Calibrating Milky Way Maps: An LSST Bright(ish) Star Survey

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Abstract

We propose a mini-survey aimed at extending the LSST photometric system to brighter stars that are otherside saturated in the 15s/30s images. The scientific goal is to put the use of faint stellar samples in the LSST surveys on a more secure footing by providing the actual LSST *ugrizy* photometry of the Gaia survey sample instead of relying on indirect calibrations and transformations from other photometric systems. The mimimal survey would be five second LSST exposure to improve the bright limit by a factor of six, but if shorter exposures are possible, we advocate for additional exposures to extend the system to even brighter stars. This mini-survey does not include time domain coverage, but instead aims at calibrating the "static sky."

1 White Paper Information

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1. **Science Category:** Mapping the Milky Way
2. **Survey Type Category:** mini-survey
3. **Observing Strategy Category:** please choose one of the following possibilities:
   - a specific pointing or set of pointings that is (relatively) agnostic of the detailed observing strategy or cadence, (e.g., a science case enabled by very deep precise multi-color photometry)

2 Scientific Motivation

We are now living through a revolution in studying the structure and kinematics of the Milky Way and Local Volume, as the Gaia DR2 (Gaia Collaboration et al., 2018) provides precise astrometry (Lindegren et al., 2018) and photometry (Riello et al., 2018) for a billion stars. This is not a matter of Gaia alone – new large spectroscopic surveys and time domain surveys also play key roles.

The LSST Science Book (LSST Science Collaborations et al., 2009) describes the next revolution, and will not be repeated here. Put simply, LSST *ugrizy* photometry will allow mapping of the Milky Way using faint stars, supported by proper motions of sources $G > 20$) too faint for Gaia or the spectroscopic surveys. Success of this future effort will depend on the astronomical community's ability to use the six-band photometry to estimate distances and intrinsic stellar parameters (temperature, metallicity, surface gravity, etc.). Here, however, there is a potential mismatch between the saturation limit of LSST and the stellar content of the solar neighborhood which is understood through Gaia and other surveys. If only the LSST main survey data is available, the community will have to rely on a series of color transformations and theoretical calibrations because most potential empiricial calibrators will be saturated. One would hardly like to base the LSST calibrations on the stars which have the largest Gaia astrometric errors and the poorest quality and least complete spectroscopy. Furthermore, the efficiency gains of changing the pair of 15s second exposures to a single 30s exposure are compelling for LSST, but this will have the side effect of aggravating the bright star problem and reducing the Gaia overlap. Our emphasis is the calibration aspect; of course, the LSST photometry of these bright(ish) stars have their own value. Additionally, some stars (like late M dwarfs) have extreme colors so that they will saturated in some filters even though the main LSST survey measures useful photometry and astrometry.

We propose that LSST pursue a mini-survey aimed at extending the LSST photometric system to stars that are saturated in the main survey, calibrating to them to the level (10 millimag) achieved for the main survey in terms of absolute and relative photometry. The LSST Science Requirements Document sets the design goal of 5 second for the minimum exposure time. This would represent a factor of six gain in reaching "bright" stars. Assuming this design goal is met, the base (minimal) mini-survey would be to obtain *ugrizy* 5-second exposures for all parts of the sky that will be regularly observed by LSST: the main (wide/fast/deep) footprint, the Galactic Plane, the Magellanic Clouds, South Celestial Cap, and the North Ecliptic Spur. We believe a single visit in each band would suffice to achieve our calibration goals. In each case, the visit would also measure numerous stars that are not saturated in the 30-second exposures, so that the photometry of the single short exposure image would be securely connected to the LSST system. Besides the direct LSST benefits to mapping the Milky Way, this mini-survey, like previous open surveys like IRAS, 2MASS, WISE, and Gaia, would enable numerous scientific investigations across many astronomy disciplines and sub-fields. We argue that "full" sky coverage will have the highest scientific payoff and will allow the calibration of rare objects (whether numerically rare, or clustered in small regions of the sky) and extension of Galactic maps in a constent way to bright/nearby regions.

The LSST stretch goal is a one second exposure, and the Science Optimization Paper has suggested that even shorter exposures may be possible (LSST Science Collaboration et al., 2017), and that these observations could take place during twilight to avoid impacting the main survey. For our purposes, using a twilight very short exposure capability to extend the photometric system to brighter stars over the entire LSST sky in all six filters would be high priority.

