Rubin LSST: Mapping the Milky Way with Star-Forming Regions

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Project and Community Workshop 2023

Overview

Open questions

Rubin LSST for Stellar Clusters Science crucial to address the key questions:

- How do stars form, evolve, and die?
- How do star clusters form, evolve, and dissolve?
- What is the structure of our Galaxy?

Introduction

- **Mapping the Milky Way (MW)** is among the most challenging objectives of Rubin LSST and modern astrophysics
- The **youngest stellar populations** are located in the spiral arms of the Galactic thin disk and are crucial **tracers of the MW Galactic Plane (GP)**
- By characterizing star forming regions (SFRs) and comparing them with their environments, we aim to enhance our **understanding of the physical mechanisms underlying star and planet formation processes.**

Stellar density law in the Galactic Thin Disk
[Cabrera-Lavers et al., 2005]:

$$\rho(r, l, b) = A \times exp\left(-\frac{r|sinb|}{h} - \frac{R}{r_1}\right) \quad (1)$$

Rubin LSST accessible volume:

$$dV = \Omega r^2 dr \quad (2)$$

Number of Young Stellar Objects (YSOs) with ages <10 Myr:

$$N(< r_{max}) = \int_0^{r_{max}} \rho(r, l, b) \; dV \quad (3)$$

h=thin disk scale height, R=Galactocentric distance, r_1=thin-disk radial scale length

[Prisinzano et al., 2023]

YSOs: Metric assumptions

- YSOs detection with the accuracy magnitude$/\sigma = 5$ for gri filters in the $r - i$ vs. $g - r$ diagram (`CoaddM5` metric)
- 3D dust map
- crowding metrics (`CrowdingM5` metric) developed within MAF based on the TRILEGAL stellar density maps [Dal Tio et al., 2022]
- $\mathrm{N_{yng}} = \frac{t_{\mathrm{yng}}}{t_{\mathrm{MW}}} \times \mathrm{N_{tot}}$ for a constant star formation rate

Metric Results

- **Crowded regions**: detections go down from more than 10,000 to surprisingly low values of 10–100 (sources/HEALPix)
- **Extincted regions**: detections here are 100-1000 (sources/HEALPix)

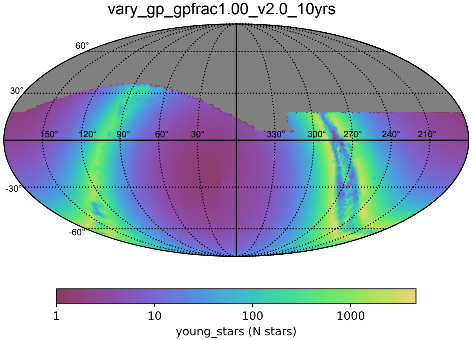
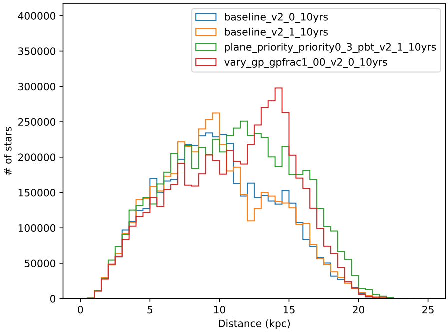
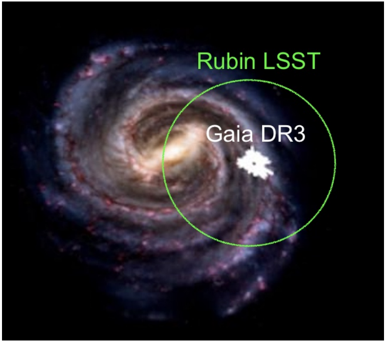


Figure: **Map of the number of YSOs** in Mollweide projection as computed by our metrics, adopting the `OpSim` surveys with WFD cadence in the GP. HEALPix grid resolution is Nside = 64

Analysis

YSO distance distributions adopting the strategy extending the WFD to the whole Galactic Plane (no restrictions for E(B-V)) and the baselines





Analysis

OpSim ID	N	FoM	N_{Crow}	FoM_{Crow}
baseline_v2.0_10yrs	8.08×10^6	1.00	4.84×10^6	1.00
baseline_v2.1_10yrs	8.10×10^6	1.00	4.87×10^6	1.01
vary_gp_gpfrac1.00_v2.0_10yrs	8.92×10^6	1.10	5.58×10^6	1.15
plane_priority_priority0.3_pbt_v2.1_10yrs	9.51×10^6	1.18	6.02×10^6	1.24

A gain from 15% to 24% in the number of detected YSOs is obtained in the **Figure of Merit (FoM)** by extending the Wide Fast Deep (WFD) cadence to the whole Galactic Plane in the gri filters

