AGN time lag metric

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As members of AGN and TVS SC, here we provide analysis of the v2.0 and v2.1 OpSims based on the AGN time lag metric.

The scientific background of the metric

One method for determining the size of regions in active galactic nuclei (AGN) that are in proximity to supermassive black holes (SMBH) is called time lag measurement, which is analogous to sonar techniques.
AGN are multicomponent objects; so their general model consists of the accretion disk (AD, with a dimension of up to several light days), the broad line region (BLR, with a dimension of tens to a few hundred light days), the corona, the molecular torus, the narrow line region (NLR), and jets.
Despite the fact that the entire large-scale structure has been identified, the characteristics of the central engine (which mostly consists of AD and BLR) are unknown because of its tiny dimensions, even when compared to the AGN that is closest to us. It is necessary to acquire supplementary knowledge in an indirect manner.
The measurement of time delay can provide information on the structure as well as the kinematics of the AD and BLR in the time domain. The variability in the emission from the accretion disk is the primary factor that drives fluctuations in the BLR lines.
Observing the time delays between AD and broad line emission in BLR can be used to calculate the BLR dimension and constrain the widely used radius-luminosity relation, which in turn allows estimation of the SMBH mass.
Similarly to the case of the BLR, the light travel time across the AD can be inferred through time delays.

Content of Cadence Analysis

Because AD and BLR are two distinct components with distinct dimension ranges that are both measured using the same technique, our AGN time lag metric addresses dimension estimates for both.
We differentiate two types of time lags of interest in the context of cadence analysis:

- i) BLR time lags in the range of [10, 400] light days:
  The plots used to interpret AGN time lag metric realization presented here are **for fiducial BLR dimension 100 light days** compiled in jupyter notebook by Lynne Jones.

- ii) AD time lags <~ 10 light days:
  For AD time lag measurement for fiducial value of 5 light days we provide separate analysis in this document.

We emphasize that our metric includes a threshold in itself. If mean 5 sigma depths in r-band are 18, 19, and 20 and/or the long gaps in coverage, then the value of our metric is returned as NaN (since it is less than the threshold, see Figure 0). The threshold value could be changed manually during the initialization of the metric (by setting a value for a threshold argument).

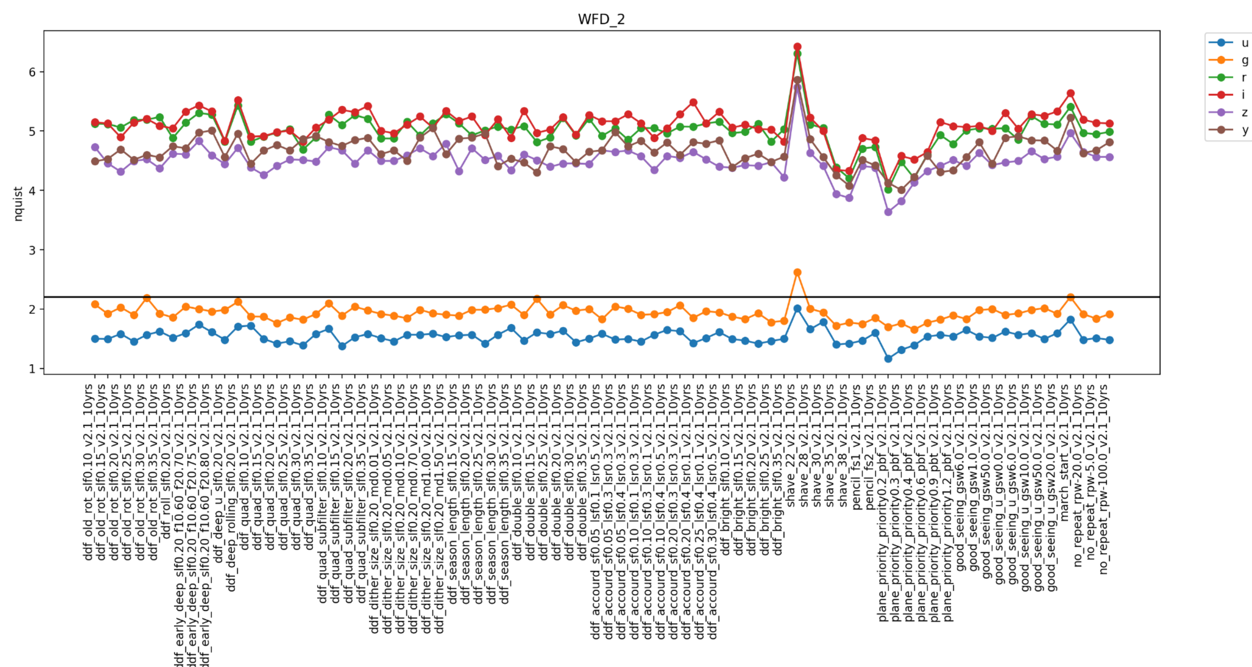

Figure 0. Illustration of AGN time lag metric being under the threshold value of 2.2 (dashed black line) for u and g bands. The y-axis contains metric values and x-axis contains observing cadences.

i) Cadence analysis of AGN time lag metric for fiducial BLR dimension of 100 light days based on jupyter notebook compiled by Lynne Jones.

