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The LSST Galaxies Science Collaboration Response to the Survey Cadence Optimization Committee Call

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ABSTRACT

This is a summary of the LSST Galaxies Science Collaboration survey strategy priorities and metrics.

1. INTRODUCTION

This Cadence Note summarizes the LSST Galaxies Science Collaboration responses to the questions posed to the community regarding LSST survey strategy. At a very high level, the collaboration's highest priorities (in rough order of priority) are as follows:

1. To have uniform high-quality data in the static-sky co-added data products §7.
2. To mitigate the effects of scattered light and spatially varying sky background as much as feasible to facilitate detection and characterization of low-surface-brightness objects and features §8.

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3. To ensure a minimum exposure time in good seeing early in the survey in one or two bands across the complete survey area.§7.
4. To obtain the full 10-year depth in one of the Deep-Drilling Fields early in the survey §3.
5. To extend the main survey into the northern hemisphere in areas of low extinction §2.
6. To include the Virgo Cluster as a mini-survey §3.
7. To optimize the *u*-band exposure time with fewer exposures and longer integrations per exposure. To help ensure good calibration by taking at least a few visits per field in good weather at low airmass §4.

The scientific goals within the collaboration are focused primarily on the static sky, with a heavy emphasis on faint, low-surface-brightness objects. Dithering, seeing, calibration, and sky-background uniformity are all important. The science goals benefit from multi-wavelength coverage, so expanding the footprint to the north and coordinating with other facilities on mini surveys is of great interest.

2. QUESTION 1: FOOTPRINT

The galaxies science would benefit from expanding sky coverage to bring in complementary data from space facilities such as *Euclid* or *Roman* or expand the opportunities for supporting observations from northern-hemisphere telescopes (e.g. for photometric-redshift calibration). Simulations (by DESC, Lochner et al. 2021) show gains in areal coverage and sample size when expanding to 20k deg^2 outweigh the resulting modest reduction in depth. The increased volume for a census of local low-surface-brightness objects is particularly helpful. Optimizing the footprint to be based on Galactic Extinction rather than Galactic Latitude is sensible.

2.1. *Euclid Overlap*

The *Euclid* mission offers data that are largely complementary to *Rubin*: higher resolution optical and near-infrared images, and low-spectral-resolution near-infrared grism spectroscopy. Rhodes et al. (2017) discuss the possible ways to optimize the overlap in sky coverage. This includes extending the LSST coverage into the north (perhaps without the *u* band) and extending coverage of the south ecliptic pole. The addition of Euclid multi-wavelength data over a larger area is advantageous because it will yield better photometric redshifts and better estimates of galaxy physical properties. If the loss in depth is taken uniformly from the original WFD allocation, increasing the survey footprint to 20k square degrees from the original 18k would result in a loss of 0.06 magnitudes. Graham et al. (2020) show improvements from the addition of Euclid NIR bands that would seem to more than compensate for the slight reduction in photometric depth. A survey strategy similar to `footprint_big_sky_dustv1.5_10yrs` or `combo_dust_v1.6_10yrs` that extends further north and concentrates on areas of low extinction is very attractive for galaxies science. Because there are not many members of the Galaxies SC that also have Euclid data rights and vice versa, the largest benefit will be accrued around the time of the Euclid public data releases. This could inform scheduling of observations and data processing.

3. QUESTION 2: ADDITIONAL OBSERVING TIME

3.1. *Deep Drilling Fields*

The Deep Drilling Fields (DDFs) already selected for LSST are among the richest in multi-wavelength data and deep spectroscopy. Galaxies science will generally benefit from high-quality co-added images, with the benefit of good seeing scaling roughly as the inverse of the square of the PSF FWHM. Optimizing seeing in the DDFs is worth doing, even at the expense of slightly worse seeing in the WFD survey. And conversely taking DDF exposures in the worst quartile of seeing is not a good investment of observing time for static science because those poorer images will do very little for the overall S/N and may simply be discarded in making the co-adds. Galaxies science will also benefit from adding LSST coverage to the Euclid Deep Field South. Full DDF depth may be overkill for this considering just LSST and Euclid and not the other data sets that will likely accumulate in this area. The Euclid limiting magnitudes will be AB ~ 26.5 in the optical and AB ~ 26 in the NIR and are thus well matched to the WFD survey depth.

Perhaps the highest priority for galaxies science is to obtain the full depth of one DDF early in the survey (preferably in the first year). This will enable both early deep science and also a good reference field for tests of systematics in the WFD survey. This also has the advantage of providing higher cadence on at least one DDF, which may be beneficial for some transients, DESC and AGN-related science. Getting full depth on one DDF early is more important than which field, so the selection should probably be driven primarily by scheduling. The CDF-S area has the highest-quality deep multi-wavelength data, but the COSMOS and XMM-LSS DDFs have large spectroscopic surveys planned with VLT-MOONS and PFS, and their locations in the sky are more favorable for complementary observations from both hemispheres.

