HD-TESS: An Asteroseismic Catalog of Bright Red Giants within TESS Continuous Viewing Zones

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Abstract

We present HD-TESS, a catalog of 1709 bright (V ∼ 3–10) red giants from the Henry Draper (HD) Catalog with asteroseismic measurements based on photometry from NASA’s Transiting Exoplanet Survey Satellite (TESS). Using light curves spanning at least 6 months across a single TESS observing cycle, we provide measurements of global asteroseismic parameters (νmax and Δr) and the evolutionary state for each star in the catalog. We adopt literature values of atmospheric stellar parameters to estimate the masses and radii of the giants in our catalog using asteroseismic scaling relations, and observe that HD-TESS giants on average have larger masses compared to Kepler red giants. Additionally, we present the discovery of oscillations in 99 red giants in astrometric binary systems, including those with subdwarf or white dwarf companions. Finally, we benchmark radii from asteroseismic scaling relations against those measured using long-baseline interferometry for 18 red giants and find that correction factors to the scaling relations improve the agreement between asteroseismic and interferometric radii to approximately 3%.

Unified Astronomy Thesaurus concepts: Asteroseismology (73); Stellar oscillations (1617)

Supporting material: machine-readable tables

1. Introduction

Bright stars are among some of the most well-studied celestial objects. They are prime targets for a myriad of studies, including high-resolution spectroscopic surveys of the solar neighborhood (e.g., Hekker & Meléndez 2007; Luck & Heiter 2007; Soubiran et al. 2010; Feuillet et al. 2018) as well as planet searches using the Doppler velocity method (e.g., Pepe et al. 2011; Addison et al. 2019). Furthermore, fundamental measurements such as angular diameters (e.g., Baines et al. 2010; von Braun & Boyajian 2017), and dynamical measurements of visual binaries (e.g., McAlister 1977; Rettter & King 1982; Mason et al. 2001) are limited to only bright stars. Some of these stars additionally serve as benchmarks for studying stellar populations in the Galaxy (Jofré et al. 2018), and therefore a precise characterization of their properties is essential.

Asteroseismology, the study of stellar oscillations, can provide precise measurements of the masses and radii of Sun-like stars (Christensen-Dalsgaard 1984; Bedding 2014; Chaplin et al. 2014; García & Stello 2015; Hekker & Christensen-Dalsgaard 2017). Over the past decade, the availability of precise, continuous photometry from space missions CoRoT (Baglin et al. 2008), Kepler (Borucki et al. 2010), and K2 (Howell et al. 2014) has enabled the seismic characterization of the fundamental properties of thousands of red giants across distant stellar populations within the Milky Way (Miglio et al. 2009; Pinsonneault et al. 2018; Yu et al. 2018), which has been pivotal in studies of Galactic archeology (e.g., Silva Aguirre et al. 2018; Zinn et al. 2020; Miglio et al. 2021). However, the asteroseismology of bright (V ∼ 7) stars has previously been limited to only several dozens of targets that can be measured from ground-based radial velocity surveys (e.g., Kjeldsen et al. 1995; Frandsen et al. 2002; Malla et al. 2020), or a small subset of Kepler/K2 stars for which smeared and halo photometry can be applied (Pope et al. 2016; White et al. 2017; Pope et al. 2019). It is only through recent space-borne photometric surveys specifically targeting bright stars such as the Bright Target Explorer (BRITE; Weiss et al. 2014) and NASA’s Transiting Exoplanet Survey Satellite (TESS; Ricker et al. 2015) that the asteroseismology of a large ensemble of bright stars is now possible.

In this paper, we aim to characterize the fundamental parameters of bright red giants observed by TESS. The prime targets for this analysis are stars near or within the TESS Continuous Viewing Zones (CVZs), which are parts of the sky with maximal overlap between the 24° × 96° TESS observing fields (sectors) within Cycles 1–3 of the mission. The long photometric time series resulting from this overlap leads to a greater frequency resolution in the Fourier domain, which in turn improves the precision of asteroseismic measurements. As a result, we aim to produce a catalog of seismically determined masses and radii for bright red giants that will be useful for informing other studies involving giant stars. This catalog also seeks to complement previous asteroseismic studies of red giants with TESS—specifically the work by Silva Aguirre et al. (2020) that measured the oscillation properties of 25 bright red stars.
giant stars, the Galactic archeology study by Mackereth et al. (2021) that seismically analyzed \(~5500\) red giants in the southern CVZ, and the near all-sky detection and seismic characterization of \(~158,000\) giants by Hon et al. (2021). In contrast to these studies, we will focus on the bright stars in both CVZs by basing our selection on red giants from the Henry Draper (HD) catalog (Cannon & Pickering 1993; Nesterov et al. 1995). The cross-match between our selection from the HD catalog with TESS observations thus yields the HD-TESS catalog whose construction we detail in the following.

