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Search for extragalactic exoplanets inner the Milky Way

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Abstract. The discovery of exoplanets beyond our Solar System in recent decades has led to searches for the origins of these other worlds. In this study, we investigate the possibility of exoplanets originating from beyond our Galaxy, but without the need for observations outside the Milky Way, considering the potential for exoplanet-hosting stars to have been accreted through the last major merger event with the dwarf galaxy Gaia-Enceladus/Sausage (GES), 10 billion years ago. Utilizing data from the GAIA DR3, NASA host stars Archive, and TESS Objects of Interest (TOI), crossmatch was performed to identify halo stars that may have been affected by GES. This merger event is considered a possible mechanism for introducing extragalactic interstellar material into the Milky Way's disk. By calculating the orbital parameters of the identified stars, it is possible to analyze their kinematics to determine if they exhibit characteristics consistent with an origin in the galactic halo. Previous results suggest the presence of a population whose kinematics indicate a possible extragalactic origin, raising the possibility of the existence of exoplanets originating beyond the Milky Way. This study contributes to a deeper understanding of the formation and evolution of planetary systems on galactic scales.

Resumo. A descoberta de exoplanetas fora do nosso Sistema Solar nas últimas décadas tem levado à buscas pelas origens desses outros mundos. Neste estudo, investiga-se a possibilidade de exoplanetas terem origens além da nossa própria Galáxia, mas sem a necessidade de observações exteriores à Via Láctea, considerando a possibilidade de estrelas hospedeiras de exoplanetas terem sido acretadas através do último grande evento de fusão, com a galáxia anã Gaia-Enceladus/Sausage (GES), há 10 bilhões de anos. Utilizando dados do catálogo GAIA DR3 e catálogos planetários do Nasa Archive e TESS Objects of Interest (TOI), foram então feitos crossmatchs para identificar estrelas do halo que possam ter sido afetadas por GES. Este evento de fusão é considerado um possível mecanismo para a introdução de material interestelar de origem extragaláctica no disco da Via Láctea. Através do cálculo dos parâmetros orbitais das estrelas identificadas, é possível analisar sua cinemática para determinar se elas possuem características consistentes com uma origem no halo galáctico. Resultados anteriores sugerem a presença de uma população cuja cinemática indica uma possível origem extragaláctica, o que levanta a possibilidade de existência de exoplanetas com origem além da Via Láctea. Este estudo contribui para uma compreensão aprofundada da formação e evolução dos sistemas planetários em escalas galácticas.

Keywords. Surveys – planetary systems – Galaxy: kinematics and dynamics

1. Introduction

The study of exoplanets has undergone remarkable growth in recent decades. Nowadays, more than 5,800 exoplanets have been confirmed, with over 7,000 candidates awaiting confirmation (NASA Archive 2024). These discoveries provide invaluable insights into planetary formation, evolution, and the characteristics of planetary systems. However, despite these impressive numbers, the vast majority of confirmed exoplanet-hosting stars are located in the solar neighborhood, predominantly within the thin disk of the Milky Way. This introduces intriguing questions about the distribution and origin of exoplanet host stars across different Galactic structures.

In this work, we investigate the possibility of identifying exoplanet host stars that may have originated outside the Milky Way but currently reside within our Galaxy. Such a scenario is plausible given the multiple merger events that shaped the Milky Way's evolutionary history. Among these, the most significant involved the Gaia-Enceladus/Sausage, a massive dwarf galaxy that merged with the Milky Way approximately ten billion years ago (Helmi 2020). This event played a major role in forming the Milky Way's stellar halo, leaving a kinematic and chemical signature detectable in the present-day stellar population.

Based on this scenario, we hypothesize that exoplanet host stars originating from extragalactic structures, such as Gaia-Enceladus, are most likely located in the Galactic halo. By exploring this possibility, we aim to broaden our understanding of the origin and distribution of exoplanet host stars across the Milky Way.

2. Methodology

In this study, we utilized data from two primary sources: the NASA Exoplanet Archive, focusing on stars with the default parameter set to 1, and the TESS Objects of Interest (TOI) catalog (NASA Archive 2024). Radial velocity measurements for both datasets were obtained from a cross-match with the third data release of Gaia (Gaia DR3) (Gaia Collaboration 2023). The cross-matching process was performed using the Taylor (2005) software.

