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Stellar Ages of TESS Stars, Adopting Spectroscopic Data from *Gaia GSP-Spec*

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Abstract: The *Gaia* DR3 *GSP-spec*/TESS (*GST*) catalog combines asteroseismic data from NASA's TESS mission with spectroscopic data from ESA's *Gaia* mission, and contains about 116,000 Red Clump and Red Giant Branch stars, surpassing previous datasets in size and precision. The Bayesian tool **PARAM** is used to estimate stellar ages using MESA models for, currently, 30,297 stars. This *GST* catalog, which includes kinematics and chemical information, is adopted for studying the Milky Way's structure and evolution, in particular its thin and thick disk components.

Keywords: fundamental parameters; stellar content; automatic stellar parametrisation; asteroseismology

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Citation: Denis, E.; de Laverny, P.; Miglio, A.; Recio-Blanco, A.; Alonso Palicio, P.; Montalban, J.; Abia, C. Stellar Ages of TESS Stars, Adopting Spectroscopic Data from *Gaia GSP-Spec*. *Galaxies* **2024**, *12*, 76. https://doi.org/10.3390/galaxies12060076

Academic Editor: Milan S. Dimitrijević

Received: 15 September 2024
Revised: 1 November 2024
Accepted: 5 November 2024
Published: 14 November 2024

1. Introduction

The study of stellar populations is fundamental to understanding the formation and evolution of galaxies and, by extension, our own Milky Way. In this article, we examine the ESA *Gaia* mission (*GSP-spec* module, [1]) and its focus on a three-dimensional map of stars in our Galaxy, with its Radial Velocity Spectrometer (RVS hereafter; [2]) providing atmospheric data and chemical compositions, as well as NASA's Transiting Exoplanet Survey Satellite (TESS) [3], which studies the internal structure of stars by detecting their oscillations. Together, they present an unprecedented opportunity to study stellar populations with higher precision.

In this context, we built the *Gaia* DR3 *GSP-spec*/TESS (*GST*) catalog, which combines asteroseismic and spectroscopic data from TESS and *Gaia* DR3, respectively. By providing high-quality atmospheric parameters, chemical abundances, and stellar ages for over 115,000 Red Clump (RC) and Red Giant Branch (RGB) stars, the *GST* catalog significantly advances the available data for Galactic Archaeology, enabling researchers to trace the formation history and evolution of the Milky Way.

This study aims to introduce this extensive catalog regarding kinematics, chemical compositions, and stellar ages, as well as its potential applications for Galactic studies, highlighting its advantages over previous datasets in size, precision, and scope. Indeed, ages of RGB stars derived from combined asteroseismic and spectroscopic data are currently available only for samples of 10,000 stars or fewer. One can cite Kepler [4], CoRoT [5], and K2 [6]. Additionally, the APOGEE survey [7] provides spectroscopic age estimates for 178,825 RGB stars using the supervised machine learning algorithm XGBoost, which is trained on a high-quality sample of 3,060 RGB and RC stars with asteroseismic ages observed by both APOGEE and Kepler in order to validate the spectroscopic ages obtained.

2. Materials and Methods

2.1. The GST Catalog

This study combines data from *Gaia* (DR3) and TESS missions. *Gaia*'s RVS provided high-quality spectra, analyzed by the *GSP-spec* module to determine stellar atmospheric parameters, in particular the stellar surface gravity log($g_{spectro}$), and individual chemical abundances. The TESS mission provided asteroseismic data, such as the surface gravity log($g_{seismic}$), the frequency of maximum power (ν_{MAX}), and the large frequency separation ($\Delta\nu$) for RC and RGB stars.

The *GST* catalog is built based on the comparison between the asteroseismic and the spectroscopic surface gravities. Indeed, we imposed a $\Delta\log(g) = \log(g)_{spectro} - \log(g)_{seismic} \leq 0.2$ dex, resulting in a catalog with 115,869 stars. Within this catalog, there is a *Golden* sample defined by the criterion $|\Delta \log(g)| \leq 0.05$ dex, containing 30,297 stars.

This catalog will be made available as an electronic table at CDS, including the stellar parameters derived from the current study [8].

Figure 1 presents the kinematics properties of the *GST* catalog. This Toomre diagram, color-coded in eccentricity e, shows that most stars are located in the Solar neighborhood, and belong to the thin and thick discs.