2. Data

There are two sources of light curves in this study. The first is the TESS Science Processing Operations Center pipeline (SPOC; Twicken et al. 2016; Jenkins 2020) obtained from the Mikulski Archive for Space Telescopes at the Space Telescope Science Institute. The second is the MIT Quick-Look Pipeline (QLP; Huang et al. 2020a, 2020b). Generally, we find that SPOC light curves better preserve flux variability corresponding to giant oscillations for bright and saturated targets with \(T_{\text{mag}} \leq 7\) compared to those from the MIT Quick-Look Pipeline (Huang et al. 2020a, 2020b). Many of the fainter HD stars in our sample, however, were not targeted by the SPOC pipeline but have light curves generated from the QLP. Because the data from QLP’s simple aperture photometry is generally adequate for observing giant oscillations at fainter magnitudes (Hon et al. 2021), our approach here is to prioritize SPOC light curves whenever possible, otherwise we default to QLP photometry.

Our analysis includes observations up to Sector 39 for stars with SPOC light curves, such that stars near the southern ecliptic poles will have up to 2 yr of data as of the end of the year 2021. For stars having only QLP photometry, we use data across Cycles 1 and 2, meaning the maximum length of the time series for such stars in this work will be 1 yr. Although QLP light curves across Cycle 3 are available (Kunimoto et al. 2021), the data have a reduced sampling cadence of 10 minutes as opposed to the 30 minutes cadence across the first two TESS Cycles. To simplify the treatment of data in this study, we incorporate a consistent observing cadence for each star’s light curve and therefore delegate the task of matching different observing cadences as part of future work.

3. Target Selection

First, we identify 5711 stars with spectral types G and K from the HD catalog that have been observed for at least six sectors in TESS Cycles 1 and 2. Next, we impose a selection based on a star’s effective temperature and radius from the TESS Input Catalog version 8.2 (TIC; Stassun et al. 2019), as follows:

1. \(R < 40.0 R_\odot\) as an upper boundary to filter out long-period variables.
2. \(R \geq 10^6 R_\odot\) with \(p = \left(\frac{T_{\text{eff}}(\text{K})}{7000} - \frac{3}{7}\right) \log\left(\frac{300}{T_{\text{eff}}(\text{K})}\right) + \log(0.7)\).

This is the boundary used by Hon et al. (2019) to discriminate early subgiant stars from those beginning to ascend the red giant branch.

This selection is depicted in Figure 1. Under this selection, we reduce the initial sample of stars to 3142, from which 2611 show red giant oscillations. Note that 2042 of the 2611 stars are already known to show oscillations based on previous work by Hon et al. (2021) This implies that 569 red giants in this sample are new inclusions that were not previously detected from one month of TESS data.

3.1. Asteroseismic Measurements

We extract initial estimates for the frequency at maximum oscillation power \(\nu_{\text{max}}\), and the large frequency separation (\(\Delta \nu\)) for the sample of 2611 giants using the SYD asteroseismic data pipeline (Huber et al. 2009). With improvements to the SYD pipeline as specified in Huber et al. (2011) and Yu et al. (2018), the pipeline has previously been applied for the asteroseismology of shorter time series, including those from K2 (Zinn et al. 2020, 2022) and even from TESS itself (Stello et al. 2022). Beginning with the SYD pipeline’s \(\nu_{\text{max}}\) estimates, we further refine the estimates by performing a Bayesian fit using a model comprising a Gaussian envelope with three background components to the star’s power spectrum as described by Themeßl et al. (2020). The resulting \(\nu_{\text{max}}\) from this final fit is our reported estimate.
The raw output from the SYD pipeline reports a $\Delta \nu$ measured automatically from the autocorrelation function of the oscillation power spectrum for each input star. However, complicating features in the frequency domain such as lower signal-to-noise ratios, additional mode structure from dipole mixed modes (e.g., Bedding et al. 2011), or the overlap of other periodic signals unrelated to oscillations (e.g., Colman et al. 2017) may result in inaccurate measurements of $\Delta \nu$. To avoid such occurrences, we first vet the SYD pipeline outputs using the neural network classifier introduced by Reyes et al. (2022). Briefly, the classifier takes as input extracted features across a variety of commonly used visual diagrams in asteroseismology — such as the autocorrelation plot and the echelle diagram of the oscillation modes — and subsequently outputs a probability indicating whether the $\Delta \nu$ measurement used to construct such diagrams corresponds to a valid measurement. To further ensure the robustness of the $\Delta \nu$ measurements, we additionally inspect the oscillation spectrum of each star using diagnostic plots, as shown in Figure 2. We perform this inspection in addition to the automatic vetting by the neural network because it allows us to recover a fraction of initially rejected stars that have $\Delta \nu$ erroneously estimated by the seismic pipeline (and thus rightfully rejected by the automatic vetting). To recover $\Delta \nu$ for such stars, we manually tune $\Delta \nu$ such that: 1) vertical ridges are formed in the echelle diagram; 2) peaks are observed at 1 and 2 $\Delta \nu$ in the autocorrelation of the oscillation spectrum, as indicated in Figure 2. The uncertainty in $\Delta \nu$ is taken as the shift required to disrupt the vertical alignment of the ridges in the echelle diagrams and is approximately at the 2%–3% level. We additionally inspect other stars that pass the automatic vetting to ensure that the same visual criteria are met.