It is worth noting that jupyter notebook provides values integrated across large areas of the sky, which might be suitable for the BLR time lag measurement cadence analysis.
Still, because our metric may return NaN (since the metric value is less than the threshold), this may influence mesh visualizations in jupyter notebooks to have white slabs.

Legend:
OpSim runs are marked in color indicating green = ok, yellow = caution, red = not suitable

-a subset of runs which focus on seasonal-length cadence

Baseline cadences:
Overall, the AGN time lag metric shows a slight improvement across all seasonal-length cadences. *Baseline_v2.0* performs slightly better than *v2.1*, but baseline_retrofoot and

retro_baseline perform roughly 10% better. However, as demonstrated in our prior investigations, **tiny differences in the baseline will have no effect on the time lag inaccuracy of estimation.**

Rolling Cadence (rolling, roll_, _six_rolling):
In general, rolling cadence is neutral for detecting BLR time lags, but it can underperform (white stripe across largely r and g band) if objects with mean 5 sigma depths of 18, 19, and 20 are omitted and/or due to the long gaps in coverage. In these cases, the value of our metric is returned NaN (since it is less than the threshold).

-intra-night cadence

Presto Color and third visits in a night (presto_gapXX, presto_gapXX_mix, presto_half families, and long_gaps family):

Our metric performance on presto_gapXX is somewhat lower than on presto_gapXX mix. The presto_half and long_gaps families are neutral. We emphasize once more that if items with mean 5 sigma depths of 18, 19, and 20 are rejected and/or the value of our measure is returned as NaN because it falls below the threshold. **As we are interested in time scales ranging from tens to hundreds of light days, presto families could not worsen time lag determination in BLR.**

suppress repeats - number of nights with visits

no_repeat_rpw_XX **cadence family is almost neutral, with a slight preference for u-band.**

Filter distribution (long_u1, long_u2):
The long_u2 family is slightly better than long_u1, perhaps due to larger number of total visits; **long_u1 is not beneficial for z-band, performing worse by ~20%.**

Varying exposure time (shave_XX<32, shave_XX>32):
It seems somewhat surprising that the shave_XX families with an exposure time per visit XX<32 show better performance for time lag detection than those with XX>32. However, the number of visits in each band as well as the area with the number of visits >825 are smaller.

good_seeing_: this family of cadences are mostly neutral for time lag determination

Vary_nes nestraceXX<35 and vary_gp_gptraceXX<35; Vary_nes nestraceXX>35 and vary_gp_gptraceXX>35 families:

Our metric performance on both families is comparable. **There is an improvement with smaller WFD level inclusion (XX<~ 35), but our metric suffers with XX>35.** This is possibly due to the highest number of visits in all bands for XX<~35.

Plane_ priority family is worse than both the preceding families.

The Galactic plane is less favorable for quasar science, suffering from higher extinction and reddening. Additionally, many "unusual" stars are located within the Galactic plane, sharing many similar observational properties with quasars, and these stars can be contaminants for quasars at various redshifts. **However, the quasars identified by LSST at the back of the galactic plane will have a specific value for time lag determination and other AGN sci-cases. Perhaps cadences with XX<35 could aid us in determining time lags for quasars at the back of the galactic plane.**

DDF Observing Strategies (ddf_), (ddf_quad, ddf_bright):
In the Jupyter Notebook, DDF cadences are displayed as integrated across all fields; nevertheless, we would want to call attention to the fact that there is a distinction between different deep drilling fields in our metric realization. The two DDFs that perform the best according to our metric are COSMOS and XMM LSS. However, the performance of other DDFs is slightly lower. The integration creates an average result that consists of two favorable fields and the rest of less favorable fields. Hence, the color mesh plot demonstrates variation in shades of redder and bluer colors. **However, even in this integrated version, we are able to see that our metric suffers in ddf_ quad and ddf_bright cadences, whilst ddf quad subfilters and ddf accordion allow for nice performance.**

Twilight NEO v2.0 simulations (twilight_neo_nightpatternXX family):
Depending on the elevation of the airmass and/or whether the object is setting or rising during twilight, AGN observations might be negatively affected.
On the other hand, our metric suggests that the twilight family is useful for time lag determination for those AGN that will be observable during this time of day (there are examples in the literature). Perhaps as each band has a greater total number of visits, allows for nice metric performance.

ii) AD time lags <~ 10 light days:

For AD time lag measurement for fiducial value of 5 light days we provide separate analysis in this document.

