Active Galaxy Science in the LSST Deep-Drilling Fields: Footprints, Cadence Requirements, and Total-Depth Requirements

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Abstract

This white paper specifies the footprints, cadence requirements, and total-depth requirements needed to allow the most-successful AGN studies in the four currently selected LSST Deep-Drilling Fields (DDFs): ELAIS-S1, XMM-LSS, CDF-S, and COSMOS. The information provided on cadence and total-depth requirements will also likely be applicable to enabling effective AGN science in any additional DDFs that are chosen.

1 White Paper Information

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This white paper addresses active galactic nucleus (AGN) science in the LSST Deep-Drilling Fields (DDFs), including transient supermassive black hole (SMBH) activity. It is thus relevant to the “Exploring the Changing Sky” main LSST science theme.
The survey type relevant to this white paper is the LSST DDFs.

This is an “integrated program” with science that hinges on the combination of pointing and detailed observing strategy.
2 Scientific Motivation

The aim of this white paper is to specify the footprints, cadence requirements, and total-depth requirements needed to allow successful AGN studies in the four currently selected LSST DDFs.

Footprints: AGNs are fundamentally multiwavelength sources, and thus their effective selection and study are largely enabled by available high-quality multiwavelength data. The LSST DDFs were chosen to have among the best multiwavelength coverage in the sky, and substantial additional multiwavelength data were gathered in the DDFs after they were announced (see Figure 1). These DDF multiwavelength data can be used to assemble a “ground-truth” complete census of reliable AGNs (with sky density 1000–2000 deg$^{-2}$), both obscured and unobscured, that is then used to train AGN selection and photometric-redshift derivation in the main LSST survey. Below we propose precise footprints for the four currently selected LSST DDFs that optimize overlap with the available multiwavelength data.

Cadence Requirements: We desire the DDFs to be observed at least every two nights in grizy over the longest possible observing seasons during the full 10 yr LSST survey (additional key cadence details are given below). This cadence is required to provide the following:

1. Photometric support for multi-object spectroscopic reverberation mapping (RM) campaigns, including the SDSS-V Black Hole Mapper (BHM; Kollmeier et al. 2018, arXiv:1711.03234) and the 4MOST TiDES-RM Project (S. Hoenig, private communication). These aim to derive broad-line region (BLR) properties and reliable SMBH masses for distant AGNs with expected observed-frame reverberation lags of 10–1000 days. Dense, high-quality supporting photometry from LSST will substantially improve the accuracy/precision of derived SMBH masses and also improve the number of reverberation-lag detections, as demonstrated via both Monte Carlo simulations (e.g., Shen et al. 2015, ApJS, 216, 4; J. Li et al., in preparation) and analyses of present RM data (e.g., Grier et al. 2017, ApJ, 851, 21).

2. Dense, high-quality photometry spanning multiple bands that is powerful for studying accretion disks via continuum reverberation lags (e.g., Fausnaugh et al. 2016, ApJ, 821, 56; Jiang et al. 2017, ApJ, 836, 186; Mudd et al. 2018, ApJ, 862, 123; Homayouni et al., arXiv:1806.08360) for $\approx$ 3000 AGNs spanning a wide range of luminosity and redshift. The proposed two-night sampling is critical to ensure a high lag recovery fraction for the relatively short accretion-disk lags expected (Yu
et al., arXiv:1811.03638), and observations spanning 10 yr will allow investigations of secular evolution of these lags that test the underlying model. Basic RM for the BLR entirely based on photometric data may also be possible (e.g., Chelouche et al. 2014, ApJ, 785, 140).

3. Data for calibrating long-term AGN variability selection using the 40,000–80,000 AGNs in the ground-truth sample (e.g., De Cicco et al. 2015, A&A, 574, 112; Falocco et al. 2015, A&A, 579, 115). Here it is essential to reach the long timescales where the red-noise power spectral density function indicates that AGN variability will be strongest, and mild long-term changes in obscuration/scattering may allow even obscured AGNs to be identified with the high LSST signal-to-noise.