The result of the vetting is shown in Figure 3. From 2611 oscillating giants, we retain 1709 for which their $\Delta \nu$ can be identified with a high level of confidence. Most giants filtered out in this vetting stage are those with $R \gtrsim 20 R_\odot$ (corresponding to $\nu_{\text{max}} \lesssim 10 \mu Hz$) and therefore have long-period oscillations for which frequency separations are typically difficult to measure with 1 to 2 yr of data. We also observe a sharp cutoff corresponding to an absence of faint stars with small radii, where stars beyond this limit show too low signal-to-noise to have
Figure 3. (Left) Radius–magnitude distribution of oscillating giants before (blue) and after (red) vetting of their large frequency separations $\Delta \nu$ as described in Section 3.1. Similar to Figure 1, the radii used in the plot are adopted from the TESS Input Catalog. The plot is aligned such that more luminous giants (with smaller $\nu_{\text{max}}$) are lower, consistent with how the $\nu_{\text{max}}$-magnitude distribution for giants is commonly visualized (e.g., Stello et al. 2017; Zinn et al. 2020; Hon et al. 2021).

detectable oscillations (Stello et al. 2017; Hon et al. 2021; Stello et al. 2022).

Finally, we categorize the giants in our sample as either those that are hydrogen shell burning while ascending the red giant branch (RGB) or core helium-burning stars within the red/secondary clump (CHeB) by applying the Hon et al. (2017, 2018) deep learning classifier, which uses the frequency distribution of oscillation modes within a star’s collapsed échelle diagram (e.g., Figure 2c) to determine an evolutionary state. The 1709 stars with $\Delta \nu$, $\nu_{\text{max}}$, and evolutionary state determinations thus form the HD-TESS catalog and are tabulated in Table 1. The $\nu_{\text{max}}$ measurements of all 2611 oscillating giants identified in this study, including those whose $\Delta \nu$ cannot be reliably measured, are tabulated in Appendix A.

### 4. Fundamental Stellar Parameters

#### 4.1. Seismic Measurements

Figure 4 shows the results of our seismic measurements, where we plot $\nu_{\text{max}}$ against the quantity $\nu_{\text{max}} \sim M^{0.25 \nu_{\text{eff}}}^{0.375}$, which acts as a temperature ($T_{\text{eff}}$)-dependent proxy for stellar mass ($M$). With TESS observations spanning at least 6 months within the CVZs, we are able to clearly distinguish between RGB and CHeB populations as predicted by Mosser et al. (2019). Other population-level features that are well resolved from the figure include the sharpness of the right edge of the CHeB distribution that marks the zero-age CHeB phase (e.g., Kallinger et al. 2010; Li et al. 2021) as well as an overdensity of RGB stars at $\sim 50 \mu$Hz indicating the luminosity bump in first ascent giants (Rebsdal & Weigert 1970; Christensen-Dalsgaard 2015; Khan et al. 2018). Additionally, we observe a systematic increase in the stellar mass proxy for both RGB and CHeB TESS populations compared to the giants from Kepler (Yu et al. 2018, black points), which we discuss further in Section 4.2.

Estimates of the mass ($M$) and radius ($R$) of each giant can be obtained using the following asteroseismic scaling relations:

$$
\frac{M}{M_{\odot}} = \left(\frac{\Delta \nu}{f_{\Delta \nu}}\right)^{-4} \left(\frac{\nu_{\text{max}}}{\nu_{\text{max}, \odot}}\right)^3 \left(\frac{T_{\text{eff}}}{T_{\text{eff}, \odot}}\right)^{3/2}
= \frac{\kappa_M}{f_{\Delta \nu}} \left(\frac{T_{\text{eff}}}{T_{\text{eff}, \odot}}\right)^{3/2},
$$

(1)

$$
\frac{R}{R_{\odot}} = \left(\frac{\Delta \nu}{f_{\Delta \nu}}\right)^{-2} \left(\frac{\nu_{\text{max}}}{\nu_{\text{max}, \odot}}\right)^{1/2} \left(\frac{T_{\text{eff}}}{T_{\text{eff}, \odot}}\right)^{1/2}
= \frac{c_{\text{R}}}{f_{\Delta \nu}} \left(\frac{T_{\text{eff}}}{T_{\text{eff}, \odot}}\right)^{1/2}.
$$