1) *WFD cadence families*

We chose several sky positions in WFD fields with large QSO number counts as indicated by Assef et al 2021 NQSO metric, and assumed that each position corresponds to a quasar object. **In WFD, our metric shows that AD time lag measurement will be of very low quality at a level of 2–10% of our imposed threshold (which is assumed to be**

2.2). An example point WFD_2=(ra=35,dec=-28) is illustrated in Figure 1, for which is shown metric values for ddf_ , shave_, plane_priority, good_seeing, and no_repeat families in all bands.

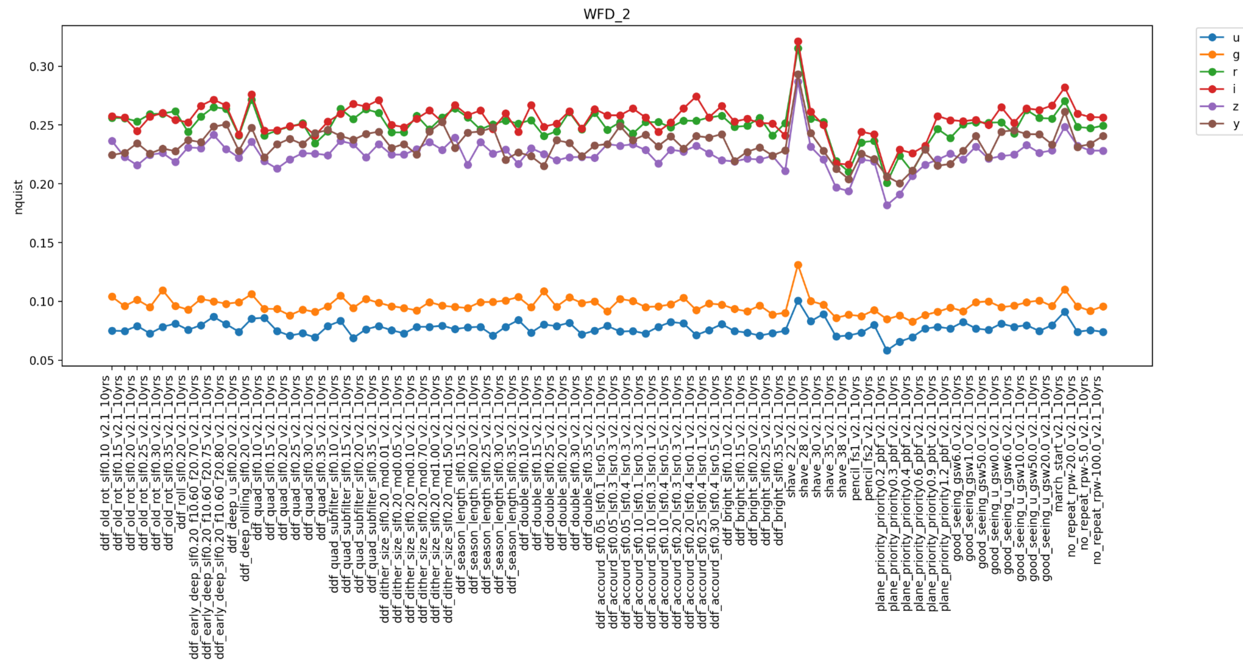

Figure 1. AGN Time Lag metric realization for fiducial AD time lag of 5 days in chosen WFD point. Y-axis shows metric value, x-axis shows cadence families. LSST bands are given in different colors. Note that the metric threshold is 2.2. The MAF implementation of our metric returns NaN for values below the threshold of 2.2.

2) DDFs :COSMOS, XMM LSS, ECDFS, ELAISS1, EDFS_a and EDFS_b

-ddf_ family of cadences, ddf_quad_subfilter: The metric realizations are shown in Figures 2-7 for COSMOS, XMM LSS, ECDFS, ELAISS1, EDFS_a and EDFS_b respectively. **All DDFs have metric values higher than the threshold of 2.2 (as represented by the dashed line). However, the ddf quad_subfilter family in all DDFs is below the threshold, so that our metric returns NaN. This creates a gap in all plots. The accordion family is the most successful family in COSMOS across all bands. XMM LSS is similar to COSMOS, but the r-band is suppressed.**
Other fields are very comparable to one another; however, their metric values are a little bit lower than in COSMOS and XMM_LSS, and the r-band is muted.
The reason for degradation of r-band is that we excluded objects with 5 sigma depth 18,19, and 20.