Conclusions

- A **gain of 15% - 24% is obtained with respect to the baseline, by extending the WFD cadence to the whole Galactic Plane** without any restriction for E(B-V)
- LSST is more sensitive than **Gaia**: much deeper to detect **further away (up to 10 Kpc) and more extincted clusters.**
- **The missed detection fraction is significantly larger in the very crowded regions than in the high dust regions.**
  This result is consistent with what was recently pointed out for **Gaia** data
  [Cantat-Gaudin et al., 2023]
- **We strongly suggest a coverage also of the inner GP at WFD level** at least **in the 3 filters gri**. This is the only chance to go very deep even in the more extincted regions to **trace the spiral arms of the MW.**

Other Science Cases that Would Benefit from this Strategy

Milky Way Star Clusters [Usher et al., 2023]

- Extending the Gaia Revolution
  - ⇒ More complete sampling of fainter stellar members
  - ⇒ Studying more distant or extincted star clusters
- Calibration of stellar evolution and stellar population models
- Galaxy Star Formation History

Solar Neighborhood Understanding [Zucker et al., 2023]

- 3D dust maps from extinction-based techniques
- clusters/streams of young stars/molecular interstellar medium relationships

Time-variabily [Street et al., 2023]

- brown dwarfs, transiting planets and white dwarfs
- RR Lyrae stars, Cepheids, SX Phoenicis, delta Scuti stars, and long-period variables

Cabrera-Lavers, A., Garzón, F., and Hammersley, P. L. (2005).
The thick disc component of the Galaxy from near infrared colour-magnitude diagrams.
, 433(1):173–183.

Cantat-Gaudin, T., Fouesneau, M., Rix, H.-W., Brown, A. G. A., Castro-Ginard, A., Kostrzewa-Rutkowska, Z., Drimmel, R., Hogg, D. W., Casey, A. R., Khanna, S., Oh, S., Price-Whelan, A. M., Belokurov, V., Saydjari, A. K., and Green, G. (2023).
An empirical model of the Gaia DR3 selection function.
, 669:A55.

References II

Dal Tio, P., Pastorelli, G., Mazzi, A., Trabucchi, M., Costa, G., Jacques, A., Pieres, A., Girardi, L., Chen, Y., Olsen, K. A. G., Juric, M., Ivezić, Ž., Yoachim, P., Clarkson, W. I., Marigo, P., Rodrigues, T. S., Zaggia, S., Barbieri, M., Momany, Y., Bressan, A., Nikutta, R., and Nicolaci da Costa, L. (2022).
Simulating the Legacy Survey of Space and Time stellar content with TRILEGAL.

Prisinzano, L., Bonito, R., Mazzi, A., Damiani, F., Ustamujic, S., Yoachim, P., Street, R., Guarcello, M. G., Venuti, L., Clarkson, W., Jones, L., and Girardi, L. (2023).
Rubin LSST Observing Strategies to Maximize Volume and Uniformity Coverage of Star-forming Regions in the Galactic Plane.
, 265(2):39.

References III

Street, R. A., Li, X., Khakpash, S., Bellm, E., Girardi, L., Jones, L., Abrams, N. S., Tsapras, Y., Hundertmark, M. P. G., Bachelet, E., Gandhi, P., Szkody, P., Clarkson, W. I., Szabó, R., Prisinzano, L., Bonito, R., Buckley, D. A. H., Marais, J. P., and Di Stefano, R. (2023).
LSST Survey Strategy in the Galactic Plane and Magellanic Clouds.
, 267(1):15.

Usher, C., Dage, K. C., Girardi, L., Barmby, P., Bonatto, C. J., Chies-Santos, A. L., Clarkson, W. I., Gómez Camus, M., Hartmann, E. A., Ferguson, A. M. N., Pieres, A., Prisinzano, L., Rhode, K. L., Rich, R. M., Ripepi, V., Santiago, B., Stassun, K. G., Street, R. A., Szabó, R., Venuti, L., Zaggia, S., Canossa, M., Floriano, P., Lopes, P., Miranda, N. L., Oliveira, R. A. P., Reina-Campos, M., Roman-Lopes, A., and Sobeck, J. (2023).

Rubin Observatory LSST Stars Milky Way and Local Volume Star Clusters Roadmap.
, 135(1049):074201.

Zucker, C., Alves, J., Goodman, A., Meingast, S., and Galli, P. (2023).
The Solar Neighborhood in the Age of Gaia.
In Inutsuka, S., Aikawa, Y., Muto, T., Tomida, K., and Tamura, M., editors, *Astronomical Society of the Pacific Conference Series*, volume 534 of *Astronomical Society of the Pacific Conference Series*, page 43.