(2)

These relations are a consequence of the approximate proportionality of $\Delta \nu$ to the square root of stellar mean density.
as well as that of $n_{\text{max}}$ to the star’s acoustic cutoff frequency (Brown et al. 1991; Kjeldsen et al. 1995; Belkacem et al. 2011). The quantity $f_{\Delta \nu}$ is a correction term used to correct for any deviations from the proportionality assumption of the former relation and has been shown to provide a better agreement between independently measured fundamental parameters from eclipsing binaries (Gaulme et al. 2016; Brogaard et al. 2018; Kallinger et al. 2018) and Gaia parallaxes (Huber et al. 2017; Hall et al. 2019; Zinn et al. 2019). Here, we adopt the solar reference values of $\Delta \nu_0 = 135.1 \mu$Hz, $n_{\text{max,0}} = 3090 \mu$Hz, and $T_{\text{eff,0}} = 5777$ K (Huber et al. 2011, 2013).

Following Sharma et al. (2016), we condense the scaling relations into a more compact form by defining the coefficients $\kappa_M = (\Delta \nu / \Delta \nu_0)^4 \cdot (n_{\text{max}} / n_{\text{max,0}})^3$ for mass and $\kappa_R = (\Delta \nu / \Delta \nu_0)^2 \cdot (n_{\text{max}} / n_{\text{max,0}})$ for radius to represent the seismic aspect of both relations. Similar to Zinn et al. (2020), the purpose of reporting such a representation is to provide the user with the choice of using their own atmospheric parameters to estimate masses and radii. Not only do the scaling relations have an explicit temperature dependence, but the correction term $f_{\Delta \nu}$ is also often computed with reference to stellar models as a function of mass, temperature, metallicity, and evolutionary phase of the star (Sharma et al. 2016; Rodrigues et al. 2017; Serenelli et al. 2017; Li et al. 2022). To obtain cursory estimates of masses and radii in Section 4.2, we adopt the Sharma et al. (2016) correction.

### 4.2. Estimating Masses and Radii

A uniform estimation of masses and radii using Equations (1) and (2) for all stars in our sample is not a straightforward task due to the lack of a homogeneous source of atmospheric parameters for such stars. We therefore collect atmospheric parameters from a variety of catalogs as follows, in decreasing priority order:

1. The SDSS/APOGEE-2 Data Release 17 catalog (Abdurro’uf et al. 2022).
2. The PASTEL catalog (Soubiran et al. 2010).
3. Spectroscopic parameters from Charbonnel et al. (2020).
4. Spectroscopic parameters from the TESS Input Catalog, which adopts such measurements across a variety of other spectroscopic catalogs (see Stassun et al. 2018, 2019).

5. Spectrophotometric temperatures and metallicities from the Starhorse Bayesian inference tool (Queiroz et al. 2018) based on Gaia EDR3 data (Anders et al. 2022).

6. Photometric temperatures from the TESS Input Catalog, which are determined using the color-$T_{\text{eff}}$ relations outlined in Stassun et al. (2019, their Section 2.3.4). Stars in this category have no metallicity information.

A breakdown of the adopted atmospheric parameters from each catalog is shown in Figure 5. Notably, spectroscopic surveys (catalogs 1–4) focus primarily on bright targets with $T_{\text{mag}} \lesssim 6$ or on fainter targets with $T_{\text{mag}} \gtrsim 9$, and therefore lack coverage for intermediate brightness stars within our sample. It is for this reason that we also include atmospheric parameters from spectrophotometric or photometric catalogs for completeness, despite their lack of precision as opposed to spectroscopic measurements (e.g., Figure 18 from Anders et al. 2022). We adopt the reported temperature and metallicity uncertainties from each catalog whenever available. For stars with multiple measurements in the PASTEL catalog, we adopt the standard deviation between the measurements as the uncertainty. Across all atmospheric parameter catalogs, we assign a minimum uncertainty of 0.05 dex for metallicity and 2% for temperature (Tayar et al. 2022).

Given the variety of atmospheric parameter catalogs used, it is difficult to calibrate each to a common temperature or metallicity scale. Although such calibrations can be performed across one large catalog to another (e.g., APOGEE versus Starhorse, Anders et al. 2022), spectroscopic catalogs of bright stars such as PASTEL combine measurements across numerous "boutique" surveys, for which systematic differences across each survey are difficult to quantify. We therefore do not make an attempt to calibrate the atmospheric parameters across each catalog to a common scale. Instead, we suggest users be aware of the origins of the effective temperature and metallicity values used for the mass or radius determination (which we report in Table 2), and be cautious of systematic offsets between temperatures and metallicity scales between different atmospheric parameter catalogs. For consistency, we recommend the use of $\kappa_M$ and $\kappa_R$ from Table 1 along with homogeneously measured atmospheric parameters.

