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Assessing the Accuracy of TESS Asteroseismology with APOGEE*

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ABSTRACT

The recent NASA TESS mission has the potential to increase the available asteroseismic sample dramatically, but its precision and accuracy have yet to be confirmed. To date, NASA's Kepler mission has been considered the gold standard for asteroseismic samples, despite data only being available for a small portion of the sky. TESS's observations cover the whole sky, and previous work has identified 158,000 potential red giant oscillators. However, the quality of these results has been questioned, both for the reliance on machine learning rather than standard by-eye verification, and for the limited length (in 1-month intervals) of the data on which it is based. Using APOGEE, which is calibrated to the asteroseismic scale of the Kepler data, we show that seismology from TESS is calibrated to the Kepler scale to better than 5% for about 90% of red giants, and has only slight trends with mass, metallicity, and surface gravity. We therefore conclude that current TESS seismic results can already be used for galactic archaeology, and future results are likely to be highly transformational to our understanding.

Keywords: Red giant stars(1372) — Asteroseismology(73)

1. INTRODUCTION

There has been much work done to understand the history and evolution of our Milky Way galaxy. For example, using photometry, kinematics, and chemical abundances to analyze the characteristics of stars, a separation between the thin and thick disks was discovered with implications for our galactic evolutionary history (Nordström et al. 2004; Miglio et al. 2012; Lane et al. 2022), and a variety of galactic merger events have been identified (e.g. Helmi et al. 2018). Despite these successes, there remains a need for exact stellar ages for the individual single red giants used for galactic archaeology. However, most standard methods, including measuring isochrones and analyzing chemistry, are not sufficiently precise. Asteroseismology, the study of oscillations, has shown promise in providing both precise and accurate stellar ages (Mosser et al. 2012; Pinsonneault et al. 2014; Yu et al. 2018; Zinn et al. 2022). Unfortunately, previous asteroseismic analyses have been limited to small fields in the sky, which is not optimal for archaeological studies related to the entire galaxy. With the new introduction of TESS, an all-sky survey including millions of red giants, and at least 158,000 identified oscillators, limited sky coverage is no longer a great concern (Hon et al. 2021). As exciting as this survey is, it is unclear how accurate its measurements are due to the shorter data collection period and the inclusion of machine learning in the seismic identification. Given the range of data that NASA's TESS satellite provides and the sheer number of stars in the study, it is imperative to review these previously unconfirmed measurements. To validate its accuracy, it must be compared to the seismic scale using data that has already been thoroughly reviewed. We use spectroscopic results from the APOGEE survey for this purpose.

2. METHODS

We refer to the recent APOGEE (Apache Point Observatory Galactic Evolution Experiment) Data Release 17 (Abdurro'uf et al. 2022), of the Sloan Digital Sky Survey (Blanton et al. 2017) project, whose purpose is to identify an archaeological record of the Milky Way galaxy through the collection of chemical abundances and radial velocities (Santana et al. 2021; Beaton et al. 2021). APOGEE collected near-infrared spectra using the APOGEE spectrographs (Beaton et al. 2021), on the SDSS telescope (Gunn et al. 2006) and at the Los Campanas observatory (Babcock 1971). The spectra were processed with an automated pipeline (García Pérez et al. 2016) using Synspec atmosphere grids

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(Abdurro'uf et al. 2022). Results were calibrated using previous asteroseismic results from Kepler, open clusters, and low extinction fields (Holtzman et al. 2015, 2018; Jönsson et al. 2020), and stars with poor results were flagged or eliminated. The data we use from TESS (Ricker et al. 2010, Transiting Exoplanet Survey Satellite) comes from the asteroseismic analysis of Hon et al. (2021). That study used machine learning to analyze long-cadence photometry from TESS taken at 30-minute intervals for one month's duration (27 days). That analysis identified potential oscillations in 158,000 red giant stars. For comparison, previous work has identified ∼20,000 red giant oscillators from Kepler (4-year duration, Yu et al. 2018), ∼20,000 red giants from K2 (∼70-day duration, Zinn et al. 2022), and 1800 Red giants in CoRot fields (∼1-3 month duration Mosser et al. 2012).