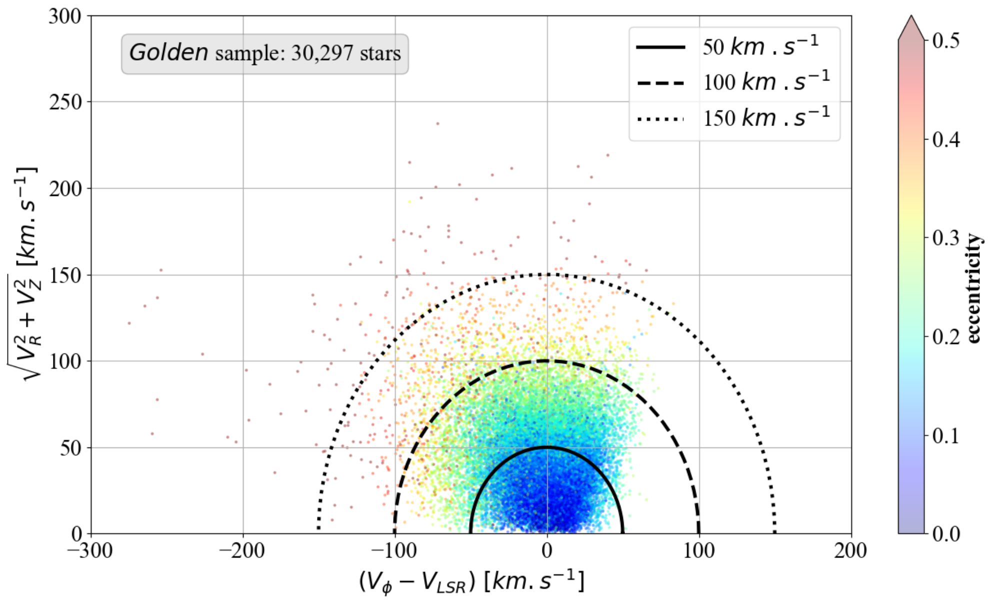

Figure 1. Toomre diagram, color-coded in eccentricity e. The solid, dashed, and dotted black lines represent the curves of the same velocity: 50 km s^{-1}, 100 km s^{-1}, and 150 km s^{-1}, respectively.

2.2. Age Determination Using the Bayesian Method

In this study, stellar ages are determined using the Bayesian tool **PARAM** (http://stev.oapd.inaf.it/cgi-bin/param, accessed on 4 November 2024) [9]. This code derives the most probable stellar properties using the comparison between observational and theoretical data, and in particular, the set of MESA [10–12] isochrones.

We used the following as the input in **PARAM** spectroscopic and asteroseismic measured data:

- *Gaia* and *GSP-spec* spectroscopic data: the effective temperature T_{eff}, the metallicity $[M/H]$, and the luminosity L;
- Asteroseismic data: the frequency of maximum power ν_{MAX}, the large frequency separation $\Delta\nu$, and mass M.

The input data act as priors and allow for an initial selection of isochrones corresponding to the measured parameters. Additionally, error estimates for all observed quantities are fully incorporated into the analysis, enabling the Bayesian tool to compute fundamental statistical properties of the estimated parameters, including the mean, median, and variance.

For more details on the Bayesian method of **PARAM**, please refer to [9].

3. Results

We derived stellar ages for the *Golden* sample. To select the most reliable ages, we applied strict filters on age uncertainty, the difference between the mode and median values of the computed ages, the difference between the spectroscopic and asteroseismic masses, and the relative difference tolerated between masses computed by scaling relations [13] and by **PARAM**. We also imposed thresholds on the minimum value of ν_{MAX} and on the maximum computed age. As a result, 2,153 high-quality stars of the *Golden* sample remained.

An initial result that allows for both an exploration of the properties of the stars in our catalog and the validation of these stellar ages is presented in Figure 2.