Table 2 tabulates the mass and radius for each star using Equations (1) and (2), with $f_{\Delta \kappa}$ computed using the Sharma et al. (2016) method, which takes into account the temperature, metallicity, and giant evolutionary state. Here, the quoted uncertainties for masses and radii are estimated from 1σ intervals from Monte Carlo sampling of the scaling relations assuming no correlations between measurements used as inputs. The resulting median uncertainty across our sample is 8.3% for mass and 3.2% for radius, neglecting any potential systematic errors between atmospheric parameter catalogs.

Figure 6 compares the distribution of seismic masses of our TESS giants with those from Kepler (Yu et al. 2018), where the TESS sample noticeably contains a greater fraction of stars above $\sim 1.5 M_\odot$. Such a result is consistent with the comparisons made using purely using the seismic mass proxy in
Figure 6. (Top) Kernel density estimates comparing the masses of HD-TESS giants (shaded) with those from a population of giants observed by Kepler (Yu et al. 2018). Compared to the Kepler giants, our TESS sample has a greater fraction of stars above 1.5$M_\odot$, which is consistent with comparisons of the seismic mass proxy $\nu_{\text{mean}} / \nu_s$ between both samples in Figure 4. (Bottom) A comparison of distances between the two giant star samples. TESS probes stellar populations mainly within the solar neighborhood, whereas Kepler probes populations much farther into the Milky Way disk.

Figure 4, and so these relative mass differences are unlikely to be caused by offsets in temperature and metallicity scales between atmospheric sources. This result suggests that HD-TESS has fractionally more young stars, which is expected of stars in the local neighborhood for which many have [Fe/H] and [$\alpha$/Fe] abundances at the solar level (e.g., Haywood et al. 2013; Hayden et al. 2015). The lower panel of Figure 6 shows that the Kepler sample comprises more distant stars, many of which belong to older Galactic populations, including the thick disk (Silva Aguirre et al. 2018; Miglio et al. 2021) as well as the Galactic halo (Epstein et al. 2014; Mathur et al. 2016).

To establish the differences in masses between the Kepler and HD-TESS data sets more concretely, we compare their empirical cumulative distribution functions (ECDFs) in Figure 7. Panel (a1) shows systematic offsets between the Kepler and TESS seismic mass proxy ECDFs that manifest as a relative overdensity of stars with $1.2M_\odot \lesssim M \lesssim 2.2M_\odot$ for HD-TESS masses in panel (b1). To include the effects of uncertainties in these comparisons, we apply a Monte Carlo approach to the $D$-statistic calculated from the two-sided Kolmogorov–Smirnov test (Massey 1951). The $D$-statistic measures the maximum vertical distance between two ECDFs, with larger values generally indicating greater levels of dissimilarity between the two compared data sets. To quantify the impact of our measurement uncertainties, we first perturb each quantity (seismic mass proxy or stellar mass) from a data set with its associated uncertainty and construct an instance of its ECDF. A single value of the $D$-statistic is then computed by comparing this ECDF to another constructed using quantities with another realization of noise or uncertainty. This process is repeated $10^5$ times to build up a $D$-statistic distribution as shown in panels (a2) and (b2) of Figure 7. The “Kepler versus Kepler” and “HD-TESS versus HD-TESS” distributions in these panels are self-similarity distributions. Specifically, these are created by comparing ECDFs of the same data set (e.g., Kepler with itself) but across different noise realizations to show how much variation in the $D$-statistic is expected from measurement uncertainties alone. Meanwhile, the “HD-TESS versus Kepler” distribution measures similarity between data sets, which shows a large offset compared to the self-similarity distributions. The implication here is that differences in the compared quantities between HD-TESS and Kepler data sets are unlikely caused by measurement uncertainties alone, and we thus conclude that the increase in average mass seen for our TESS data set relative to Kepler is indeed significant.

5. Scientific Uses for This Catalog

Owing to their brightness and intrinsic luminosity, nearby red giants have historically been prime candidates for studies of local stellar populations, such as chemical abundance surveys using high-resolution spectroscopy (e.g., Hekker & Meléndez 2007; Luck & Heiter 2007; Liu et al. 2014; Takeda & Tajitsu 2014; Luck 2015) and planet searches using the radial velocity technique (e.g., Döllinger & Hartmann 2021, and references therein). Beyond local surveys, many of these giants have been individually studied for a wide variety of science cases. Figure 8 shows that the number of times some of the brightest targets have been included in a publication ranges in the hundreds, while even for fainter targets there still exists a subset of giants ($T_{\text{mag}} \gtrsim 6$) that are of great interest scientifically. Prior to TESS, however, a vast majority of these giants have not had any precise seismic characterization to complement the studies involving such stars. Although this paper is primarily concerned with assembling a catalog of seismic measurements, we highlight several useful science cases of our catalog unique to bright stars that we will pursue further in future work.

