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Stellar density tomography of the Galaxy

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Abstract. This work investigates the three-dimensional structure of the Milky Way through stellar density tomography, using M-giants as tracers to map asymmetries and substructures that serve as remnants of its formation process. The methodology consists of a differential analysis of stellar density between symmetric regions of the Galaxy (equatorial, meridional, and diagonal) based on two distinct catalogs: the 2MASS sample to select M giants and the *StarHorse* catalog. Data processing included the symmetric removal of high-reddening regions ($E(B-V) > 0.55$) to remove extinction biases. The results, enhanced by the precision of the *StarHorse* catalog, confirm a stellar predominance in the southern hemisphere and map with greater definition structures such as the Sagittarius stream, Monoceros, the Galactic Warp, and Triangulum-Andromeda. The analysis also allowed for the association of overdensities with the Hercules-Aquila Cloud and the Virgo Overdensity, in addition to revealing the complex nature of other structures that appear to be a superposition of multiple overdensities. The complex scenario of observed overdensities reinforces the interaction of the Milky Way with other galaxies and objects, showing that stellar density tomography is an effective approach for Galactic Archeology.

Resumo. Este trabalho investiga a estrutura tridimensional da Via Láctea através da tomografia de densidade estelar, utilizando gigantes M como traçadores para mapear assimetrias e subestruturas que servem como remanescentes do seu processo de formação. A metodologia consiste em uma análise diferencial da densidade estelar entre regiões simétricas da Galáxia (equatorial, meridional e diagonal) baseada em dois catálogos distintos: a amostra do 2MASS para seleção de gigantes M e o catálogo *StarHorse*. O processamento de dados incluiu a remoção simétrica de regiões de alto avermelhamento ($E(B-V) > 0.55$) para remover vieses de extinção. Os resultados, aprimorados pela precisão do catálogo *StarHorse*, confirmam uma predominância estelar no hemisfério sul e mapeiam com maior definição estruturas como a corrente de Sagitário, Monoceros, o Warp Galáctico e Triângulo-Andrômeda. A análise também permitiu a associação de sobredensidades com a Nuvem Hércules-Aquila e a Sobredensidade de Virgo, além de revelar a natureza complexa de outras estruturas que parecem ser uma sobreposição de múltiplas sobredensidades. O cenário complexo de sobredensidades observadas reforça a interação da Via Láctea com outras galáxias e objetos, mostrando que a tomografia de densidade estelar é uma abordagem eficaz para a Arqueologia Galáctica.

Keywords. Galaxy: structure – halo – stellar content

1. Introduction

The analysis of large-scale asymmetries in the Galaxy allows us to probe the interaction history of the Milky Way with other objects (Searle & Zinn 1978). These asymmetries often manifest as signatures of localized events, such as mergers or tidal disruptions. In this scenario, the search for stellar overdensities (and corresponding deficits) provides a mapping of the current Galactic structure. Following the methodology proposed by Rocha-Pinto et al. (2004) (hereafter RP04), we perform a differential analysis of the stellar density between symmetric regions of the Milky Way, assuming an initially smooth distribution.

2. Methodology

The methodology focuses on the study of stellar number density. We adopt a Cartesian coordinate system to evaluate stellar positions, following the convention where the X-axis connects the Sun to the Galactic Center (GC); the Y-axis is orthogonal to X and coplanar with the Galactic disk; and the Z-axis is perpendicular to the plane formed by X and Y. The investigation relies on the differential analysis of two primary symmetries: (i) Equatorial, comparing the Northern ($b > 0°$) and Southern ($b < 0°$) Galactic hemispheres; and (ii) Meridional, comparing the Western ($0° < l < 180°$) and Eastern ($180° < l < 360°$) hemispheres.

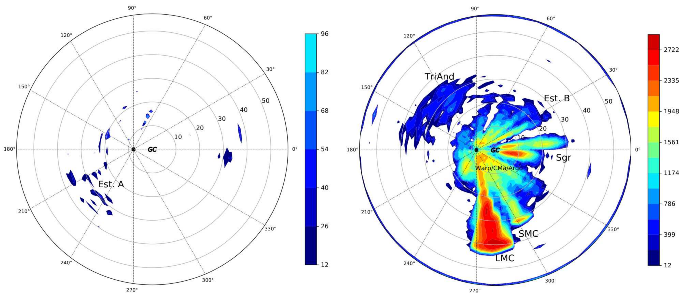
3. Data Construction

We employed two primary catalogs in this study. The first utilizes a color cut (based on Majewski et al. 2003) applied to 2MASS (Skrutskie et al. 2006) to identify M giants, deriving distances statistically. This sample contains over 3 million objects. The second catalog applies surface gravity and color cuts to the *StarHorse* dataset to select the same stellar class: $\log g < 2.7$ and $(G_{BP} - G_{RP})_0 > 0.75$, resulting in a catalog exceeding 30 million objects. We excluded regions with high reddening ($E(B-V) > 0.55$) to avoid biases associated with high extinction. Additionally, we removed the sample in the opposite region to evaluate asymmetry.

4. Results

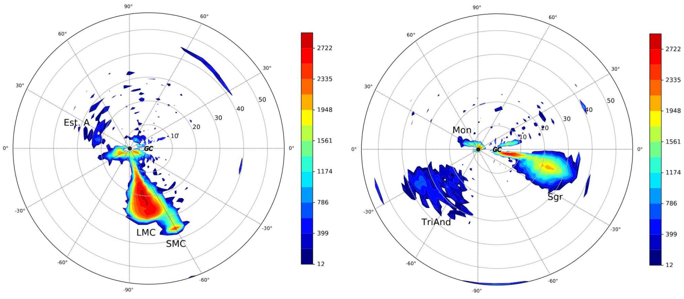
We define the "West" meridian as $0° < l < 180°$ and the "East" meridian as $180° < l < 360°$, facilitating the location denomination from a Solar perspective toward the Galactic Center.