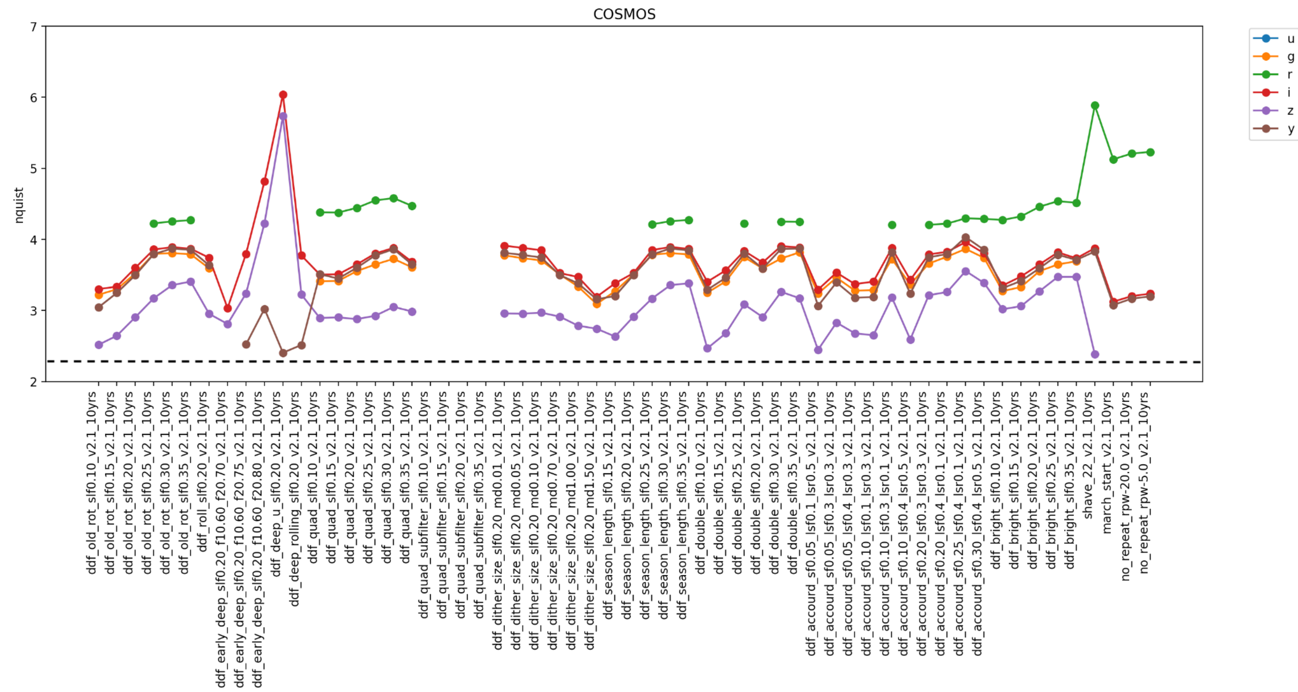

Figure 2. AGN Time Lag metric realizations in COSMOS field for different ddf cadence families. Horizontal dashed line represents a metric threshold of 2.2.

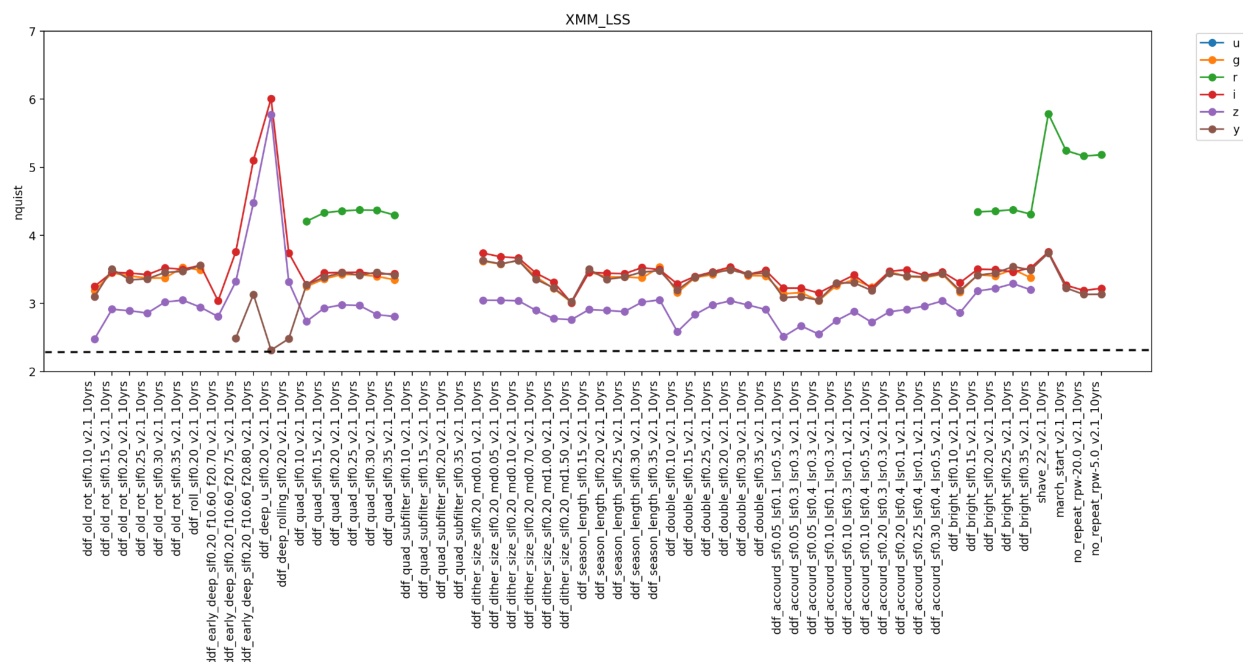

Figure 3. The same as Figure 2 but for XMM_LSS.