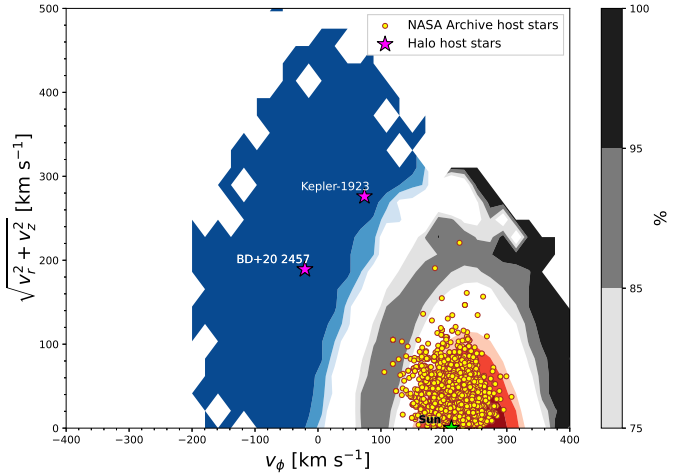
Additionally, our analysis incorporated photogeometric distances from Gaia's Early Data Release 3 (EDR3) (Bailer-Jones et al. 2021) to calculate orbital parameters. These distances, derived from a combination of photometric and astrometric data, provide robust information for studying stellar dynamics. Orbital parameters were computed using the AGAMA code (Vasiliev 2019), using the McMillan (2017) potential. This methodology follows the procedure described in (Perottoni et al. 2021).

The AGAMA code outputs kinematic parameters, including total energy, angular momentum components, and velocity components. These parameters were essential for identifying the dynamic characteristics and galactic origins of the stars in our sample. We applied the code to the two samples: NASA host stars (4,113 targets) and TOI (6,418 targets).

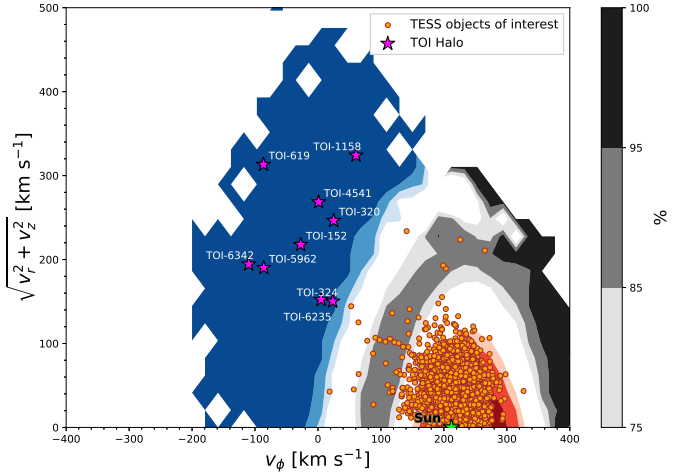
3. Results

We analyzed the kinematics of the selected samples using Toomre diagrams, which are instrumental in distinguishing stars

based on their Galactic components—thin disk, thick disk, and halo. Figure 1 present the Toomre diagrams for the NASA Exoplanet Archive and TESS Objects of Interest (TOI) samples, respectively.



(a) NASA Archive host stars.



(b) TESS objects of interest.

FIGURE 1: Toomre diagram. The thin disk, thick disk, and halo are represented by red, gray, and blue colors, respectively, with shading intensity corresponding to the fraction of a given population in that region (75%, 85%, or 95%). In the diagram for the NASA Archive (top panel), two stars are located in the halo region. For the TESS Objects of Interest (bottom panel), nine stars are found in the halo region.

In Figure 1a, it is evident that most confirmed exoplanet host stars from the NASA sample are concentrated in the thin disk, aligning with the expected distribution of such stars in the Galactic plane. Among these, two stars—BD+28 2457 and Kepler-1923—are likely part of the halo, based on their kinematic properties. This observation suggests that a small fraction of confirmed exoplanet hosts may originate from regions outside the thin disk, warranting further investigation into their dynamical and chemical characteristics.

By expanding the analysis to include the TOI sample, which comprises stars not yet confirmed as exoplanet hosts, the number of potential candidates increases significantly. In Figure 1b, we identify nine stars as potential halo members: TOI-152, TOI-320, TOI-324, TOI-619, TOI-1158, TOI-4541, TOI-5962, TOI-6235, and TOI-6342. Additionally, a notable number of objects are located in the thick disk and transitional regions, indicating a broader distribution of kinematic properties among the TOI sample compared to the NASA sample.

The TOI stars' inclusion highlights the potential for identifying exoplanet host candidates beyond the traditional thin disk population. If these TOI candidates are confirmed as exoplanet hosts by TESS, this would represent a significant step forward in understanding the kinematics and origins of exoplanetary systems in more diverse galactic environments. Such confirmations would also provide an opportunity to explore the role of dynamical interactions, such as mergers, in shaping the distribution of exoplanet hosts across different Galactic components.

In addition to the Toomre diagram analysis, the orbital parameters computed using the AGAMA code provided valuable insights into the likely formation structures of the analyzed stars. These parameters enable us to infer the Galactic components or merger remnants where the host stars might have originated, enhancing our understanding of their kinematic and dynamical history.