In Fig. 1, the difference between the hemispheres allows us to identify a structure denominated Est. A ($l \approx 210° - 240°$) in the North. In the South, we observe well-known structures: the Triangulum-Andromeda overdensity (Rocha-Pinto et al. 2004; TriAnd) at $l \approx 120°$, the Magellanic Clouds (LMC and SMC), the Sagittarius stream (Majewski et al. 2003; Sgr), and the Galactic Warp (Martin et al. 2004; also known as CMa/Argo) near $l \approx 240°$. Besides these, it is also possible to observe another feature, labeled Est. B ($l \approx 30° - 60°$).



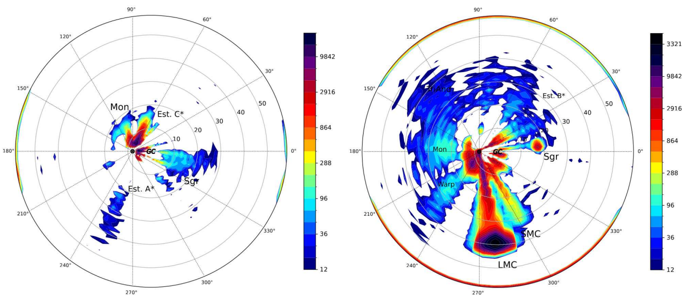
(**a**) North hemisphere excess (**b**) South hemisphere excess

Figure 1: Equatorial asymmetries using RP04.



(**a**) East meridian excess (**b**) West meridian excess

Figure 2: Meridian asymmetries using RP04.



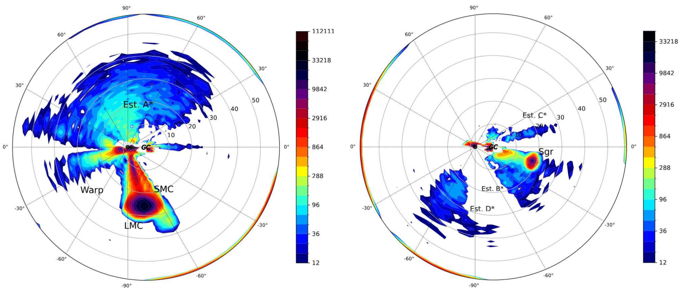
(**a**) North hemisphere excess (**b**) South hemisphere excess

Figure 3: Equatorial asymmetries using *StarHorse*.

Analyzing the projection of the meridians in Fig. 2, we obtain a novel perspective on structures such as TriAnd. In this view, TriAnd appears distinctively in the West meridian below the plane at $b \approx -30°$, while Monoceros (Lais Borbolato et al. 2024; Mon) is visible in the North at $b \approx 30°$. Additionally, in the East meridian, we identify the Galactic Warp near $b \approx -30°$.

Figure 3 displays the excesses found using the *StarHorse* catalog. This dataset, being more robust and precise, allows for a refined analysis. Here, we can observe numerous structures; for the unidentified ones, we added an asterisk (*) to differentiate them from the RP04 catalog. In the North, we see Monoceros ($l \approx 90° - 150°$) and Sagittarius ($l \approx 350°$), as well as Est. A* and Est. C*. In the South, we identify the Magellanic Clouds, Sagittarius, the Galactic Warp ($l \approx 230°$), Monoceros ($l \approx 180°$), TriAnd ($l \approx 120°$), and Est. B* ($l \approx 50°$).

Regarding the meridional projections shown in Fig. 4, the West meridian (Fig. 4b) highlights Sagittarius ($b \approx -15°$) and the signature of Est. D* ($b \approx -50°$), alongside Est. C* and Est. B*. The East meridian (Fig. 4a) reveals a northern overdensity at high latitudes ($b \approx 75°$), likely associated with Est. A*, as well as the Warp ($b \approx -15°$) and the Magellanic Clouds.



(**a**) East meridian excess (**b**) West meridian excess

Figure 4: Meridian asymmetries using *StarHorse*.

5. Conclusion

We also performed an analysis of diagonal symmetries (considering mirrored positions in both longitude and latitude), but no substantial deviations were found. This analysis highlights the critical importance of data quality and the application of multiple visualization techniques to distinguish genuine structures from artifacts.

Our results demonstrate that differential analysis is an effective method for mapping the global stellar distribution in the Galaxy, particularly when applied to large datasets, as successfully demonstrated with the *StarHorse* catalog.

A notably higher stellar density is observed in the Southern Hemisphere, primarily due to the presence of Sgr and LMC/SMC, alongside some unidentified overdensities that warrant further investigation. Conversely, this method has shown a strong dependence on sample size, revealing little to no significant substructure in projections derived from smaller catalogs.

Finally, the complex nature of the observed stellar distribution supports the hierarchical formation scenario of the Milky Way, emphasizing the history of interactions with other objects and their subsequent accretion onto our system.

References

Ibata, R. A., Gilmore, G., & Irwin, M. J., 1994, Nature, 370, 194
Lais Borbolato et al, 2024 ApJ, 960, 52
Majewski, S. R. et al., 2003, ApJ, 599, 1082
Martin, N. F., et al., 2004, SF2A-2004: Semaine de l'Astrophysique Francaise, 619
Rocha-Pinto, H. J., et al., 2004, ApJ, 615, 2004
Searle, L., & Zinn, R., 1978, ApJ, 225, 357
Skrutskie, M. F. et al., 2006, AJ, 131, 1163