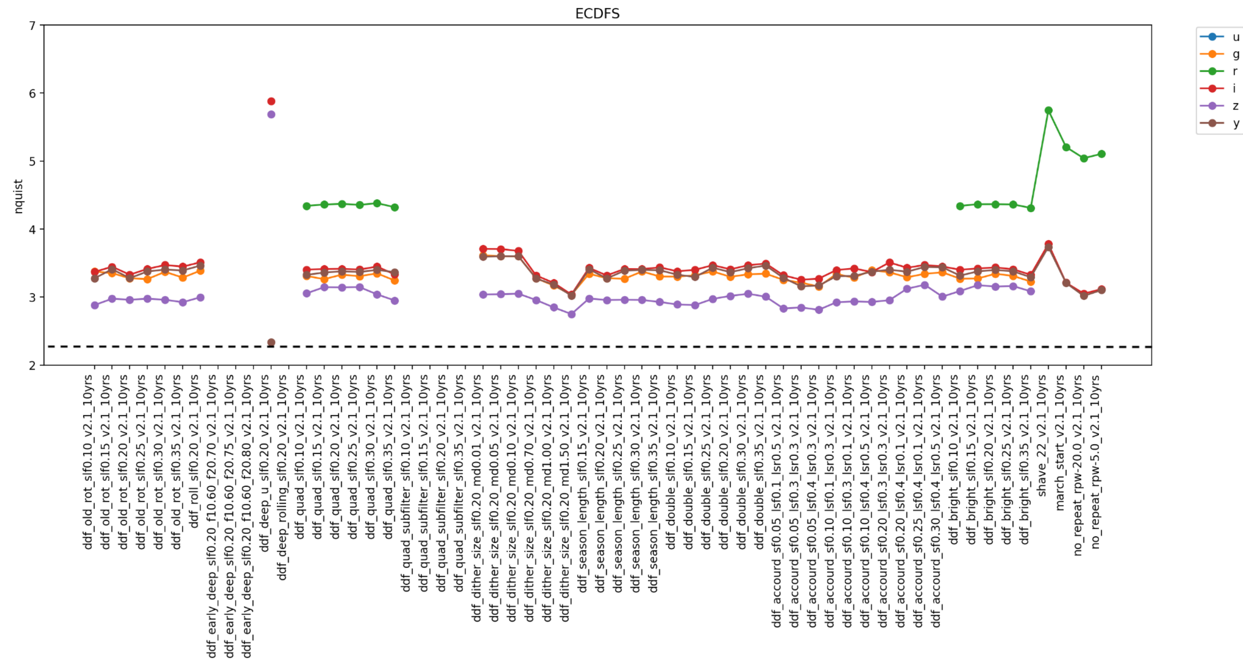

Figure 4. The same as in Figure 2 but for ECDFS.

