LSST CADENCE NOTE: BLAZAR VARIABILITY

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1 Introduction

With their emission coming from a relativistic jet pointing towards us, blazars are fundamental sources to study extragalactic jets and their central engines, supermassive black holes fed by accretion discs. Blazar emission is Doppler beamed and boosted; its variability is unpredictable and occurs on time-scales from minutes to years. The study of blazar variability requires well-sampled light curves and colour trends in time. To avoid bias due to variability, colour indices must be built with data acquired close in time, preferably within a few hours and in any case within the same night. Outbursts are the events that provide us the best test bench to shed light on the underlying physics, especially when studied in a multiwavelength context. But the identification of outburst states with LSST to trigger follow-up observations can be hindered by saturation. This can have a negative impact on the synergy between LSST and other observing facilities.

2 Metrics and results

We aim at testing i) light curve sampling, ii) colour indices sampling and iii) amount of saturation. To check our requirements in a quantitative way, we used two metrics.

With the help of Peter Yoachim we investigated a **blazar_saturation_metric**. This simulates a sky filled with the 3561 known blazars listed in the BZCAT5 catalogue (https://www.asdc.asi.it/bzcat/). We consider the catalog magnitude of each blazar as its base-level brightness, and let the source flare, with flaring timing (period) and characteristics (outburst amplitude and time spent in outburst) randomly determined in a reasonable range (see Fig. 1, left panel). We note that the sources are spread over all the extragalactic sky, both in the northern and in the southern hemisphere. The metric estimates the fraction of sources detected in outburst and that of saturated observations. The results are shown in the right panel of Fig. 1. The largest number of detected sources and sources detected in outburst are obtained in the runs alt_dust..., alt_roll_mod2_dust..., footprint_big_sky_dust... and roll_mod2_dust... The number of saturated observations goes from $\sim 3\%$ to $\sim 6\%$ and of course the Opsim runs with single exposures of 30 sec perform worse than runs with double exposures of 15 sec. Intermediate saturation levels are obtained with the short_exp... (better 5 times a year than twice) and by the filterdist... cadences. We stress that although the saturation seems to affect only a small fraction of outbursts, these bright events are the most interesting ones to understand the jet physics and trigger follow-up observations at high energies, particularly in the TeV regime. In Fig. 2 we plot the sky maps highlighting whether a source has been observed to flare (left) and the fraction of saturated observations (right) obtained with the baseline_nexp2_v1.7_10yrs Opsim run.

The **TransitAsciiMetric** was adopted to investigate sampling of both light curves and colour indices. We used a well-sampled blazar light curve and interpolated among data points to have a continuous coverage. The results are shown in Fig. 3 for the WFD, and in Fig. 4 for the DDFs. They test a location in the sky at RA=30° DEC=-30° for the WFD, and RA=34.39° DEC=-5.09° for DDF (within XMM-LSS). Colour indices are obtained with data separated by a maximum of 0.1 d, but the results are approximately the same if we enlarge the time interval to one day.