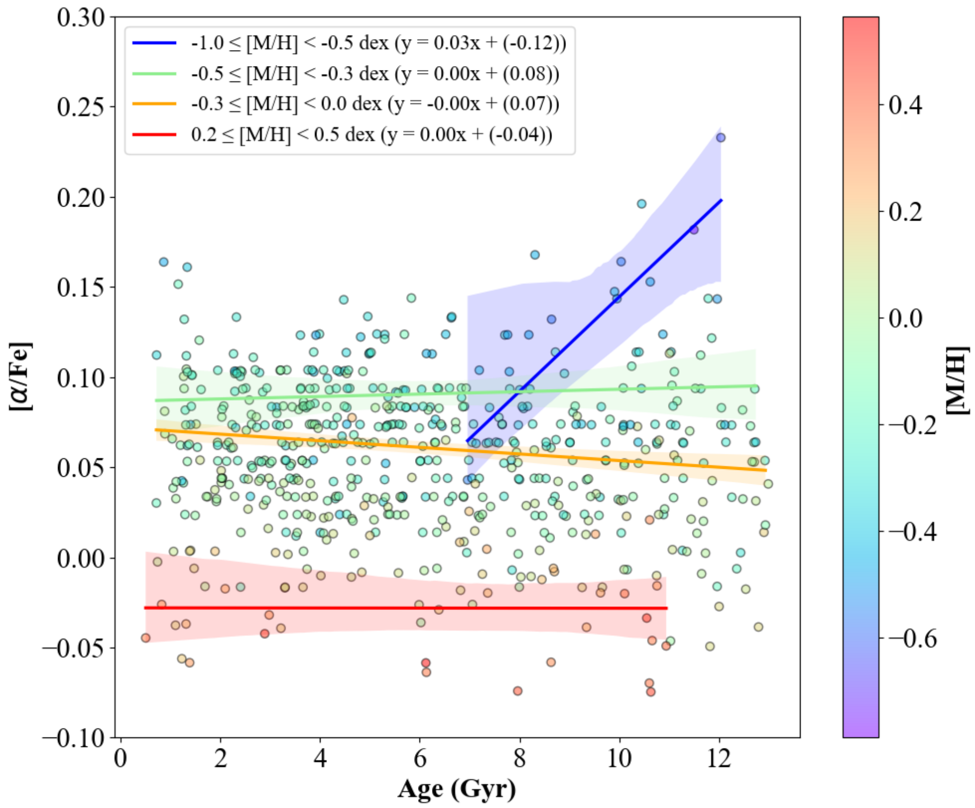

Figure 2. $[\alpha/Fe]$ versus stellar age, color-coded indicating $[M/H]$. The $[\alpha/Fe]$-age trend is examined within four different metallicity bins. The red, yellow, green, and blue lines correspond to the Theil–Sen linear regression for each metallicity range, with the shaded respective regions indicating the 95% confidence interval bounds for the fit.

Figure 2 illustrates the $[\alpha/Fe]$-age trend, with a color code indicating the stellar metallicity $[M/H]$. The $[\alpha/Fe]$-age trend is examined within different metallicity bins. It is worth noting that the relative uncertainties on stellar ages are lower than 50%, while the uncertainties on $[\alpha/Fe]$ are lower than 0.05 dex. One can note a notable spread in stellar age for each $[\alpha/Fe]$ value, and especially for $[\alpha/Fe]$ values lower than 0.15 dex. Then, we can observe that metal-rich stars populate the lower envelope of the disc, while the upper envelope mainly consists of metal-poor stars. For $[M/H] \geq -0.5$ dex (illustrated by red, yellow, and green lines), stars range in age from 0 to 13 Gyr, showing a flat trend in the $[\alpha/Fe]$-age plane with no slope variation across metallicity bins. Chemical evolution models and radial migration could explain this pattern if we assume a coexistence of various stellar populations, each with its enrichment history and origin within the Galactic discs.

Then, for stars with lower metallicity ($[M/H] \leq -0.5$ dex, illustrated by the blue line), we can observe a linear increase in $[\alpha/Fe]$ with age (positive slope).

We retrieved the same conclusions as those of Santos-Peral (2021) [14], validating the calculated stellar ages.

4. Summary

In this study, we built the *GST* catalog of Red Clump (RC) and Red Giant Branch (RGB) stars by combining asteroseismic data from TESS with spectroscopic measurements from *Gaia* DR3 *GSP-spec*. This catalog, composed of over 115,000 stars, surpasses the precision and scale of previous astero-spectroscopic catalogs and will thus allow the effective study of the Milky Way's structure and evolution. The first age estimates of a subsample of a few thousand stars have led to preliminary results confirming established trends in the Galactic disc stellar population, such as the $[\alpha/Fe]$-age relation. Future work will focus on expanding the age determinations to the entire catalog. The stars included in the *GST* catalog, along with their parameters derived from the present study, will be made available in an electronic table. This will be announced in a future paper [8]. The *GST* catalog will be a valuable resource for advanced studies devoted to the Milky Way's formation and evolution, with implications for both Galactic Archaeology and stellar physics.

Author Contributions: Conceptualization, E.D., P.d.L., A.M. and A.R.-B.; methodology, E.D., P.d.L., A.M. and A.R.-B.; software, E.D., P.d.L. and A.M.; validation, E.D., P.d.L., A.M., A.R.-B., P.A.P., C.A. and J.M.; formal analysis, E.D., P.d.L. and A.M.; investigation, E.D., P.d.L., A.M. and A.R.-B.; resources, E.D., P.d.L., A.M., A.R.-B. and P.A.P.; data curation, E.D. and A.M.; writing—original draft preparation, E.D.; writing—review and editing, E.D. and P.d.L.; visualization, E.D. and P.d.L.; supervision, P.d.L.; project administration, E.D. and P.d.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The data will be made available later, as indicated, in a future paper (Denis et al., in preparation) [8].

Acknowledgments: This research has been partially founded by the project PID2021-123110NB-I00, financed by MICIU/AEI/10.13039/501100011033, and by FEDER, Una manera de hacer Europa, UE. AM and JM acknowledge support from the ERC Consolidator Grant funding scheme (project ASTEROCHRONOMETRY, https://www.asterochronometry.eu, G.A. n. 772293).

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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