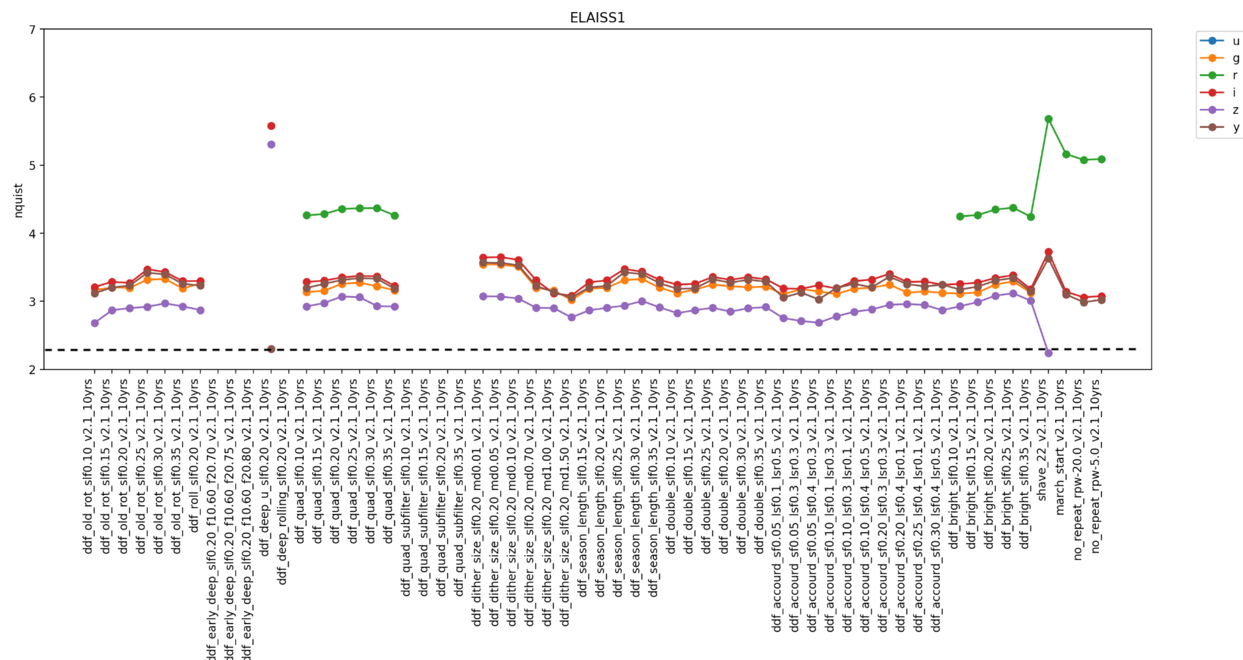

Figure 5. The same as Figure 2 but for ELAISS1.