3.2. *The Virgo Cluster*

The Virgo Cluster, centered at (RA, Dec)=(12:27, +13), is the largest overdensity within 20 Mpc. Due to its proximity, it has been the bedrock for studies of early-type galaxies, dwarf galaxies, intracluster light (Mihos et al. 2016), stellar populations, super-massive blackholes and other topics. If it is so well studied, why should the LSST include it? From the Galaxies perspective, the LSST data will expand over existing surveys in area, depth, band coverage and uniformity. The point-source depth in the Next Generation Virgo Cluster Survey (NGVS) was 25.2 in the r band (Ferrarese et al. 2012). The collaboration has not done a detailed study of the tradeoff of depth vs area. The NVGS covered 104 square degrees. So covering that area to the depth of the WFD survey adds minimally to the overall WFD footprint (0.6%) but gets 2.5 magnitudes deeper than the NGVS. This will enable better measurements of the faint end of the luminosity function, the outskirts of galaxies, and intracluster light, essential to improve our understanding of galaxy stellar mass assembly and quenching in cluster environments.

It is worth noting, particularly for those interested in time-variable phenomena associated with stars, that the stellar mass encompassed by the LSST field-of-view varies by many orders of magnitude from field to field if you limit the distance to a few tens of Mpc. For maximizing the enclosed stellar mass within ~ 25 Mpc, the Virgo cluster is **by far** the best place to point. Single-visit depth gets down to an r-band absolute magnitude of -6.3. This reaches into the realm of Cepheids and long-period variables, which could be detected individually in the outskirts of galaxies, or statistically via "shimmering" in the higher-surface-brightness regions (Conroy et al. 2015).

4. QUESTION 3: U-BAND EXPOSURE TIME

Longer u-band observations are preferable for galaxies science over the original 2×15 second strategy. The suggested 50 seconds with a slight reduction in observing time for the other bands in the WFD survey is definitely preferable. The most important gain will be providing better identification of galaxies at redshifts $z \sim 3$ via the Lyman break. Metrics that just look at the average performance of photometric redshifts across all redshifts tend to dilute this benefit, making it less apparent. The calibration of u-band observations is generally quite challenging (atmospheric extinction and scattering are both much more significant in the u band than at longer wavelengths). The photometric accuracy in the co-added images is critical for getting good photometric redshifts. Taking some reference u-band observations for each LSST field at low airmass during good photometric conditions will assist in the overall calibration.

Long term sky brightness, atmospheric transparency, and seeing behavior has been monitored for sites with 8-meter telescopes (e.g., Taylor et al. 2004). Optimal focus and seeing is harder to achieve in the u-band for a given survey field than at longer wavelengths, and can also depend on the direction in which the telescope and dome are pointing compared to the prevailing wind direction at that site. In particular, after many nights and observing seasons, the seeing distribution N(FWHM) may not be the same for survey fields in different directions, especially in u-band. This is mitigated by LSST relative to other surveys due to the strategy of obtaining a very large number of relatively short – but sky-limited – u-band exposures. A useful data product would be co-adds using only good-seeing data (e.g., Ashcraft et al. 2018). These "best-resolution" u-band images could be useful for some science goals, even if not uniform over the entire WFD footprint. These complement the co-adds that use most or all of the data, which will have better extended-sources sensitivity.

5. QUESTION 4: FILTER DISTRIBUTION

The planned filter distribution for WFD is acceptable for galaxies science. Going deeper in z and y bands at the expense of g, r and i would probably be better for galaxies science because it would provide improved photometric redshifts for higher redshift galaxies. The bluer bands may well be sufficiently crowded that uncertainties for many types of measurements are heavily influenced by crowding (or, equivalently, de-blending issues) rather than purely by photon noise. However, the collaboration has not tried to quantify this using simulations.

6. QUESTION 5: VISIT PAIRS AND TRIPLETS

Because the science goals for the Galaxies SC rely primarily on co-added data, optimizing for good seeing and good photometry are much more important for galaxies science than obtaining two or three visit pairs per night. Spreading out the visits is clearly much less optimal than observing each field for the total exposure time at low airmass. In the absence of other science drivers, it would be better to do fewer, longer visits per night.