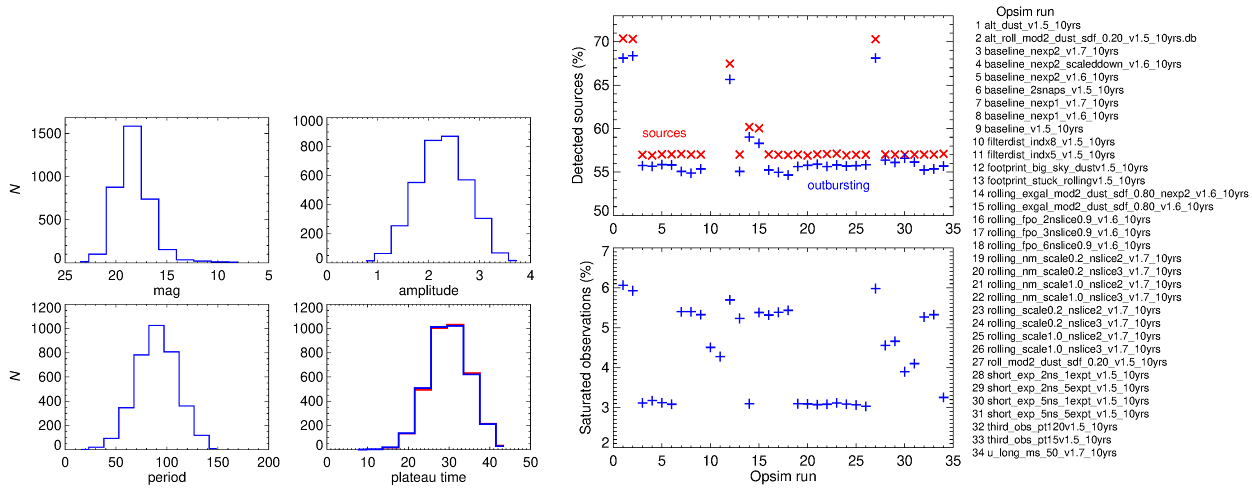

Figure 1: *Left.* The parameter distributions for the flaring sources used in the saturation metric; from top left in clockwise direction: the catalog magnitudes used as base-line brightness, the outburst amplitude (mag), the plateau time (d), the period (d). *Right.* The percentage of detected sources (red) and of sources detected in outburst (blue) (top), and of saturated observations (bottom) for various Opsim runs listed on the right.

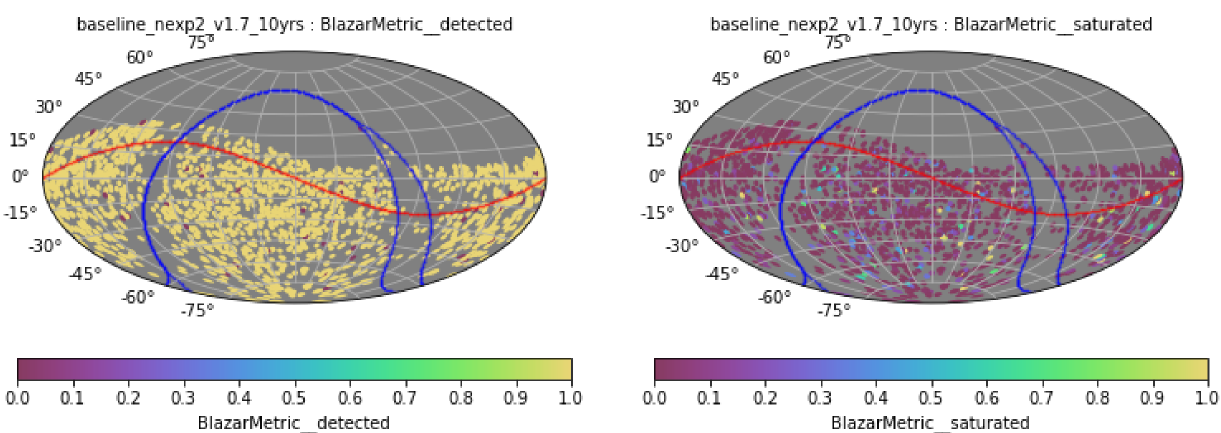

Figure 2: The sky map of sources detected in outburst (left; it gives 1 if the source is seen to brighten by at least 0.5 mag with good photometry) and fraction of saturated observations (right) for the baseline_nexp2_v1.7_10yrs Opsim run.

