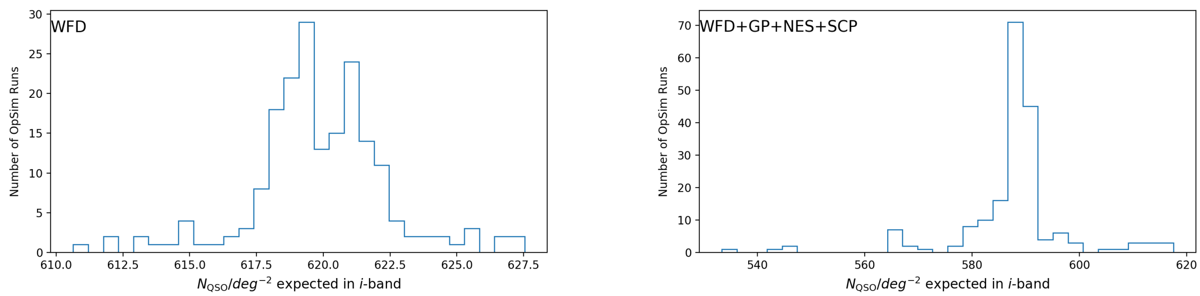

Figure 2. Histogram of the number of quasars expected to be detected by each of the OpSim runs in the coadded 10-yr observations of LSST. The left panel shows the numbers expected in the WFD alone, while the right panel shows those expected in the WFD plus all the non-DDF mini surveys (i.e., GP, NES and SCP).

10.2 of the LSST science book. This is primarily due to changes in the QLF parametrization considered here with respect to that of Hopkins et al. (2007), which was considered for the LSST Science Book.

In general, the main difference between the numbers expected in each OpSim run is due to the WFD area covered, likely implying that most of them, if not all, reach depths beyond the knee of the QLF in the majority of the redshift range. In fact, as shown in Figure 2, we find that in the WFD alone the average number density of quasars expected changes only by ∼5% between all the OpSim runs, between 610 and 630 quasars/deg^2. If we also consider the mini surveys, the averages are lower while the spread is larger (between 540 and 620 quasars/deg^2), but this is to be expected given that these mini surveys will be considerably shallower. Considering that all OpSim runs return similar number densities in the WFD, we should be able to probe similar quasar populations at the faint end with any of them, suggesting there is not a strong driver to avoid any particular one because of that. Given this small range in average number densities, however, it can be advantageous to cover larger areas in order to find the rarest objects, such as high redshift and extremely luminous quasars.

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.

Our analysis shows that WFD footprint size is the most important parameter for determining the total number of quasars expected in i-band. Hence, larger footprints are preferable in order to find rare quasars as the number density is little affected by differences in i-band depth between OpSim runs. In particular we find that the OpSim runs `wfd_depth_scale0.70_noddf_v1.5_10yrs`, `wfd_depth_scale0.65_noddf_v1.5_10yrs` and `footprint_big_wfdv1.5_10yrs` all return more than 13 million expected quasars. We note, however, that this preference is not strong and OpSim constraints explored in other cadence notes by the AGN SC may be more important.

> 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.

Using the extra time in the non-DDF surveys will have the added benefit of increasing the number of luminous quasars by covering more area, however at the cost of a noticeable decrease in the average number of quasars per sq. degree of about $\sim$10%. However it might be preferable to invest in the DDFs instead in order to find a greater number of fainter and higher redshift AGN, and form a reliable sample to train algorithms for quasar selection and photometric redshift estimations.

> 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 applicable to the metric tested here.

> 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 applicable to the metric tested here.

> 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.

Not applicable to the metric tested here.

> 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.

Not applicable to the metric tested here.

> 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 to the metric tested here.

REFERENCES

Hopkins, P. F., Richards, G. T., & Hernquist, L. 2007, ApJ, 654, 731, doi: 10.1086/509629

Shen, X., Hopkins, P. F., Faucher-Giguère, C.-A., et al. 2020, MNRAS, 495, 3252, doi: 10.1093/mnras/staa1381