4. Critical tests of general AGN continuum variability, as described by damped random walk and other models (e.g., MacLeod et al. 2012, ApJ, 753, 106; Kasliwal et al. 2015, MNRAS, 451, 4328). Well-calibrated continuum-variability models, including both flux and color information, will be essential for making optimum use of AGN variability information in the main LSST survey. Exceptional modes of AGN variability will also be investigated, including color-dependent AGN periodicity or quasi-periodicity on week-to-year timescales from, e.g., accretion-disk “hot spots”, density waves, or close binary SMBHs (e.g., Graham et al. 2015, MNRAS, 453, 1562; Bhatta et al. 2016, ApJ, 832, 47; Charisi et al. 2018, MNRAS, 476, 4617; Smith et al. 2018, ApJL, 860, L10).

5. Exploration of transient phenomena such as stellar tidal disruptions (e.g., Stone et al. 2018, arXiv:1801.10180), changing-look AGNs, jet-linked flares, and intermediate-mass black hole outbursts. Such transient behavior arises over timescales spanning days to years.

**Total-Depth Requirements:** We desire total depths of $z \approx 27.9$ and $y \approx 26.5$ to detect statistically meaningful samples of $\approx 30$ ($\approx 100$) AGNs at $z \gtrsim 7$ ($z \gtrsim 6$); e.g., see Matsuoka et al. 2018, arXiv:1811.01963). The total depths of $g$, $r$, and $i$ will be 28.3–28.7 after satisfying the AGN variability cadence requirements. We require the total depth in $u$ also reach $\approx 28.3$ to effectively improve photometric-redshift quality (especially in reducing outliers) for AGNs detected in $g$, $r$, and $i$ at $z \lesssim 4$. These deep optical data will also help determine the nature of optically faint AGNs identified at radio, X-ray, and other wavelengths (e.g., Richards et al. 1999, ApJ, 526, 73; Mainieri et al. 2005, A&A, 437, 805; Luo et al. 2010, ApJS, 187, 560).
3 Technical Description

3.1 High-level description

Below we specify the footprints, cadence requirements, and total-depth requirements needed to allow the most-successful AGN studies in the four currently selected LSST DDFs: ELAIS-S1, XMM-LSS, CDF-S, and COSMOS.

3.2 Footprints – pointings, regions, and/or constraints

The LSST field of view is sufficient to cover the prime multiwavelength data available in each of the four DDFs, so we request a single pointing position for each of the DDFs. To optimize overlap with the available multiwavelength data, we propose that the four LSST DDFs be centered at the positions listed in the table in this section.

| Field Name | Central RA (J2000) | Central Dec (J2000) |
|------------|-------------------|---------------------|
| ELAIS-S1   | 00:37:48          | −44:01:30           |
| XMM-LSS    | 02:22:18          | −04:49:00           |
| CDF-S      | 03:31:55          | −28:07:00           |
| COSMOS     | 10:00:26          | +02:14:01           |

In Figures 2–5, we show how the resulting LSST fields align versus the available multiwavelength data. In choosing the field central positions, we have prioritized ensuring overlap with the sky regions covered by the SERVS (Mauduit et al. 2012, PASP, 124, 714), 5 Ms XMM-SERVS (e.g., Chen et al. 2018, MNRAS, 478, 2132), VIDEO (Jarvis et al. 2013, MNRAS, 428, 1281), and Spitzer DEEPDRILL (M. Lacy et al., in preparation) programs; the SERVS, XMM-SERVS, and VIDEO coverage is closely overlapping. Additional deep Spitzer coverage to be obtained via the “Cosmic Dawn Survey” (PI: P. Capak; Program 13058) should lie within the LSST CDF-S field, and additional Spitzer coverage to be obtained via the “Missing Piece” survey (PI: A. Sajina; Program 14081) should lie within the LSST COSMOS field. Deep Herschel coverage is also deemed essential, since it is needed for measurements of star formation in AGN hosts and will be irreplaceable in the near future.
Small ($< 5'$) observation-to-observation offsets are acceptable to accommodate dithering (which is desired). The rotational dithering plan put forward by the Dark Energy Science Collaboration (DESC) will likely be acceptable for our AGN studies.

We note that the XMM-LSS field is located near the bright ($V = 6.5$) star Mira (located at $\alpha_{2000} = 02:19:20.8$ and $\delta_{2000} = -02:58:39.5$). Mira lies 1.98 deg from the XMM-LSS field center listed above, and thus it will lie just outside the LSST field of view (see Figure 6). An analysis of possible optical artifacts due to Mira is needed by LSST imaging-system experts. If required, the central pointing position for the XMM-LSS field could be shifted southward by up to 0.2 deg without significant loss of overlap with extant multiwavelength data. Additional southward shifting may also be possible if necessary, likely combined with some shifting in right ascension as well.