5.1. Stellar Multiplicity

The ever-increasing precision of astrometry from the Gaia space mission (Gaia Collaboration et al. 2018, 2021) has proven extremely valuable for the study of both resolved (e.g., El-Badry et al. 2019, 2021; Makarov & Fabricius 2021) and unresolved stellar companions (e.g., Belokurov et al. 2020; Penoyre et al. 2022) of nearby stars. Of particular interest are binary systems for which one of its components is an oscillating giant because these enable direct constraints on the age of the coeval companion. In Figure 9(a), we show a cross-match of our TESS sample to the catalog of astrometric binaries from El-Badry et al. (2021), yielding a total of 99 oscillating giants with a low chance alignment probability (< 0.1). Figures 9(b)–(f) show that the stars comprising the secondary component in these binary systems span a variety of evolutionary stages based on the color–magnitude diagram, ranging from parts of the main sequence to white dwarfs. Because the giants in our sample generally have well-characterized oscillations, this offers the opportunity of calibrating age relations in other parts of the color–magnitude diagram, such as gyrochronology (Skumanich 1972; Barnes 2007), activity indicators along the main sequence (e.g., Pace 2013), and the cooling-age relation for white dwarfs (Winget et al. 1987). These 99 oscillating giants are tabulated in Appendix B.

The orbital solutions of resolved astrometric binaries, measured by methods such as speckle interferometry (e.g.,
or from space astrometry (Makarov & Fabricius 2021; Makarov 2021), provide an estimate of the mass ratio of the binary system. In such scenarios, the availability of precise mass constraints for one component (in this case, the red giant primary) for such systems translates into a mass determination of both binary components, which is valuable not only for testing stellar evolution theory, but for estimating masses of stars for which model-independent masses are rare such as subdwarfs and white dwarfs. A cross-match of our sample with the Washington Double Star Catalog (Mason et al. 2001) reveals that 91 of our TESS giants are in known double star systems, while a cross-match with the Fourth Catalog of Interferometric Measurements of Binary Stars (Hartkopf et al. 2001) yields 57 stars with previously measured positions. These are tabulated in Appendix C.

5.2. Benchmarking Asteroseismic Radii with Interferometry

The direct measurement of stellar radii using interferometry provides a powerful, model-independent approach to validate the accuracy of radii inferred using the asteroseismic scaling relations (Huber et al. 2012; White et al. 2015). Given known offsets of masses and radii from asteroseismic scaling relations with respect to stellar models (e.g., Epstein et al. 2014; Sharma et al. 2016) and eclipsing binaries (e.g., Brogaard et al. 2018), it is important that comparisons between interferometric radii with seismic radii be performed across a wide range of metallicities, Mason et al. 1999; Balega et al. 2002) or from space astrometry (Makarov & Fabricius 2021; Makarov 2021), provide an estimate of the mass ratio of the binary system. In such scenarios, the availability of precise mass constraints for one component (in this case, the red giant primary) for such systems translates into a mass determination of both binary components, which is valuable not only for testing stellar evolution theory, but for estimating masses of stars for which model-independent masses are rare such as subdwarfs and white dwarfs. A cross-match of our sample with the Washington Double Star Catalog (Mason et al. 2001) reveals that 91 of our TESS giants are in known double star systems, while a cross-match with the Fourth Catalog of Interferometric Measurements of Binary Stars (Hartkopf et al. 2001) yields 57 stars with previously measured positions. These are tabulated in Appendix C.

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temperatures, and evolutionary stages. The bottleneck, however, has been the availability of precise seismic data for interferometric targets, for which to date only seven giants with $R \geq 3 R_\odot$ have had published joint seismic-interferometric coverage (Huber et al. 2012; Johnson et al. 2014; Beck et al. 2015). The HD-TESS catalog can significantly alleviate this limitation by providing a large number of bright targets amenable to both asteroseismology and interferometry.

Figure 10 compares radii for 16 red giants with published interferometric measurements—a factor of 2 increase from the literature. The power spectrum and seismic measurements for each of these 16 giants are presented in Appendix D. The interferometric radii from each literature study (Baines et al. 2010, 2011, 2016; Ligi et al. 2016; von Braun & Boyajian 2017; Baines et al. 2018; White et al. 2018; Karovicova et al. 2020) are computed by combining reported limb darkened angular diameters with parallaxes from Gaia EDR3. In Appendix E, we perform the same analysis as in this Section using interferometric radii derived but using Hipparcos parallaxes (van Leeuwen 2007), where we generally find worse agreement. We thus use Gaia EDR3 parallaxes for the rest of the analysis presented here. We correct for potential zero-point offsets in the parallaxes following Lindegren et al. (2020) and the correction recommended by Zinn (2021).