Therefore, the TESS sample represents a significant potential increase in the available targets compared to previous work. Using the asteroseismic results from Hon et al. (2021), and the spectroscopic APOGEE data, we created a file containing values from TESS and those from APOGEE in a similar fashion to APOKASC (Pinsonneault et al. 2018). Specifically, we used the correspondence between TIC_ID and 2MASSID from TIC-v7 (Stassun et al. 2019), eliminating any stars that did not have a matching counterpart in the other dataset. Following this process, we found 15018 matches between the APOGEE (Abdurro'uf et al. 2022) and TESS data. We added to our table calculations of seismic log(g) and mass in a similar fashion to Hon et al. (2021), using GAIA DR2 radius (Gaia Collaboration et al. 2018), APOGEE DR17 temperature, and $\nu_{\rm max}$. Once we calculated the seismic log(g) and mass, we used standard equations for error propagation to calculate errors for both seismic log(g) and mass, appropriately naming them as "e_mass" and "e_LoggSeis" within the catalog. For further discussion, we will be referring to the aforementioned catalog. The catalog can be viewed at this link: https://zenodo.org/record/7814297

3. ANALYSIS

Here we rely on the transitive property. We know that the APOGEE spectroscopic surface gravity was carefully calibrated on the Kepler asteroseismic gravity scale (Holtzman et al. 2015). Therefore, we assume that if the new TESS surface gravity matches the surface gravities from APOGEE, they must be consistent with that same Kepler scale. In general, we found this to be the case, there is agreement to better than 5%, signifying a very accurate calibration between APOGEE and TESS. We searched for possible dependencies of the offset between the asteroseismic and spectroscopic surface gravities on metallicity, [α/M], log(g), temperature, and mass. (Figure 1). We found evidence for slight potential trends with mass, metallicity, and surface gravity. Previous work has identified significant inconsistencies in the asteroseismic results in surface gravity as a function of metallicity (Epstein et al. 2014). Here, we see at most a slight trend with metallicity. We note that the largest offsets that we discovered tended to be for the clump stars. Since oscillation spectra are sensitive to evolutionary states (Mosser et al. 2012; Elsworth et al. 2019), and the APOGEE spectroscopic gravity requires an evolutionary state-dependent correction (Holtzman et al. 2015, 2018), there are several possible explanations for this phenomenon. We suggest that it might indicate a small fraction of spectra have been assigned an incorrect spectroscopic evolutionary state, which means their gravities are incorrectly calibrated. In Figure 1, we also show histograms of the difference between the TESS asteroseismic and APOGEE spectroscopic gravities scaled by the claimed uncertainty for each star. Given that this is significantly wider than the standard normal distribution, we assert that the predicted uncertainty is underestimated for the majority of stars. Comparisons between the Kepler and APOGEE data indicate that the spectroscopic uncertainties in DR17 may be underestimated by at least a factor of two (M. Pinsonneault et al., in prep.), but this would not be sufficient to match the observed differences in our sample, suggesting that there are additional uncertainties that are also underestimated.

4. CONCLUSION

Our analysis indicates that the asteroseismic results from Hon et al. (2021) are quite reliable. For more than 98% of stars, the inferred asteroseismic gravity matches the spectroscopic gravities to better than 10%, suggesting that the true giants have been identified. The precision for $\nu_{\rm max}$ is also quite good – for 90% of stars, the agreement on the inferred log(g) is better than 5% (~ 0.05 dex in log(g)). We observe slight differences between the spectroscopic and asteroseismic gravities that correlate with mass, log(g), and [M/H], but no significant overarching offsets. We do note that there is a slightly larger offset on average for clump stars, which we attribute to one of the following: 1. A slight failure rate in correction identifying the stars' evolutionary state using only spectroscopic information, which is required to precisely calibrate the spectra to the Kepler asteroseismic scale. 2. Slight evolutionary state-dependent errors in the correction factor applied to the APOGEE spectroscopic gravities 3. Evolutionary state-dependent challenges in correctly pinpointing $\nu_{\rm max}$ in short data sets using only a neural network. Given these results, we encourage both