3 Technical Description

We are agnostic as to the detailed design of this mini-survey. A single-visit survey might be taken in twilight or perhaps a single additional 5-second exposure could be taken the first time a given field is visited in a given filter. Either of these would minimize impact on the overall survey efficiency. (One would need to develop the scheduling software accordingly.) For our purposes, there is no need to repeat the field on the same night or ever, nor to obtain more than one filter of a given field in the same night. This mini-survey is aimed at extending the photometric system for the "static" sky. It would be highly desirable to complete the short exposure survey in Year 1, so that it is part of the first data releases. (Astrometry with short exposures is problematic and could not compete with Gaia in any case.)

If the entire LSST footprint cannot be observed then a smaller survey would still have value. [On the opposite extreme, there would be value in extending the system to a single visit into the rest of the northern hemisphere at +20 or +30. One would like, for example, to have the actual Pleiades lower main sequence ($\delta = +24$) on the LSST system!]

We anticipate that this survey would be processed by the standard LSST DM pipeline. It might require some additional resources for quality assurance. However, this would likely be beneficial to the LSST Project in assessing the quality and consistency of the photometric calibration. Development of a very short exposure time survey during twilight would clearly require additional resources.

3.1 High-level description

The minimum sequence would be a single 5 second exposure for each field observed by LSST. This would not require any additional capability beyond the LSST design goals. If shorter exposures are possible, an additional 1 second exposure and an even a shorter exposure is desired. The goal is to maximize sky area average in all six filters, but not try for time domain coverage.

3.2 Footprint – pointings, regions and/or constraints

The entire southern hemisphere plus any northern hemisphere sky that is regularly observed. A stretch goal would be to observe uniformly further north, i.e., to +20 or +30, to increase the overlap with more surveys and thereby increase calibration and cross-check samples.

3.3 Image quality

No constraints as long as stellar photometry is possible.

3.4 Individual image depth and/or sky brightness

No constraints. If possible, twilight observing might minimize impact on other operations.

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

One visit per filter. Co-adds not relevant.

3.6 Number of visits within a night

One only.

3.7 Distribution of visits over time

The full southern hemisphere short exposure survey should be completed in Year 1 to enable scientific studies in the first data release. Repeats in later years might improve knowledge of the calibration, but the main goal is simply to obtain "static science" LSST system photometry in all six bands for stars brighter than the main survey saturation limit.

3.8 Filter choice

We advocate for all six filters.

3.9 Exposure constraints

The minimum goal would be a single 5 second exposure but additional, shorter exposures are desirable. The exact exposure times are not important: seven seconds would be useful if five is not possible, etc.

3.10 Other constraints

Any other constraints.

3.11 Estimated time requirement

The proposed observations might represent an impact at the 1-2% level in Year 1, and no impact in later years.

3.12 Technical trades

To aid in attempts to combine this proposed survey modification with others, please address the following questions:

1. *Increasing the number of visits at the expense of sky coverage would sharply drop the calibration value. Additional visits, of course, would open other science goals.*
2. *We strongly believe Year 1 observations; however, spreading the observations over several years would be acceptable. It would be better to get all six filters in one region of the sky than cover different areas with a subset of filters.*
3. *We need short exposure times.*
4. *Coadded depth and uniformity is not relevant to this proposal.*
5. *Any time-domain studies with an appropriate short exposure would not need to be duplicated.*

Properties	Importance
Image quality	2
Sky brightness	3
Individual image depth	1
Co-added image depth	3
Number of exposures in a visit	2
Number of visits (in a night)	3
Total number of visits	3
Time between visits (in a night)	3
Time between visits (between nights)	3
Long-term gaps between visits	3
Photometric Calibraton (10 mmag)	1
Photometric Calibraton (5 mmag)	2

Table 1: **Constraint Rankings:** The key constraints are reaching the photometric calibration quality rearched inthe LSST WFD survey (uniformity and absolute photometry design goals: 10 mmag, stretch goals: 5 mmag), complete, uniform sky coverage, and the short exposure time. This minimal project does not include any time domain goals.

4 Performance Evaluation

The goal being to extend the LSST photometry system, the appropriate metric is the matching the survey "external absolute photometry" at the design spec, which is 10 millimags. Thus the metrics are sky coverage, photometric quality, and the brightest magnitude observed.

5 Special Data Processing

The processing should be handled by the standard pipeline; it is mainly producing images and calibrated stellar photometry but with a shorter exposure time. We anticipate that the photometric calibration will be of great interest to the Stars, Milky Way and Local Collaboration (as well as others) who could verify performance if the Project does not have resources for detailed quality assurance.

6 References

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