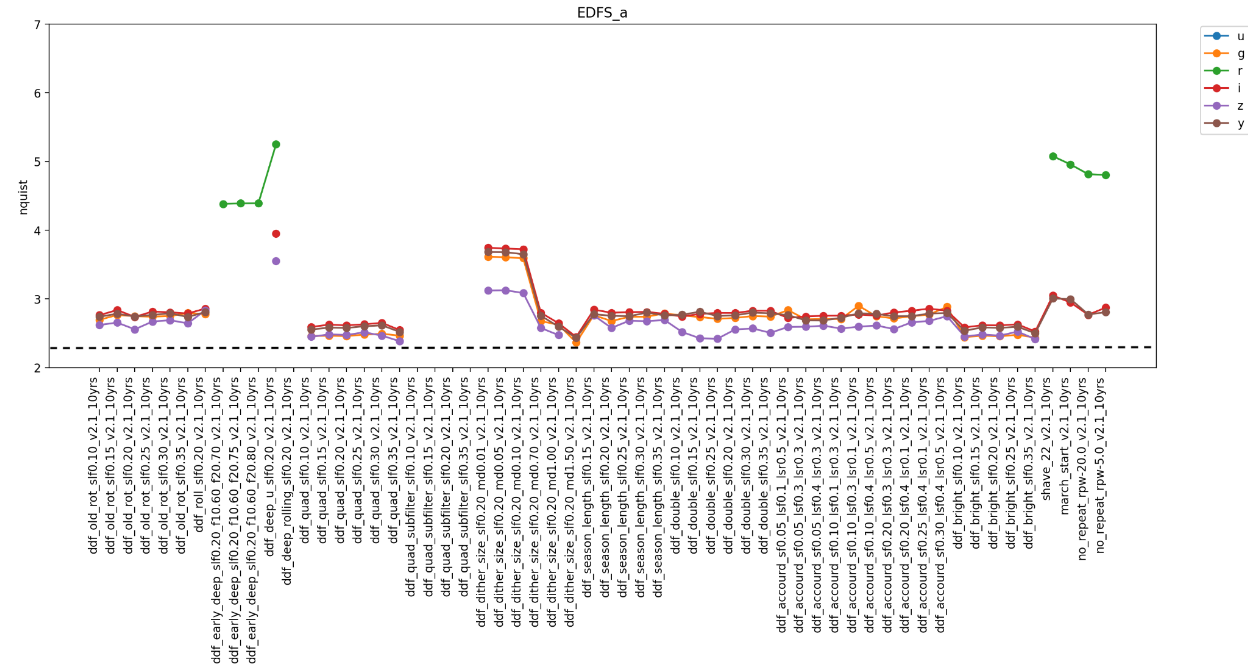

Figure 6. The same as Figure 2 but for EDFS_a

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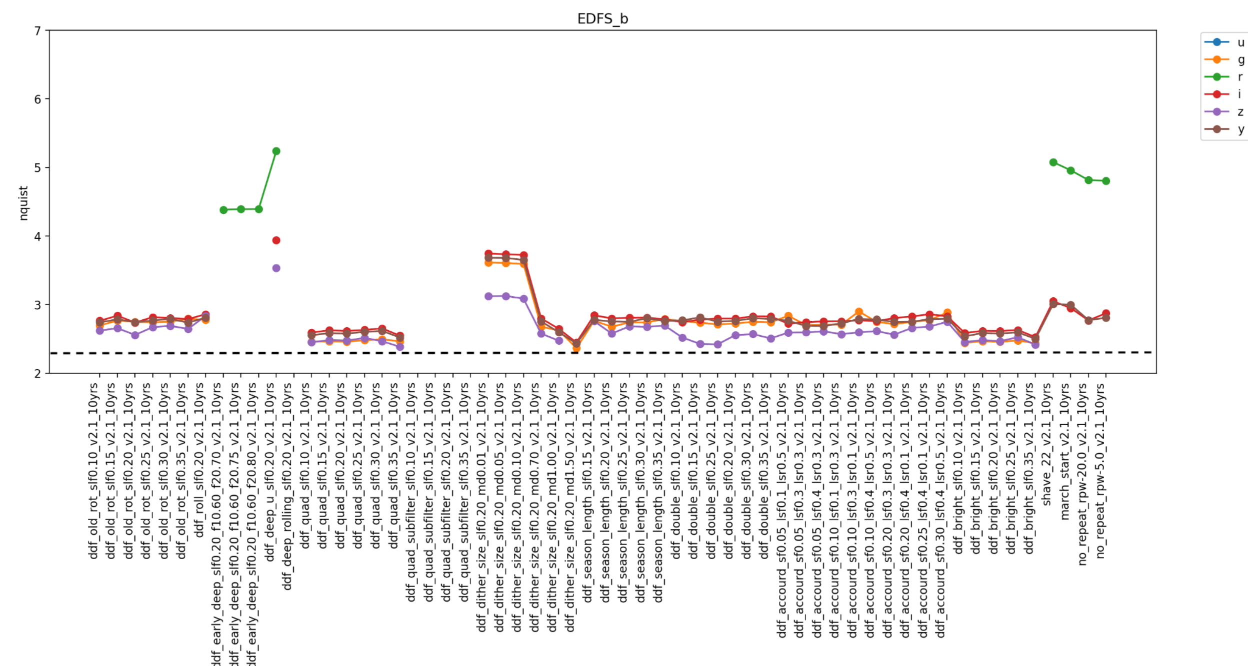

Figure 7. The same as Figure 2 but for EDFS_b.

-shave_, plane_priority, good_seeing, no_repeat: **As can be seen in Figure 8, these families have a preference for the r, i and y bands, whereas the other bands are more muted across all DDFs.**

-baseline_families: metric performs similarly well (far above the threshold) across the DDFs, however g and z bands are muted across the DDFs (see Figure 9).