The multi-object RM projects described above will utilize wide-field spectrographs with fields that fit within the LSST field size. For reference, the SDSS-V Apache Point Observatory (APO) and Las Campanas Observatory (LCO) spectrograph field sizes are $\approx 6 \, \text{deg}^2$ and $\approx 2.6 \, \text{deg}^2$, respectively. The SDSS-V RM team is considering performing multiple spectroscopic pointings within the DDFs observed at LCO in order to fill the DDFs more completely. The 4MOST spectrograph field size is $\approx 3.5 \, \text{deg}^2$. Other spectrographs that will likely be used for intensive DDF follow-up studies (e.g., Subaru PFS and VLT MOONS) fit well within the LSST field size.

Our focus in this white paper is on the four currently selected LSST DDFs, so we have not suggested footprints for new DDFs. This being said, we desire to perform AGN studies in any other suitable new DDFs that are selected, such as the Akari Deep Field-South being proposed by the DESC; this field will have excellent synergy with Euclid and WFIRST. We would like to have the opportunity to provide constructive input on new DDF footprints, cadences, and other properties from the perspective of AGN investigations.

### 3.3 Image quality

We request that the delivered $r$-band image quality be better than 1.2", with other filters to be scaled accordingly. This should be achieved by LSST on most observing nights (e.g., see Figure 1 of Ivezić et al. 2018, arXiv:0805.2366 and associated discussion). Indeed, the median $r$-band free-air seeing at Cerro Pachón is 0.65". We therefore expect to have many
observations with superb seeing that can be co-added for optimal AGN host-galaxy studies.

3.4 Individual image depth and/or sky brightness

To optimize photometric-redshift derivation and source characterization for AGNs and galaxies in the DDFs, we would like to achieve a relatively uniform depth across the LSST filters (see Chapters 3 and 10 of the LSST Science Book). This is economically possible for $ugri$ but less so for $z$ and $y$. We thus request, every two nights, 1 visit in $g$, 1 visit in $r$, 3 visits in $i$, 5 visits in $z$, and 4 visits in $y$. Here each visit is the standard 30 s. The 3 visits in $i$ can be back-to-back for sake of efficiency, as can the 5 visits in $z$ and 4 visits in $y$. The $u$-band is addressed below. The following table summarizes the desired visits (depths quoted are $5\sigma$ design-specification depths):

| Quantity of Interest          | $u$ | $g$ | $r$ | $i$ | $z$ | $y$ |
|-------------------------------|-----|-----|-----|-----|-----|-----|
| Visits Every 2 Nights         | 4   | 1   | 1   | 3   | 5   | 4   |
| Depth Every 2 Nights          | 24.6| 25.0| 24.7| 24.6| 24.2| 22.9|
| Total Visits in 10 yr          | 3600| 900 | 900 | 2700| 4500| 3600|
| Total Depth in 10 yr           | 28.3| 28.7| 28.4| 28.3| 27.9| 26.5|

The $grizy$ visits in a given night should be obtained as close in time as reasonably possible to minimize any intranight variability effects. If it can be accommodated, the order of priority for observations should be $g$, then $i$, then $r$, $z$, and $y$. The bluest filter ($g$) is the most important for monitoring continuum variations; $g-i$ is the most widely useful color for AGN studies; and the remaining filters are ordered by their expected total depth per night. The priority with which bands are to be observed is relevant because observations potentially can be interrupted at any time due to, e.g., environmental conditions crossing a threshold that halts observing in the current field, or unexpected software or hardware faults.

The absolute number of visits every two nights is set by our requirements for total survey depth as well as our coordination with the DESC (see §3.12 for more details). The DESC wishes to obtain deep $grizy$ imaging with a three-night cadence, primarily to allow study of faint, distant supernovae. Indeed, they desire even deeper $griz$ imaging than we request. We can accommodate such deep imaging provided it does not lead to a reduction in the observing frequency from our desired two-night cadence, and it will provide outstanding photometric signal-to-noise for AGN variability studies.