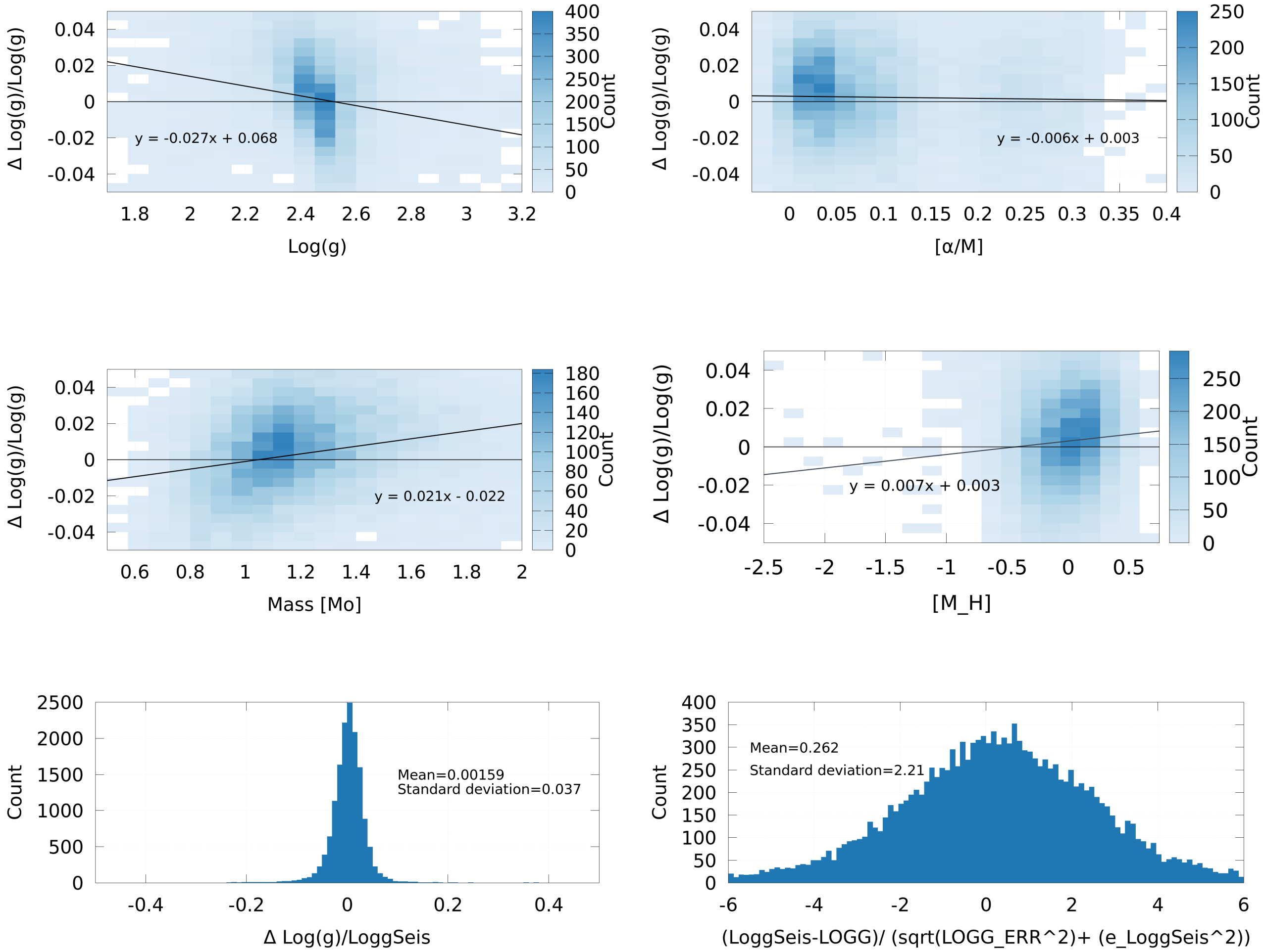

Figure 1. Top four: Graphical heat map representation of the offset between the spectroscopic and asteroseismic surface gravities (Seismic - Spectroscopic) compared to spectroscopic log(g), [α/M], mass, and [M/H]. The darkness is representative of the concentration of stars in a given area, and no significant trends can be seen within these graphs except for slight trends with mass and metallicity and a slight trend in the red clump (top right). **Bottom left**: Offset between the spectroscopic and asteroseismic results. A mean of 0.001 and uncertainty of 3.5% indicate excellent agreement between the measurements. **Bottom right**: Histogram comparing the measured offsets before the seismic and spectroscopic results scaled by the claimed uncertainties for each measurement. The distribution is much wider than the standard-normal distribution, suggesting that the claimed uncertainties are underestimated by a factor of 2.

future investigations into the precise details of TESS asteroseismology of red giants, as well as usage of the current TESS results for galactic archaeology purposes.

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The TESS Asteroseismic Investigation is organized within the TESS Asteroseismic Science Consortium (TASC). The data platform for TASC is provided via the TESS Asteroseismic Science Operations Center (TASOC), hosted at the Stellar Astrophysics Centre (SAC) at Aarhus University, Denmark. TASOC provides long-term storage of all data products. TASC membership is open to the entire TESS community and any member of TASC can apply to become a member of a given working group within TASC. The TASC Coordinated Activity "TESS Data for Asteroseismology" (T'DA) is responsible for maintaining the TASOC portal and for providing data products for TASC.

All users are welcome to contact the T'DA team if they require custom treatment for a specific target or group of targets. For such cases, the team requests that the T'DA members involved in this treatment should be offered co-authorship on any paper that results.

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