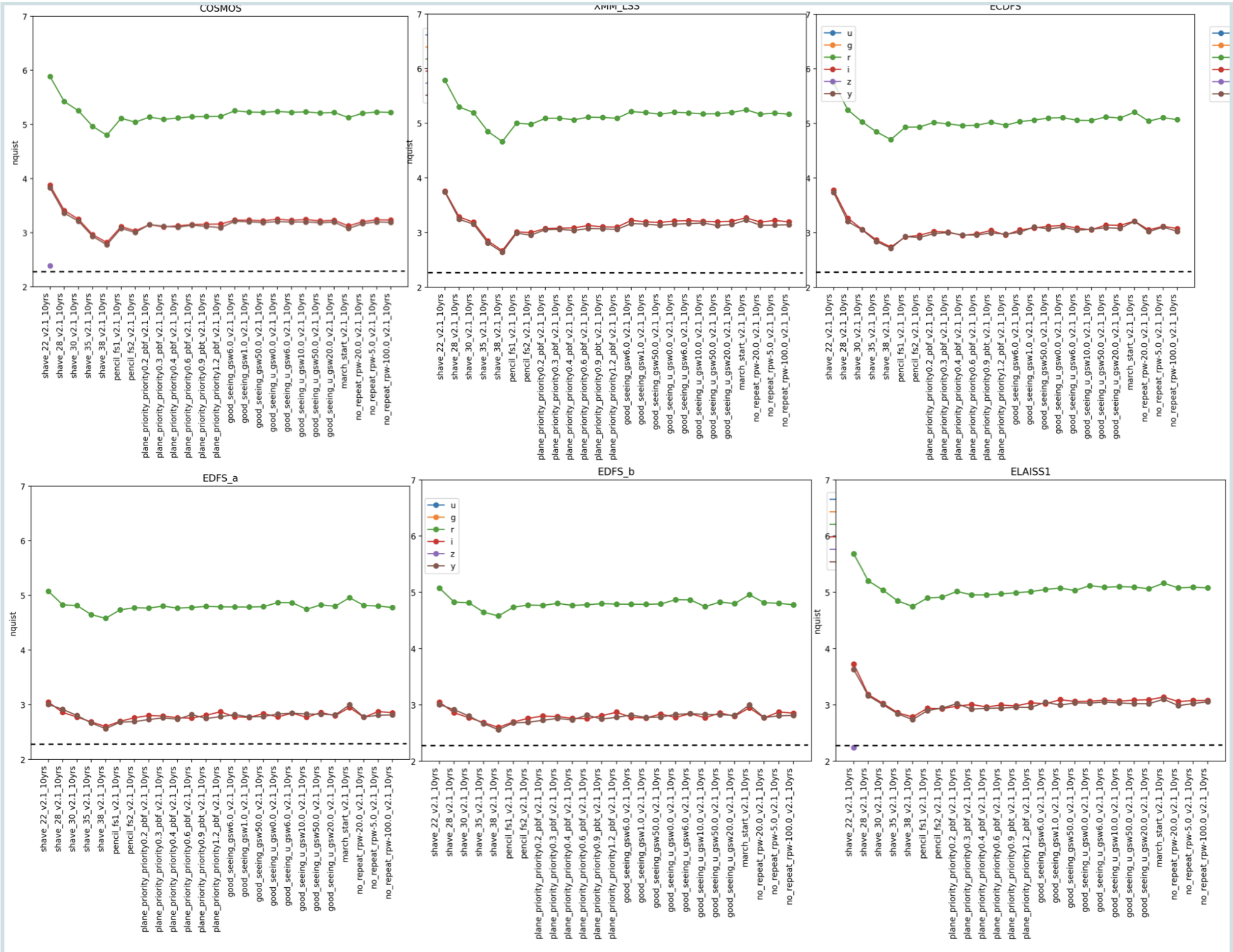

Figure 8. Metric realization in COSMOS, XMM_LSS, ECDFS (top row) and EDFS_a, EDFS_b, ELAISS1 (bottom row) for observing strategies shave_, plane_priority, good_seeing, no_repeat.

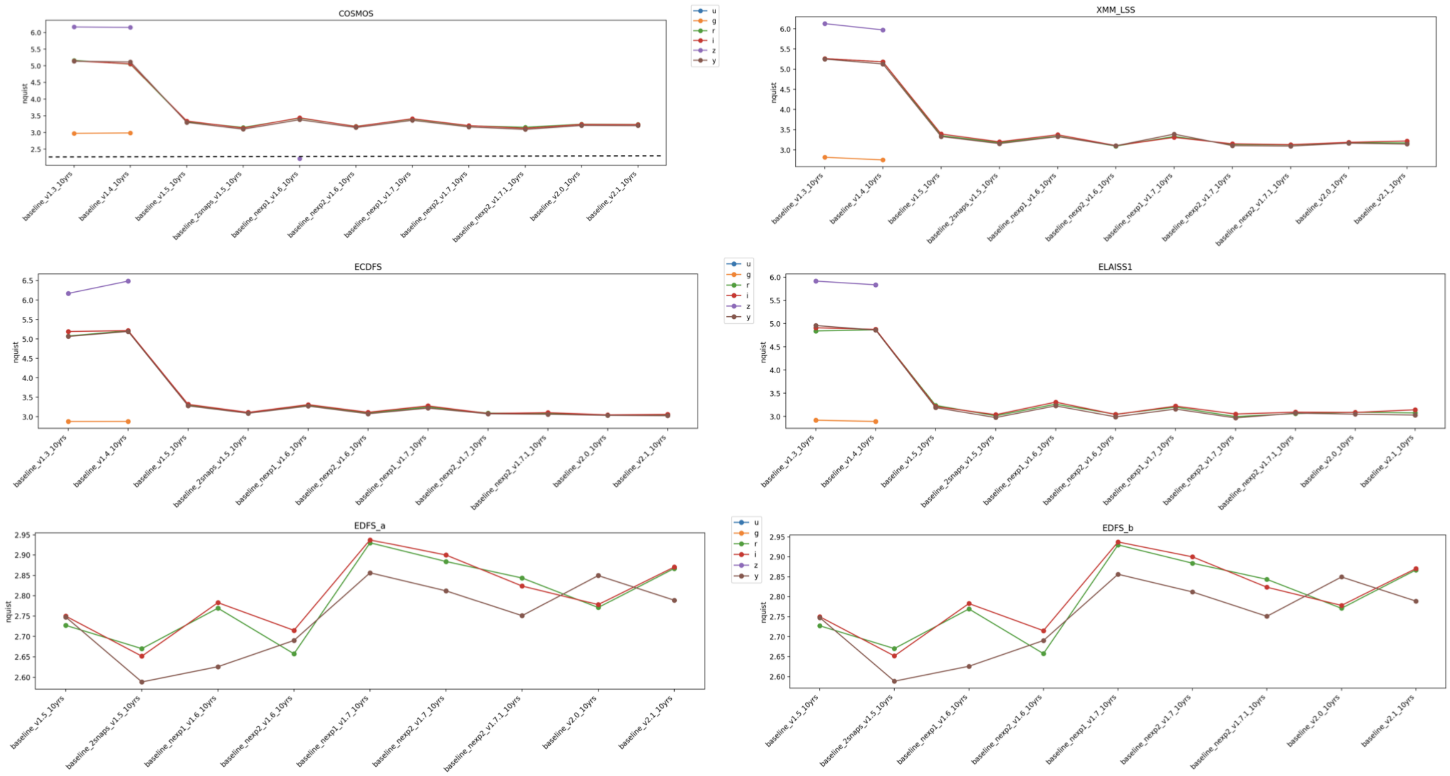

Figure 9. Metric realization in COSMOS, XMM_LSS, (top row), ECDFS, ELAISS1 (middle row) and EDFS_a, EDFS_b (bottom row) for baseline_ strategies.