Observations in the $u$-band are critical for AGN photometric-redshift
derivation and AGN physics studies, and thus we desire to obtain deep $u$ coverage in the DDFs as well. We recognize that this coverage likely cannot be obtained in the same synoptic manner requested for the other bands since the $u$ filter will often not be in the filter wheel and $u$ observations will be concentrated during dark time to improve efficiency. We request 60 visits per month in $u$, and we would like these to have the best synoptic coverage that general LSST operations can reasonably allow (each $u$ synoptic observation would ideally have 4 consecutive visits in $u$ to match the depths of the other bands). When the $u$ filter is available, it should have the highest priority for observation to ensure that an adequate number of visits are obtained with that filter.

The $u$-band is also critical for distinguishing the tidal disruption and accretion of a star by a SMBH (a tidal disruption event) from more common extragalactic transients such as supernovae. In particular, the $u - r$ color and color evolution with time can effectively remove most supernovae that happen to be coincident with the nuclei of galaxies (e.g., van Velzen et al. 2011, ApJ, 741, 73). Given the slow rise times of tidal disruption events of 1–2 months (e.g., van Velzen et al. 2018, arXiv:1809.02608), $u$-band coverage with a cadence of 1–2 weeks would be sufficient to confirm the persistent blue nature of a transient on its rise to peak and beyond. Similarly, $u$-band coverage is valuable in searching for the expected relativistic Doppler boosting associated with gas bound to the individual SMBHs in close-separation SMBH binaries (e.g., Charisi et al. 2018).

3.5 Co-added image depth and/or total number of visits

With observing-season lengths of 7–8.5 months annually, and weather losses of 25%, we expect to obtain the following approximate total numbers of visits over the 10 yr LSST survey: 3600 visits in $u$, 900 visits in $g$, 900 visits in $r$, 2700 visits in $i$, 4500 visits in $z$, and 3600 visits in $y$. These are expected to reach co-added depths of 28.3 mag in $u$, 28.7 mag in $g$, 28.4 mag in $r$, 28.3 mag in $i$, 27.9 mag in $z$, and 26.5 mag in $y$. As desired, the depths are relatively uniform in $ugri$. In $z$ and $y$ the depths are unavoidably somewhat shallower, but they have been made as deep as economically possible. Achieving high sensitivity in $z$ and $y$ is critically important, despite the relatively high expense; e.g., for selecting and studying high-redshift AGNs.

3.6 Number of visits within a night

This topic is addressed in §3.4.
3.7 Distribution of visits over time

Our time-domain science described in §2 requires observations at least every two nights in grizy. We desire observations of each field spaced every other night throughout their observing seasons. To mitigate the effects of weather or other losses, if no observations (or incomplete observations) are made in a given night then we would request elevated priority for the next available night in order to make up the loss if possible, after which we would resume observations on the originally planned nights. This approach would yield some observations separated by one night instead of two; such observations will be useful for AGN variability studies on shorter timescales.

RM studies benefit from the longest observing seasons possible; this increases the chances of robust lag detection, allows access to longer lags corresponding to higher SMBH masses, and minimizes missed lags due to non-overlapping data in cross-correlation analyses. We therefore do not want the DDF observations by LSST to be tightly clustered in a narrow time window, as has been done in some recent LSST operations simulations (to minimize typical airmass). The current planning for SDSS-V calls for its RM fields to be observed spectroscopically for 6–7 months each year, and we expect similar windows for 4MOST RM. We request that the LSST observations span, at least, this same time window plus 1–1.5 month precursor observations every season before the spectroscopic observations begin. The precursor observations will allow the “driving” AGN continuum to be sampled earlier than the “responding” BLR emission. We can tolerate airmass values up to $\approx 2.0$ in order to achieve these long (7–8.5 month) LSST observing seasons. We are aware that the DESC also desires the longest LSST observing seasons possible in order to optimize their studies of distant supernovae, and we expect that a mutually agreeable solution can be found.

The search for SMBH binaries will also benefit from the longest observing seasons possible. Discriminating true periodicity from an accreting SMBH binary vs. red noise associated with a normal AGN (powered by a single accreting SMBH) requires observing multiple cycles of variation. Specifically, three or more well-sampled cycles are required to reduce the false-alarm probability, as shown from simulations (Vaughan et al. 2016, MNRAS, 461, 3145) and extended baseline monitoring of reported SMBH binary candidates (Liu et al. 2018, ApJ, 859, 12). Longer observing windows will allow LSST to detect larger ranges of periods robustly within its 10 yr baseline. The periods of interest for which a SMBH binary ($10^7$–$10^9$ M$_\odot$) is in the gravitational-wave driven regime of orbital decay span a week to a
few years, easily probed by the DDFs if observed over the widest observing seasons possible. Also, given that the residence time for SMBH binaries increases for longer orbital periods (e.g., Haiman et al. 2009, ApJ, 700, 1952), the probability of detecting a SMBH binary increases as longer periods are probed.