Three comparisons are presented in Figure 10: (a) Using the Sharma et al. (2016) correction, which provides a $f_{\Delta \nu}$ dependent on the $T_{\text{eff}}$, [Fe/H], and evolutionary state of each star reported in this work; (b) No corrections (i.e., $f_{\Delta \nu} = 1$) with the adopted $T_{\text{eff}}$ in this work, (c) No corrections and using the $T_{\text{eff}}$ reported from each interferometric study. The latter comparison is made in the interest of consistency as the quoted literature $T_{\text{eff}}$ values are typically derived using angular diameters through an application of the Stefan–Boltzmann law. We observe the following:

1. The application of a star-dependent correction factor $f_{\Delta \nu}$ generally improves the agreement between seismic and interferometric radii, especially for low-luminosity giants with $R \lesssim 15 R_\odot$. In particular, we find the median fractional difference between the corrected seismic radii and interferometric to be approximately at the 3.2 $\pm$ 1.7% level. In contrast, the use of no correction factor in Figures 10(b)–(c) results in greater median fractional differences ($\sim$5%–6%). These findings are in accordance with other benchmark studies of asteroseismic radii using Gaia parallaxes (Zinn et al. 2019) as well as using dynamical radii from eclipsing binaries (Gaulme et al. 2016; Brogaard et al. 2018; Kallinger et al. 2018), and further confirms that a correction factor to the asteroseismic scaling relations is indeed warranted.

2. The similarity of trends between panels (b) and (c) suggests that the improvements seen in (a) are mostly from the adoption of a star-dependent $f_{\Delta \nu}$, rather than by...
Our main conclusions are as follows:

1. We present a catalog of fundamental asteroseismic parameters $\Delta \nu$ and $\nu_{\text{max}}$ and evolutionary states for 1709 bright, oscillating red giants from the Henry Draper Catalog. These stars and required to have been observed for at least 6 months within one TESS observing cycle throughout Cycles 1–3 and thus are located near the TESS continuous viewing zones.

2. We provide seismic mass ($\kappa_M$) and radius ($\kappa_R$) coefficients for users that wish to use their own effective temperatures and metallicities when applying the asteroseismic scaling relations to estimate masses and radii. With the application of such scaling relations, we determine masses with a typical precision of 8.3% and radii with a typical precision of 3.2% for the stars in our sample using a compilation of atmospheric parameters from the literature. Compared to the population of Kepler red giants, the HD-TESS sample is systematically more massive, with a larger fraction of stars having $M > 1.5M_{\odot}$.

3. 99 stars in our sample are known astrometric binaries from Gaia EDR3, while 40 are well-known visual binaries with archival measurements from the Washington Double Star catalog. These binaries include those with subdwarfs and white dwarfs as the secondary.

4. We benchmark radii from asteroseismic scaling relations against radii measured using interferometry for 16 giants in our sample. Our results show that the median fractional difference between the two radii is approximately 3% for giants with $R < 15R_*$ when calculating interferometric radii using Gaia parallaxes. Reaching this level of agreement between the two approaches, however, requires a correction factor to the scaling relations, in agreement with other independent benchmarking studies.

6. Conclusions

Our main conclusions are as follows:

1. We present a catalog of fundamental asteroseismic parameters $\Delta \nu$ and $\nu_{\text{max}}$ and evolutionary states for 1709 bright, oscillating red giants from the Henry Draper Catalog. These stars and required to have been observed for at least 6 months within one TESS observing cycle throughout Cycles 1–3 and thus are located near the TESS continuous viewing zones.

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The preliminary work here highlights the value of TESS observations in calibrating methods of inferring fundamental stellar parameters of well-studied bright stars. The large number of precise seismic measurements from this work, which when combined with accurate Gaia parallaxes and ground-based spectroscopy, will allow more frequent and consistent benchmarks of asteroseismic inference methods against interferometry. Neither the highlighted science cases nor the seismic measurements provided in this work are exhaustive in nature. As TESS pursues further observing cycles, not only will the asteroseismic precision of frequently visited regions of the sky increase, but more bright stars near us—particularly those closer to the ecliptic plane—will also eventually be accessible with precision asteroseismology. In that sense, the work presented here acts as a precursor for a more comprehensive asteroseismic catalog of bright stars in the near future, where we will aim for a much more extensive sky coverage.

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Facility: TESS.