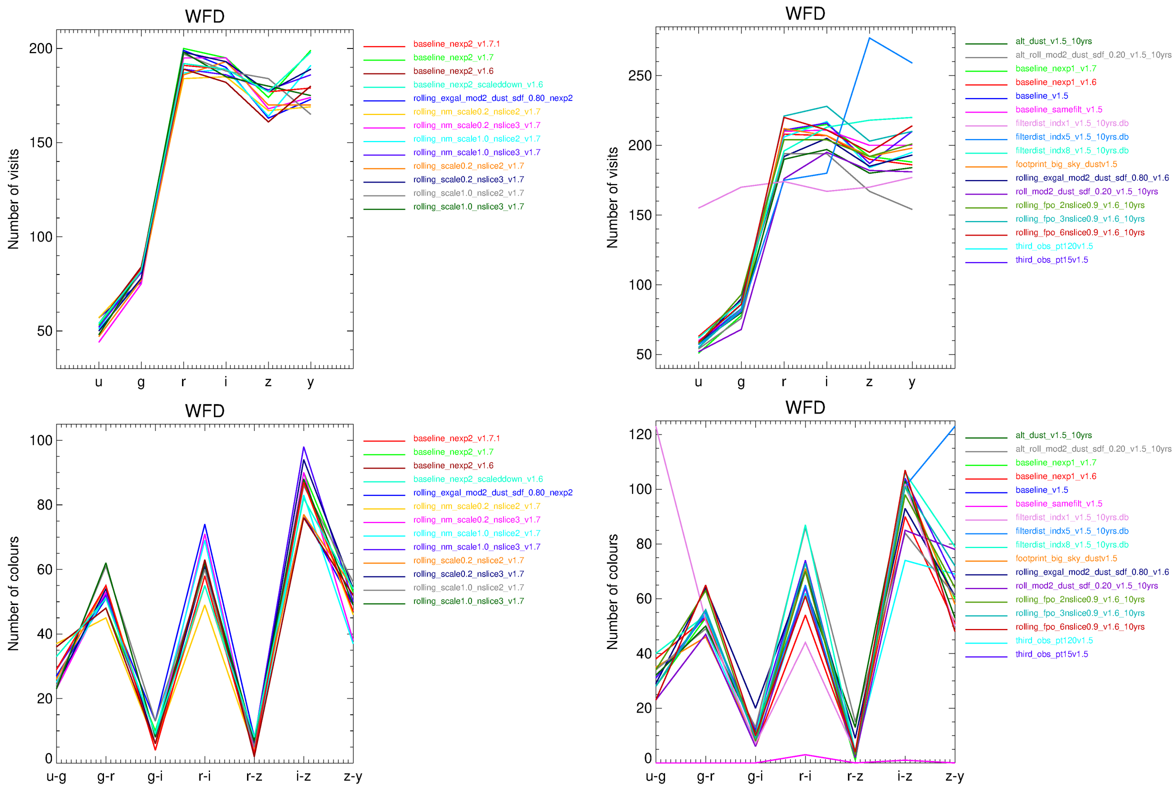

Figure 3: Results of the TransitAsciiMetric for the WFD. We show the number of visits (top) and the number of colour indices obtained with close-in-time observations (bottom). Plots on the left refer to Opsim runs with 15 s exposures, plots on the right to runs with 30 sec exposures.

In the WFD case, among the OpSim runs with 2x15s exposures, the baseline_nexp2_v1.7 is the best performing in terms of light curve sampling, because it yields the maximum number of points in the best-sampled r-band light curve, and around the maximum number in the other bands. The 30 sec exposure cases lead to about 10% more visits, but at the expenses of increasing saturation. Some rolling cadences can produce better sampling than the baseline runs. The number of colour indices obtained in the WFD is very small. The maximum number of points is obtained in $i - z$. Among the 2x15s cases, this is achieved with the rolling_nm_scale1.0_nslice3_v1.7 run, and in the 1x30s cases with the rolling_fpo_6nslice0.9_v1.6 run. As expected, the simulation baseline_samefilt_v1.5 cannot provide colours with the close-in-time requirement.

As for DDFs, the baseline_nexp2_v1.7.1 OpSim produces the best overall sampling of the light curves. The about 10% more points that can be obtained with 1x30s exposures are not worthwhile because of the greater impact of saturation. Here again some rolling cadences can give better sampling. The number of colour indices in DDFs is potentially very useful in blazar variability studies (but see answer to Q2). The run baseline_nexp2_v1.7.1 leads to a maximum number of $g-i$, $g-r$, and $u-g$, and close to the maximum of $r-i$, colour indices. Among the 1x30s runs the rolling_exgal _mod2_dust_sdf_0.80_v1.6 produces the best sampling in almost all colours.

In conclusion, our metrics can put constraints on the exposure time, favouring 2x15 sec snapshots, and strongly disfavour visits in a pair in the same filter.

Finally, we would like to mention the synergy with other cadence notes, which are presented by Eric C. Bellm et al., Will Clarkson et al., Xiaolong Li et al.