The SDSS-V BHM will operate from 2020–2025 (Kollmeier et al. 2018) and the 4MOST TiDES-RM Project will operate from ≈ 2021–2026 with a possible additional five-year extension (S. Hoenig, private communication). SDSS-V BHM will target the XMM-LSS, CDF-S, and COSMOS DDFs, and it aims to deliver ≈ 300 SMBH masses in these fields. 4MOST TiDES-RM will target all four DDFs, and it aims to deliver ≈ 700 SMBH masses in these fields. Both of these campaigns are expected to be ongoing at the start of LSST full science operations in 2022–2023, so LSST synoptic observations of the DDFs should begin promptly. If possible, we also strongly desire LSST synoptic observations of the DDFs during the LSST Science Verification period in 2021–2022. The DDFs are among the best testing fields during the Science Verification period, which can be used to test the stability and performance of LSST as functions of time and observing conditions (e.g., seeing and airmass) for the same set of well-characterized sources. Doing so will also benefit time-domain science greatly by extending the effective total time baseline and delivering early time-domain data.

3.8 Filter choice

Our filter constraints are described above.

3.9 Exposure constraints

We request standard 30 s exposures per visit. We desire to avoid saturation for AGNs as bright as $i = 16$, and this should be possible according to Section 3.2 of the LSST Science Book.

3.10 Other constraints

Our constraints are suitably described above.

\footnote{We also note that the Maunakea Spectroscopic Explorer (MSE) aims to perform RM in the near-equatorial DDFs with observations perhaps beginning in ≈ 2026 (e.g., Flagey et al. 2018, arXiv:1807.08019).}
3.11 Estimated time requirement

We can estimate the fraction of the total LSST time that we request be dedicated to this program. With \( \approx 7.5 \) month observing seasons, we will have \( \approx 112 \) observing nights each season in the absence of weather losses. Including 25\% weather losses, this number will be reduced to \( \approx 84 \). Each of these will utilize 18 visits, following §3.4 (the \( u \)-band observations will be parcelled out differently, but we have used the appropriate average value here). Thus, annually each DDF will require 1512 visits. For 10 yr and four DDFs, the total number of DDF visits will be 60480. The total number of visits of LSST is \( \approx 2.8 \) million, and thus we request \( \approx 2.2\% \) of the total LSST time.

A more accurate estimate of the fraction of total time required will come from the full requested simulation of this program. For example, this will allow a more reliable assessment of weather losses.

3.12 Technical trades

What is the effect of a trade-off between your requested survey footprint (area) and requested co-added depth or number of visits?

Not applicable. This white paper is focused upon the four LSST Deep-Drilling Fields that have already been selected: ELAIS-S1, XMM-LSS, CDF-S, and COSMOS. Thus, the total solid-angle coverage on the sky is already largely fixed.

If not requesting a specific timing of visits, what is the effect of a trade-off between the uniformity of observations and the frequency of observations in time? e.g. a ‘rolling cadence’ increases the frequency of visits during a short time period at the cost of fewer visits the rest of the time, making the overall sampling less uniform.

We are requesting a specific timing of visits. We do not want a “rolling cadence” in the DDFs.

What is the effect of a trade-off on the exposure time and number of visits (e.g. increasing the individual image depth but decreasing the overall number of visits)?

Decreasing the overall number of visits would have a substantial negative effect upon this program. Even a minor reduction in the overall number
| Properties                          | Importance |
|------------------------------------|------------|
| Image quality                      | 2          |
| Sky brightness                     | 2          |
| Individual image depth             | 1          |
| Co-added image depth               | 1          |
| Number of exposures in a visit     | 2          |
| Number of visits (in a night)      | 1          |
| Total number of visits             | 1          |
| Time between visits (in a night)   | 2          |
| Time between visits (between nights)| 1         |
| Long-term gaps between visits      | 1          |
| Other (please add other constraints as needed) | 1 |