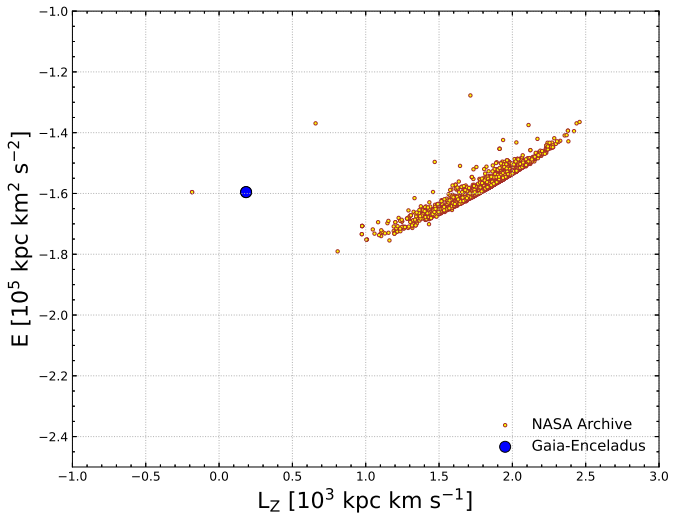
In Figure 2a, we observe that one star from the NASA Archive sample exhibits dynamical properties consistent with the Gaia-Enceladus/Sausage structure, as classified following the criteria established by Horta et al. (2023). This finding suggests that the star was likely accreted during a major merger event.

For the TESS Objects of Interest sample, shown in 2b, the analysis reveals three stars with kinematic characteristics indicative of the Gaia-Enceladus/Sausage structure and two stars with properties associated with the Proto-Milky Way. These results further reinforce the hypothesis that exoplanets can form and persist in a variety of Galactic environments, spanning different dynamical scenarios and epochs of Galactic evolution. The identification of exoplanet host star candidates in structures such as Gaia-Enceladus/Sausage and the Proto-Milky Way underscores the potential complexity of planetary system formation across the Galaxy. The stars linked to these ancient structures provide a unique opportunity to study the interplay between Galactic evolution and exoplanetary science.

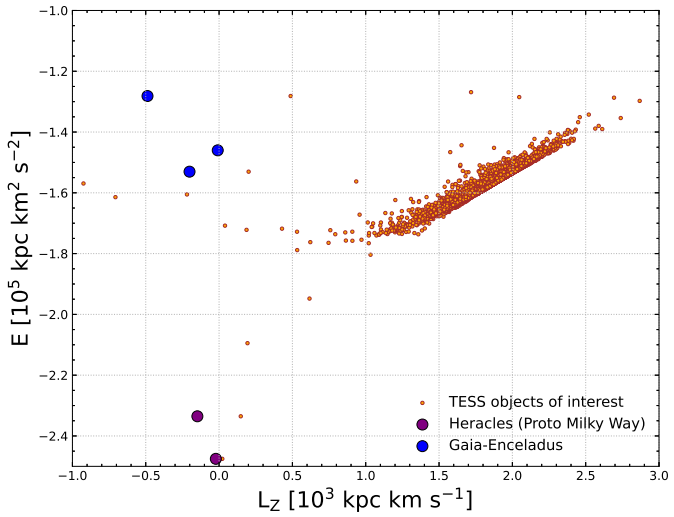
4. Conclusions and Future Perspectives

The results of our study suggest that, if extragalactic exoplanets exist within the Milky Way, they are likely associated with the Galactic halo. We identified possible connections to structures such as Gaia-Enceladus/Sausage and the proto-Milky Way among the candidate host stars. We currently compute orbital parameters for various multi-resolution spectroscopic catalogs, including APOGEE, GALAH, LAMOST, RAVE, SEGUE, and Gaia DR3. This sample is comparable to the TIC, which allows for anticipating the orbital parameters of future TESS data releases.

Our plans include publishing a catalog containing the computed orbital parameters, covering over 30 million stellar objects. This resource will be invaluable for the broader astronomical community, facilitating studies of Galactic structure, stellar kinematics, and exoplanetary science. Additionally, we will conduct a detailed chemical study of the stars, as metallicity is a crucial indicator of stellar origin. Different regions of the Galaxy exhibit characteristic metallicity values, which are essential for confirming the origins of the candidate host stars in the Galactic halo. The integration of kinematic and chemical data will provide a comprehensive framework for understanding the relation-



(a) NASA Archive host stars.



(b) TESS objects of interest.

FIGURE 2: The $E - L_Z$ diagram displays the orbital energy versus the angular momentum of stars, which helps in identifying their likely origin within the Galactic structure. In the NASA Archive sample (top panel), one star exhibits characteristics consistent with the Gaia-Enceladus/Sausage structure. For the TESS Objects of Interest sample (bottom panel), three stars show kinematics indicative of Gaia-Enceladus/Sausage, while two others are consistent with the Proto-Milky Way. This classification relies on the structure identification criteria outlined in Horta et al. (2023).

ship between Galactic evolution and the distribution of exoplanetary systems.

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