Title: Incorporation of Multi-wavelength Observations
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0. Summary Statement

We discuss the importance of multi-wavelength photometric observations beyond *ugrizY* for the accuracy of photometric redshift estimates. Given the extremely wide-ranging importance and utility of these measurements for the LSST community, we advocate that DM should allocate resources to the production of matched photometric catalogs from other surveys in the DDFs and the WFD, particularly in the NIR and MIR where applicable. This task is currently outside the scope of the LSST Photo-z Roadmap (*DMTN-049 2*), yet, many science goals will be severely-hindered by relying on LSST-only photo-z estimates, requiring replication of these procedures by most, if not all, the Science Collaborations (SCs). DM taking leadership in producing these catalogs will result in more accurate and uniform photometric redshift estimates available to the whole community, a better efficiency of the limited resources of the SCs, and should ultimately improve the science output of the survey.

1. Scientific Utility

1.1 Photometric Redshift Accuracy

Due to its unprecedented depth, the great majority of objects detected by LSST will lack spectroscopic follow-up observations. Extragalactic science with LSST will require that users rely on photometric redshifts to derive physical parameters for most extragalactic sources. Broad-band photometric redshifts rely on mapping Galactic-extinction corrected (see this LoR) observed colors to redshift, either through SED modeling, machine learning, or hybrid techniques (see the recent review by Salvato et al. 2019 for details). As such, the larger number of independent colors that can be used, the better the accuracy of the photometric redshift estimates. Unfortunately, optical-only colors can lead to significant levels of inaccuracy and degeneracies. Figure 1, taken from Salvato et al. (2019), shows a comparison of photometric and spectroscopic redshifts estimates using SED fitting for a sample of normal galaxies in the COSMOS field. Adding the NIR J, H and K bands to the optical *ugriz* leads to more accurate photometric redshift estimates compared to those obtained solely using *ugriz* ($\sigma_{NMAD} = 0.031$ vs. 0.042, see Salvato et al. 2019 for details), as well as to a lower fraction of catastrophic outliers (3% vs 12%). Similarly, the results from Laigle et al. (2019) suggest that the LSST photometry alone may be able to provide reliable estimates for $z < 1.5$ and $i < 23$ mag galaxies, but not for higher redshift or fainter galaxies. We note as well that Graham et al. (2020) shows that adding NIR bands to the LSST photometry is necessary to considerably reduce the fraction of catastrophic outliers.

For AGN the situation is even more stark. As discussed in Chapter 10 of the LSST Science Book, as well as in a Cadence Note about quasar counts submitted by the AGN SC, LSST will detect over 10M quasars and as many as 100M AGN through its 10yr lifetime, significantly increasing the number of AGN known and enabling a slew of science studies. However, AGN photometric redshifts have much worse accuracy than those of galaxies due to the lack of strong features in their broad-band SEDs (e.g., Salvato et al. 2019). This is especially the case when only optical photometry is used, which maps the featureless accretion disk power-law emission below $z \sim 2$, when the Lyman break and IGM absorption features are redshifted into the *u*-band. As an example, Figure 2 below shows that the (*i*-*z*) color of a QSO changes much more mildly than for inactive galaxies as a function of redshift. Figure 5 of Brescia et al. (2019) shows that the accuracy for X-ray selected AGN in the SDSS Stripe 82 improves by a factor of approx. 1.6 when adding VHS, *WISE* and *IRAC* observations to the SDSS photometry compared to using SDSS alone. The catastrophic outliers also drop from 24.9% to 13.2% when adding the IR photometry. Similar results were obtained as well by Schindler et al. (2017; see their Figure 6) comparing photometric redshifts of luminous quasars obtained with random forest and support vector machines using SDSS *ugriz* with and without WISE W1 and W2. The addition of WISE results in a dramatic decrease of outliers and an improved photo-z accuracy, dropping the mean squared error from 0.503 to 0.277. The *Y*-band observations of LSST, as well as the potential to use differential chromatic refraction (see Yu et al. 2020 and the AGN SC Cadence Note on DCR), will improve the accuracy compared to only using *ugriz*, but significant further gains remain possible by adding NIR and MIR photometry from other surveys.

1.2 Photometric Redshift Outliers and AGN Identification

Multi-wavelength photometry is also crucial for AGN identification. LSST observations alone will only be able to identify a small fraction of the ~100M AGN that will be detected. The identification of the great majority will necessarily depend on the analysis of longer and shorter wavelength observations. In particular, reddened AGN are much more easily identified using NIR observations, which can probe the dust torus emission or the longer wavelength emission from the accretion disk, depending on redshift (see, e.g., the review on AGN selection by Padovani et al. 2017). X-ray observations, particularly in the harder energy bands, provide the most unbiased AGN identification, although they are typically harder to obtain (see, e.g., Padovani et al. 2017). We note that some of the dispersion in AGN photometric redshifts in the previous examples is driven by AGN variability, as the observations of different surveys are not obtained simultaneously, and LSST will be no exception to this. However AGN identification with significant multi-wavelength observations should be robust even for low photo-z accuracies (see, e.g., Assef et al. 2010). Even if one is not able to obtain an accurate photometric redshift for an AGN, identifying an object as such could be important for science goals that require accurate photometric redshift distributions and that may suffer from AGN contamination.