Table 1: **Constraint Rankings:** Summary of the relative importance of various survey strategy constraints. Please rank the importance of each of these considerations, from 1=very important, 2=somewhat important, 3=not important. If a given constraint depends on other parameters in the table, but these other parameters are not important in themselves, please only mark the final constraint as important. For example, individual image depth depends on image quality, sky brightness, and number of exposures in a visit; if your science depends on the individual image depth but not directly on the other parameters, individual image depth would be ‘1’ and the other parameters could be marked as ‘3’, giving us the most flexibility when determining the composition of a visit, for example.

of visits (e.g., from a two-night cadence to a three-or-four-night cadence) would damage the relatively rapid time-domain science including continuum RM studies of accretion disks (point #2 in §2), general/exceptional AGN variability studies (point #4 in §2), and exploration of transient SMBH phenomena (point #5 in §2). A larger reduction in the overall number of visits would damage the program even more broadly; e.g., harming photometric support of multi-object spectroscopic RM campaigns (point #1 in §2).

What is the effect of a trade-off between uniformity in number of visits and co-added depth? Is there any benefit to real-time exposure time optimization to obtain nearly constant single-visit limiting depth?

We do not want a reduction in the number of visits or a reduction in the uniform two-night cadence. We do desire a relatively constant single-visit
depth, but our constraints here are not highly demanding. For example, it would be helpful to implement a first-order correction for expected light loss when the airmass is high. Single-visit depths that are constant to within 0.2 mag should be acceptable.

Are there any other potential trade-offs to consider when attempting to balance this proposal with others which may have similar but slightly different requests?

We have coordinated significantly with the DESC in designing the cadence proposed here; this productive coordination started at the LSST Cadence Hackathon at the Flatiron Institute in 2018 September. While we have made much progress in converging upon a cadence solution that is agreeable to both Science Collaborations, there are still some remaining tensions (particularly regarding a two-night vs. three-night cadence). The DESC wishes to obtain deep grizy imaging every three nights, primarily to allow study of faint, distant supernovae; indeed, they desire even deeper griz imaging than we request. We can accommodate such deep imaging provided it does not lead to a reduction in the observing frequency from our desired two-night cadence, and it will provide outstanding photometric signal-to-noise for AGN variability studies. Both Science Collaborations share a strong preference for the longest LSST observing seasons practically possible.
4 Performance Evaluation

The following heuristics tied to observing strategy can be used for evaluation of performance:

1. We require that the LSST DDFs cover the prime multiwavelength data available in each of the four fields, as illustrated in Figures 1–5. In choosing the field central positions provided in §3.2, we have prioritized ensuring overlap with the sky regions covered by the SERVS, XMM-SERVS, VIDEO, and Spitzer DEEPDRILL programs; the SERVS, XMM-SERVS, and VIDEO coverage is closely overlapping. Deep Herschel coverage is also deemed essential, since it is needed for measurements of star formation in AGN hosts and will be irreplaceable in the near future. A relevant existing metric is “NightPointingMetric”.

2. We require the DDFs to be observed at least every two nights in grizy in as regular a manner as possible. Many additional relevant details, including $u$-band requirements, are provided in §3.4. Multiple-band coverage is especially required for photometric RM of AGN accretion disks, general AGN variability characterization, and SMBH transient characterization (see §2). Longer sampling timescales would have a substantial negative effect upon this program. Even a minor increase in the sampling timescale (e.g., from two nights to three-or-four nights) would damage the rapid time-domain science including continuum RM studies of accretion disks (point #2 in §2), general/exceptional AGN variability studies (point #4 in §2), and exploration of transient SMBH phenomena (point #5 in §2). A larger increase in the sampling timescale would damage the program even more broadly; e.g., harming photometric support of multi-object spectroscopic RM campaigns (point #1 in §2). Relevant existing metrics include “InterNightGapsMetric”, “LongGapAGNMetric”, and “MeanNightSeparationMetric”.

3. To optimize photometric-redshift derivation and source characterization for AGNs and galaxies in the DDFs, we would like to achieve a relatively uniform depth across the LSST filters. This is economically possible for $ugri$ but less so for $z$ and $y$. We thus request, every two nights, 1 visit in $g$, 1 visit in $r$, 3 visits in $i$, 5 visits in $z$, and 4 visits in $y$. Here each visit is the standard 30 s. The 3 visits in $i$ can be back-to-back for sake of efficiency, as can the 5 visits in $z$ and 4 visits in $y$. The $u$-band is addressed in §3.4. This pattern of visits across the LSST bands has been developed with some coordination with the
requirements of the DESC, and it will satisfy our desires for total ugrizy depths described in §1. Relevant existing metrics include “AccumulateCountMetric”, “AccumulateM5Metric”, “Coaddm5Metric”, “CrowdingMagUncertMetric”, “HistogramM5Metric”, and “NVisitsPerNightMetric”.