Appendix A

Frequency at Maximum Power for 2611 Oscillating Giants

Table A1 lists the $v_{\text{max}}$ measurements for 2611 oscillating giants from the HD catalog that show oscillations in this work. The table entries comprise the 1709 stars forming the main HD-TESS catalog (Table 1) as well as 903 additional red giants whose $\Delta \nu$ cannot be measured in this study.

| HD Number | TIC Identifier | $v_{\text{max}}$ $\mu$Hz |
|-----------|----------------|--------------------------|
| 22349     | 31852879       | 34.04 ± 0.50             |
| 23128     | 238180822      | 25.24 ± 0.39             |
| 23253     | 31959761       | 55.80 ± 1.25             |
| 23266     | 311925612      | 28.29 ± 0.75             |
| 311763    | 272472375      | 18.67 ± 1.50             |
| 370635    | 370115759      | 22.95 ± 0.35             |

Note. Each star’s identifier in the Henry Draper (HD) catalog and the TESS Input Catalog (TIC) is provided. The full version of this table is available in a machine-readable format in the online journal, with a portion shown here for guidance regarding its form and content. (This table is available in its entirety in machine-readable form.)

Appendix B

Spatially Resolved Astrometric Binaries from Gaia EDR3

Table B1 lists the 99 oscillating giants in our sample that have been identified as being part of an astrometric binary system in the El-Badry et al. (2021) catalog. From the cross-match, we select only binaries with a computed chance alignment probability less than 0.1.

| HD Number | Primary Source ID | Secondary Source ID |
|-----------|-------------------|---------------------|
| 24272     | 4667870070470785792 | 4667870070470786816 |
| 27068     | 4676770239141111424 | 4676770239141111040 |
| 27670     | 4676012709989349376 | 467601278708825344 |
| 28633     | 4656569496121672832 | 4656569461261934592 |
| 311373    | 5215069141868112256 | 5215069141868555648 |
| 311734    | 5263024685110990720 | 5263024685110990592 |

Note. The binaries are from the El-Badry et al. (2021) catalog. The quoted Gaia source IDs are those from Early Data Release 3 (Gaia Collaboration et al. 2021). The full version of this table is available in a machine-readable format in the online journal, with a portion shown here for guidance regarding its form and content. (This table is available in its entirety in machine-readable form.)

Appendix C

Double Stars and Interferometric Binaries

Table C1 lists a cross-match of our oscillating giant sample to the Washington Double Star Catalog (Mason et al. 2001). Table C2 presents a cross-match to the Fourth Catalog of Interferometric Measurements of Binary Stars (Hartkopf et al. 2001). The full version of both tables is available in a machine-readable format in the online journal, with a portion shown here for guidance regarding their form and content.

| HD Number | WDS Identifier |
|-----------|----------------|
| 23817     | WDS J03442-6448A |
| 24461     | WDS J03480-7048A |
| 25106     | WDS J03549-6627AB |
| 27256     | WDS J04144-6228A |
| 239229    | WDS J19490+5916A |
| 269894    | WDS J05385-7045AB |

| HD number | TIC ID |
|-----------|--------|
| 132464    | 219018004 |
| 132698    | 288185404 |
| 137292    | 219731897 |
| 141264    | 272746493 |
| 238629    | 199713797 |
| 270011    | 389325554 |

(This table is available in its entirety in machine-readable form.)
Appendix D
Power Spectra of Oscillating Giants with Interferometry

Figure 11 shows the échelle diagram and power spectra of the 16 oscillating red giants with interferometric radii discussed in Section 5.2.

Figure 11. Seismic visual diagnostic plots for the 16 oscillating giants benchmarked against interferometric measurements in Section 5.2, categorized by their evolutionary state (RGB = hydrogen shell burning, CHeB = core helium burning). The stars are ordered in decreasing $\Delta \nu$ from the top left to the bottom right in each category. The blue horizontal line in each panel corresponds to $\nu_{\text{max}}$, while the green vertical line corresponds to the location of the radial mode ridge in the échelle diagrams.
Appendix E
Seismic Radii versus Interferometric Radii Computed Using Hipparcos Parallaxes

Figure 12 repeats the analysis in Section 5.2 but uses interferometric radii derived from Hipparcos (van Leeuwen 2007) parallaxes instead of Gaia EDR3. The results shown here do not change the conclusions from Section 5.2; however, the overall worse agreement suggests that Gaia parallaxes are more accurate as well as more precise for the giants analyzed in this study.

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Figure 12. Comparisons of radii from the asteroseismic scaling relations with linear radii from interferometry across literature for 16 oscillating giants from our TESS giant sample. This Figure is identical to Figure 10, except that the interferometric radii are derived using Hipparcos parallaxes as opposed to Gaia EDR3 parallaxes.