Multi-wavelength observations beyond the wavelength ranges of LSST are hence crucial for maximizing the scientific output of the survey. Significant amounts of multi-wavelength data will be available throughout the LSST footprint. This will be particularly the case in the DDFs, which were chosen to coincide with fields that are very well studied at other wavelengths at comparable depths to LSST. In the WFD, surveys like *WISE*, *eROSITA* and VHS can prove crucial to identify a number of AGN and improve their photometric redshifts. Although they are too shallow to detect most of the LSST objects outright, we stress that in many cases upper-limits can provide strong constraints as well, particularly placing limits on the AGN contribution in extragalactic sources. Furthermore, within the lifetime of LSST, *Euclid*, and eventually *Roman*, observations will be delivered for a significant fraction of the WFD, allowing for a much deeper NIR view of the LSST sources than ever before.

The AGN SC has a subgroup dedicated to the issue of gathering multi-wavelength observations, and the collaboration road map[1] has identified it as one of the key tasks to enable AGN science. Undoubtedly, many more, if not all, of the LSST Science Collaborations are planning similar tasks to incorporate multi-wavelength photometry from additional surveys. This is a time-consuming task that is far from trivial (for a recent, relevant example on the complexities of broad-range multi-wavelength catalogs in the context of photometric redshifts see Ni et al. 2021). We believe that the DM's efforts to obtain accurate photometric redshifts should necessarily include developing the framework and tools necessary to produce matched catalogs from multi-wavelength surveys complementary to LSST. This will result in more accurate photometric redshifts, better source type identification and photo-z outliers and lower amounts of task replication between the SCs, yielding better, more efficient, science results from LSST.

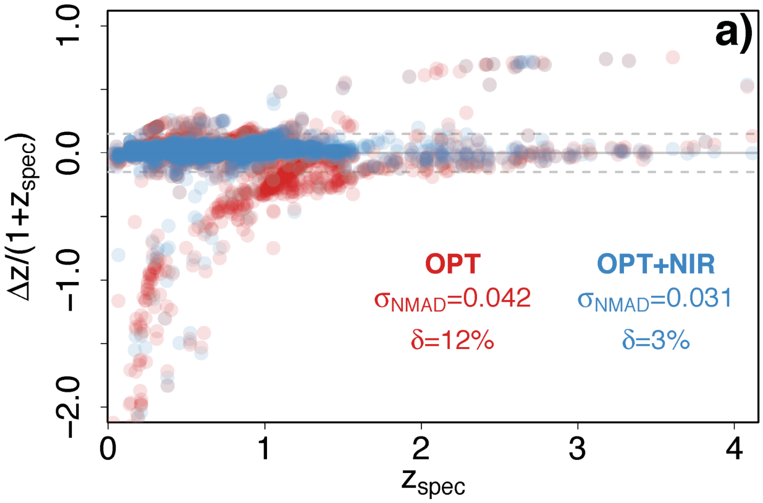

Figure 1: Comparison of photo-z for galaxies computed using the optical bands (*ugriz*; red) or the optical and near infrared (NIR) (ugrizJHK; blue). The addition of NIR infrared photometry improves dramatically the precision at $z > 1$. Sources external to the dashed lines $\pm\, 0.15\,(1 + z_{spec})$ are considered outliers. (*Figure and caption taken from Salvato et al. 2019*).

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[1] https://agn.science.lsst.org/sites/default/files/LSST_AGN_SC_Roadmap_v1p0.pdf

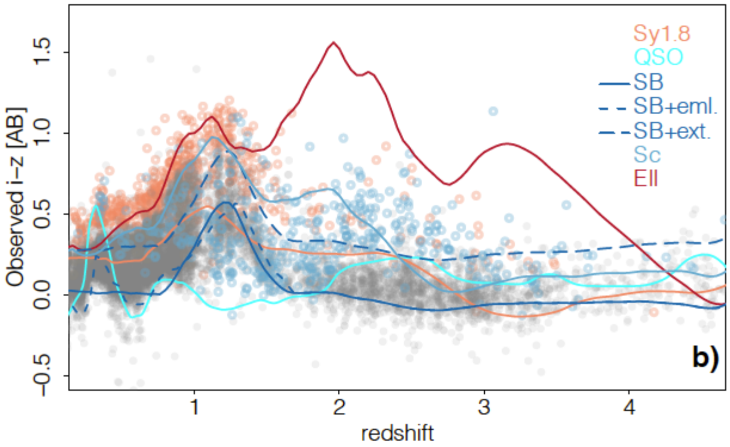

Figure 2: *(i-z)* color as a function of redshift. The solid lines represent the expected redshift evolution of the *(i-z)* color for the templates presented in the left panel, without any extinction. The feature in the QSO color track around z~0.3 corresponds to the Hα emission line, the brightest optical AGN emission line, being redshifted into the *i*-band. (*Figure and caption adapted from Salvato et al. 2019*)

3. References

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