3 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

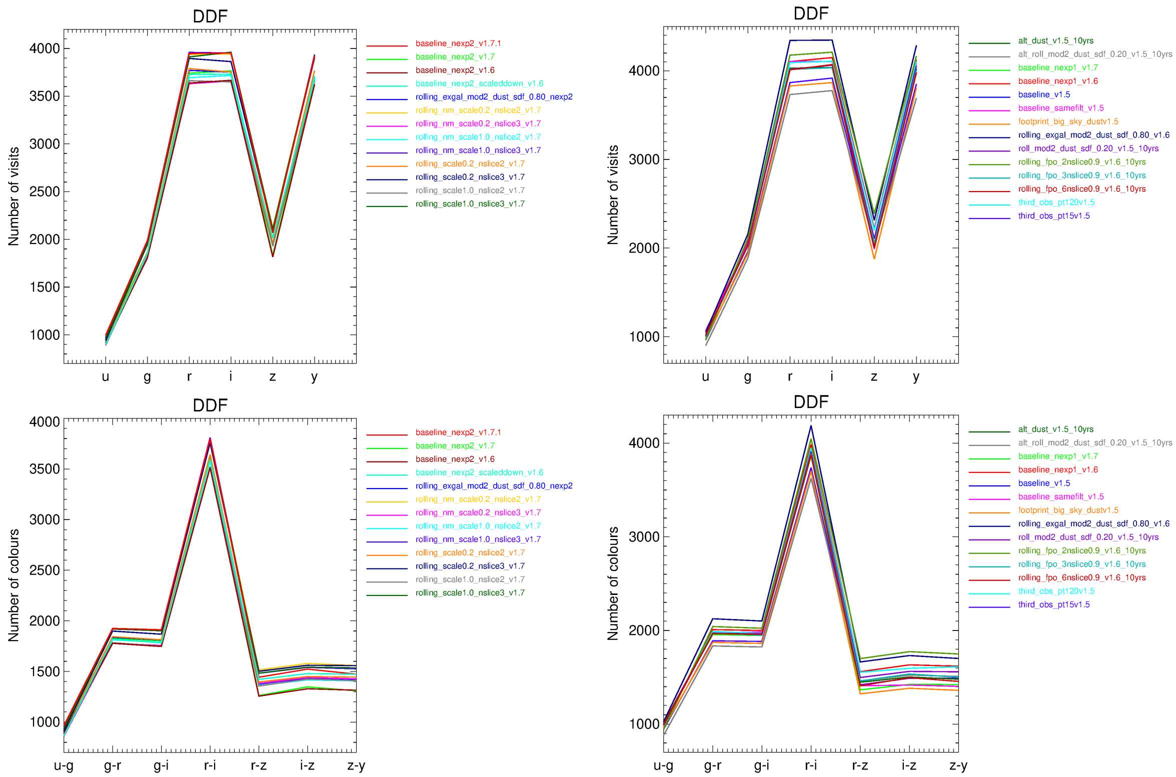

Figure 4: As in Fig. 3, but for the DDF case.

about 10%. If available, please mention specific simulated cadences, and specific metrics, that support your answer.

Blazar variability science in general prompts to better sampling rather than to more extended area. However, Fig. 1 shows that the footprint_big_sky_dustv1.5_10yrs leads to a 10% more detections of known sources and possible outbursts, which is valuable. Unfortunately, this OpSim run includes 1x30s exposures, which worsen saturation.

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.

In the White Paper by Raiteri et al. (2018, https://arxiv.org/abs/1812.03151), we proposed an interactive mini-survey in star trail mode to solve the problem of saturation of bright blazars or faint blazars in outburst, and at the same time search for very fast transients like e.g. possible optical counterparts of fast radio bursts. The mini surveys GP, NES and SGP are too poorly sampled to be really useful for blazar variability science. In contrast, in DDFs the samplings of light curves and colours made with close-in-time visits meet the requirements for blazar variability studies. The DDFs limit is to cover too small portions of the sky for such rare sources as blazars. However, DDFs can offer the possibility to reveal new sources, likely faint blazars at high redshift and are of utmost interest for the more general study of AGN variability. It would be preferable to have shorter sequences more often.

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.

We favour visits with 2x15 sec exposures in all bands to mitigate saturation. In the specific case of the *u* band, we compared the median saturation mag of the baseline_nexp2_v1.7_10yrs Opsim run with that of the u_long_ms_50_v1.7_10yrs run. We found that the median saturation mag in u band peaks around 13.1 in the baseline simulation, and around mag 14.4 in the case with u exposures of 50 sec. Therefore, we lose a range of about 1.3 mag going from 15 sec to 50 sec exposure times. The number of blazar outbursts that will reach a brightness level greater than 14.4 in u band is expected to be small, but these are certainly the most interesting ones, making a broad multiwavelength study, up to TeV energies, possible.

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.

Different types of blazars have different colours, so skewing towards blue/red would favour the study of some objects and disfavour that of the others.

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.

We need colour indices made with observations close in time, therefore we favour the two visits in a pair in different filters. Our metrics overall show no remarkable benefit in adding a third visit.

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.

In general, even if some rolling cadences seem to perform well in terms of sampling, regular monitoring may be preferable. The AltSched N/S nightly pattern of visits increases the number of detected sources and flaring sources, but it is not beneficial from the point of view of the number of visits and colours. Increasing the season length could be useful to reduce the seasonal gap in the light curves.

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.

No requirement on dithering.

4 Acknowledgements

We are deeply indebted to Peter Yoachim, who made the development of the blazar saturation metric possible. We are grateful to all our SC coordinators, and in particular to Federica, Rachel, Sara, Niel, Gordon, Sebastian, Jan-Torge for their precious work!