4. We require the longest observing seasons possible. For example, this increases the chances of robust RM lag detection, allows access to longer RM lags corresponding to higher SMBH masses, minimizes missed RM lags due to non-overlapping data in cross-correlation analyses, and aids searches for SMBH binaries. The current planning for SDSS-V calls for its RM fields to be observed spectroscopically for 6–7 months each year, and we expect similar windows for 4MOST RM. We request that the LSST observations span, at least, this same time window plus 1–1.5 month precursor observations every season before the spectroscopic observations begin. The precursor observations will allow the “driving” AGN continuum to be sampled earlier than the “responding” BLR emission. We can tolerate airmass values up to \( \approx 2.0 \) in order to achieve these long (7–8.5 month) LSST observing seasons. A relevant existing metric is “CampaignLengthMetric”.

5. We request that the delivered \( r \)-band image quality be better than 1.2”, with other filters to be scaled accordingly.
5 Special Data Processing

Below we provide a list of our main special data processing requests. We share many of the same desires as the DESC.

1. A pipeline that creates single-night DDF co-adds in each filter is recommended for AGN variability and SMBH transient studies. This pipeline should also perform difference-imaging analysis (DIA), and create DIASource and DIAObject catalogs for the DDFs. These images and catalogs should be updated and made available via the Science Platform as promptly as possible, before the start of the next observing night.

2. Alert packets should be created from the DDF DIASources and provided to the community efficiently.

3. As described in §3.7, observations of the DDFs are desired during the LSST Science Verification period. These should be co-added to create deep template images for the DDFs, in order to allow effective DIA for the DDFs during the first year of LSST operations.

4. Annually, we request that weekly, monthly, and yearly co-adds in each filter for each DDF be created. These will allow, e.g., variability studies at fainter levels than are possible in the nightly co-adds. These should be used to create DIASource and DIAObject catalogs for the DDFs reaching the faintest flux levels possible.

5. Annually, we request that co-adds be created in each filter from the 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, and 90% of observations with the best imaging quality. These can be used for optimal studies of AGN host galaxies.

6. As described in §3.2, there is a bright star, Mira, lying close to the XMM-LSS field. An analysis of possible optical artifacts and data-processing issues due to Mira is needed by experts in the LSST Project. Data processing should be performed in a manner that minimizes problems in science analysis due to Mira.
Table 1. Current and scheduled 1–10 deg² multiwavelength coverage of the XMM-SERVS fields. References: [a] Franzen et al. (2015); [b] Jarvis et al. (2017); [c] Oliver et al. (2012); [d] Lonsdale et al. (2003); [e] Mauduit et al. (2012). Note that SERVS has recently been expanded to cover the full LSST deep drilling fields (Spitzer Program ID 11086). [f] Jarvis et al. (2012); [g] http://www.ast.cam.ac.uk/~shmerjy/VEILS/veils_index.html; [h] http://wpid2017.london/slides/mondaysession3/SurveyStatus-Scaramella.pdf; [i] Dey et al. (2014); [j] Albare et al. (2015); [k] Tarry et al. (2012); [l] Vaccari et al. (2010); [m] http://www.lsst.org/news/enews/deep-drilling-201202.html; [n] Kelso et al. (2014); Patel et al. (2015); [o] Cai et al. (2011); [p] https://devilsurvey.ucmpjs.cn/; [q] http://www.ros.ac.uk/xr2k/MOONS/VT7-MOONS.html; [r] Tadada et al. (2010); [s] http://www.galexcaltech.edu/researcher/techdoc-ch2.html. [t] http://personal.psu.edu/wkb3/xmservs/xmservs.html.