7. QUESTION 6: ROLLING CADENCE, SEASON LENGTH AND ALTSCHED

As mentioned in several places above, optimizing for good seeing and good photometry is more important for galaxies science than the timing or spacing of the observations. While the seeing quality should average out over the course of the 10-year survey, it may make sense to try to optimize early in the survey to give a good starting point for the catalogs. Photometric uncertainties for point sources scale as $\sigma_f = \sigma N^{1/2}$, where σ is the pixel-to-pixel (sky) noise. N is the number of "noise pixels" defined as $N \propto 1/\sum_i \mathrm{PSF_i}^2$. This means that for a point source, the signal-to-noise ratio scales roughly as the PSF width. An exposure in $0.5''$ seeing is worth two in $0.7''$ and four in $1''$ seeing.

While the impact of seeing is not quite as dramatic for galaxies, the ability to distinguish nearby peaks in the light profile is important. Finding peaks is currently the first step in the detection and de-blending procedure. This affects the detection of compact galaxies in the first place and affects the ability to disentangle overlapping galaxies. The ability to separate point sources (i.e. the minimum separation before they will be identified as one object by a peak finding algorithm such as that used in SExtractor) scales linearly with the PSF width. So images taken in $0.5''$ seeing are 1.4 times as valuable as those taken in $0.7''$ seeing. *Uniformity* of the catalog in detection and de-blending is important because it affects a lot of the analysis thereafter, including morphology, photometry, and completeness. Lochner et al. (2021) have a metric for uniformity of depth for data releases in years 1, 3, 6 and 10, which may well be compatible with the above recommendation, since the standard computation of depth described in SMTN-002 (https://smtn-002.lsst.io) accounts for variations in seeing FWHM.

While it is undoubtedly impractical to optimize for seeing uniformity across the entire survey in all bands, it seems prudent to put some effort into ensuring *some* uniformity in the first year or two of the survey. We suggest prioritizing the r band because it is likely to be the deepest for typical galaxies. In part, this should be considered as risk mitigation. If multi-band detection strategies yield catalogs with field-to-field variations in completeness and biases that are too difficult to characterize, using a single band as the detection (peak-finding) band will yield a catalog that is much simpler to interpret (albeit with fewer sources).

A modest and probably achievable proposal would be to try to ensure that at least 25% of the r-band exposure time on every patch of sky in the first year is obtained in the best quartile of seeing. This might not happen naturally without giving some weight to seeing in the scheduling system. A more ambitious request would be to put 50% of the r-band exposure time in the first year in the best quartile of seeing, at the expense of poorer seeing in other bands. (50% of the r-band visits in the first year is 9 visits.) This would almost certainly result in a better catalog for galaxy research and probably weak lensing measurements as well. It would be useful in any case to run some OpSim experiments to see if this level of prioritization would have adverse impacts on other LSST science area.

A possible figure of merit could be

$$\mathrm{FOM_{seeing}} = \mathrm{mean}(0.7/\theta)^2/(1+\sigma^2(0.7/\theta)). \tag{1}$$

This rewards both good seeing and uniformity, and could be applied to the r-band in the first year.

There is also interest within the collaboration in optimizing the seeing in *two* bands. Combining with the request above, this would naturally be the g-band. Thus, pursuing a strategy similar to that implemented in `goodseeing_gi_v1.5_10yrs`, at least in the early years of the survey, would enhance galaxies science at nearly no cost to the depth.

The collaboration has not looked in detail at whether a two-band strategy that optimizes g and i is better or worse for galaxies science than one that optimizes g and r. The $g-i$ colors offer more leverage for estimating spectral slopes, while the $g-r$ colors offer the prospect of finding spectral breaks. It is likely that the sky background will make the r band better for detection than i band. Strong-lensing science, of interest to many in the Galaxies SC, favors multi-band seeing optimization, including particularly in the blue, over optimizing in a single band. That said, it is worth noting that the argument above for uniformity in one high-priority band is motivated by optimizing *the first step* in catalog generation (peak finding) which is at least arguably more important because current strategies for de-blending start with a catalog of peaks.

8. QUESTION 7: DITHERING

The main motivation for dithers is to improve the removal of instrument signatures. We trust that commissioning will guide the optimal strategy. To average over residual uncertainties in instrumental signatures, galaxies science favors including relatively large dithers (many arcminutes to degree scale) over a strategy that would involve only small (arcsecond scale) dithers. Rotational dithers could be advantageous for trying to mitigate the effects of scattered light, but this needs to be verified during commissioning, because it is possible that they will introduce more calibration problems than they will mitigate.

For the deep-drilling fields, it seems preferable to combine rotational dithers with dithers over a small fraction of the field to try to get most of the area at the full depth. The LSST field-of-view is already larger than most of the valuable multi-wavelength data overlapping these fields, so the science motivations tend to argue for keeping them as deep as possible rather than widening them.

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