| Band   | Survey Name                                      | Coverage (XMM-LSS, W-CDF-S, ELAS-S1) | Notes                             |
|--------|-------------------------------------------------|--------------------------------------|-----------------------------------|
| Radio  | Australia Telescope Large Area Survey (ATLAS)⁹ | ~3.7, 2.7 deg²; 15 μJy rms depth at 1.4 GHz |                                    |
|        | MIGHTREE Survey (Starting Soon)⁹               | 4.5, 3, 4.5 deg²; 1 μJy rms depth at 1.4 GHz |                                    |
| FIR    | Herschel Multi-tiered Extragal. Surv. (HerMES)⁹| 0.6–18 deg²; 5–60 mJy depth at 100–500 μm |                                    |
| MIR    | Spitzer Wide-area IR Extragal. Survey (SWIRE)⁹ | 9.4, 8.2, 7.0 deg²; 0.04–30 mJy depth at 3.6–160 μm |                                    |
| NIR    | Spitzer Extragal. Rep. Vol. Survey (SERVS)⁹     | 4.5, 3, 4.5 deg²; 2 μJy depth at 3.6 and 4.5 μm |                                    |
|        | VISTA Deep Extragal. Obs. Survey (VIDEO)⁹      | 4.5, 3, 4.5 deg²; JHK to m_A = 23.8–25.7 |                                    |
|        | VISTA Extragal. Inf. Legacy Survey (VEILS)⁹    | 3.3, 3 deg²; JHK to m_A ≈ 24.5–25.5 |                                    |
|        | Euclid Deep Field⁹                              | ~10, ~10 deg²; YJH to m_A ≈ 26, VIS to m_A ≈ 26.5 |                                    |
| Optical | Dark Energy Survey (DES)⁹                      | 9, 6, 9 deg²; Multi-epoch g, r, z to m_A = 27 co-added |                                    |
| Photometry | Hyper Supercam (HSC) Deep Survey⁹           | 5.3, ~4 deg²; giz to m_A ≈ 25–27.5 |                                    |
|        | Pan-STARRS1 Median-Deep Survey (PS1MD)⁹       | 8, ~8 deg²; Multi-epoch giz, m_A = 26 co-added |                                    |
|        | VST Opt. Imaging of CDF-S and E1 (VOICE)⁹    | ~4.5, 3 deg²; Multi-epoch apri, m_A = 26 co-added |                                    |
|        | LSST deep-drilling field (Planned)⁹          | 10, 10, 10 deg²; n/arcmin ≥ 1000 visits per field |                                    |

Optical/NIR

| Band    | Survey Name                              | Coverage (XMM-LSS, W-CDF-S, ELAS-S1) | Notes                             |
|---------|------------------------------------------|--------------------------------------|-----------------------------------|
| Spectroscopy | Carnegie–Spitzer–IMACS Survey (CSI)¹⁰ | 6.9, 4.8, 3.6 deg²; 140000 redshifts, 3.6 μm selected |                                    |
|         | PRS3 Multiobject Survey (PRIMUS)⁹       | 2.9, 2.0, 0.9 deg²; 77000 redshifts to i_A = 23.5 |                                    |
|         | AAT Deep Extragal. Legacy Survey (DEVILS)⁹ | 3.0, ~1.5 deg²; 41500 redshifts to F = 21.2 |                                    |
|         | VLT MOONS Survey (Scheduled)⁹          | 4.5, 3, 4 deg²; 210000 redshifts to i_A = 23.5 |                                    |
|         | Subaru PFS survey (Planned)⁹           | 5.3, ~5 deg²; F = 23.4 for HSC deep fields |                                    |
| UV      | GALEX Deep Imaging Survey⁹              | 8, 7, 7 deg²; Depth m_A = 25 |                                    |
| X-ray   | XMM-SERVS⁸                              | 5.3, 4.5, 3 deg²; 4.7 Ms XMM-Newton time, ≈ 50 ks depth |                                    |
Figure 2: Comparison of the planned LSST field vs. some of the key available multiwavelength data (as labeled) for ELAIS-S1. The background grayscale image shows the available Spitzer 3.6 \( \mu \text{m} \) data.
Figure 3: Comparison of the planned LSST field vs. some of the key available multiwavelength data (as labeled) for XMM-LSS. The background grayscale image shows the available Spitzer 3.6 μm data.
Figure 4: Comparison of the planned LSST field vs. some of the key available multiwavelength data (as labeled) for CDF-S. The background grayscale image shows the available Spitzer 3.6 μm data.
Figure 5: Comparison of the planned LSST field vs. some of the key available multiwavelength data (as labeled) for COSMOS. The background grayscale image shows the available Spitzer 3.6 µm data.
Figure 6: The relative locations of the XMM-LSS field and the bright ($V = 6.5$) star Mira. An analysis of possible optical artifacts due to Mira is needed by LSST imaging-system experts. See §3.2 for further discussion.