

## TESS Reveals HD 118203 b to be a Transiting Planet

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### ABSTRACT

The exoplanet HD 118203 b, orbiting a bright ( $V = 8.05$ ) host star, was discovered using the radial velocity method by da Silva et al. (2006b), but was not previously known to transit. *TESS* photometry has revealed that this planet transits its host star. Five planetary transits were observed by *TESS*, allowing us to measure the radius of the planet to be  $1.133^{+0.031}_{-0.030} R_J$ , and to calculate the planet mass to be  $2.173^{+0.077}_{-0.080} M_J$ . The host star is slightly evolved with an effective temperature of  $T_{\text{eff}} = 5692 \pm 83$  K and a surface gravity of  $\log g = 3.891^{+0.019}_{-0.020}$ . With an orbital period of  $6.134980^{+0.000038}_{-0.000037}$  days and an eccentricity of  $0.316 \pm 0.021$ , the planet occupies a transitional regime between circularized hot Jupiters and more dynamically active planets at longer orbital periods. The host star is among the ten brightest known to have transiting giant planets, providing opportunities for both planetary atmospheric and asteroseismic studies.

*Keywords:* planets and satellites: detection — planets and satellites: general — methods: data analysis  
 — stars: individual (HD 118203)

## 1. INTRODUCTION

The dawn of planetary transit science began with the transit detection of planets that had been discovered with the radial velocity (RV) technique. The first of these was HD 209458 b (Charbonneau et al. 2000; Henry et al. 2000) which, for several years thereafter, was the only known transiting planet. To date, there are eleven planets for which transits were detected after an initial RV discovery: HD 80606 b (Fossey et al. 2009; Garcia-Melendo & McCullough 2009; Laughlin et al. 2009), 55 Cancri e (Winn et al. 2011; Demory et al. 2011), GJ 436 b (Gillon et al. 2007), HD 149026 b (Sato et al. 2005), HD 189733 b (Bouchy et al. 2005), HD 17156 b (Barbieri et al. 2007), HD 97658 b (Dragomir et al. 2013), GJ 3470 b (Bonfils et al. 2012), HD 219134 b (Motalebi et al. 2015), and HD 219134 c (Gillon et al. 2017). These transiting exoplanets are important because their host stars are bright, especially relative to the typical hosts of transiting exoplanets (Kane 2007; Kane et al. 2009). The brighter host stars enable detailed follow-up observations to be carried out to study the planetary atmospheres, such as the *Spitzer* observations of HD 189733 b (Knutson et al. 2007). The Transit Ephemeris Refinement and Monitoring Survey (TERMS) has continued to observe known exoplanets using photometric and RV techniques to refine orbits and investigate a variety of stellar and planetary signatures (Dragomir et al. 2011; Kane et al. 2011; Pilyavsky et al. 2011; Dragomir et al. 2012a,b; Hinkel et al. 2015; Kane et al. 2016). For the Transiting Exoplanet Survey Satellite (*TESS*), a primary goal is the detection of planets transiting bright host stars (Ricker et al. 2015) and the subsequent characterization of the atmospheres of some of those planets (Kempton et al. 2018).

Through analysis of the *TESS* observation strategy and the known exoplanet demographics, Dalba et al. (2019) predicted that several known RV planets would be discovered to transit. The prediction was consistent with the early *TESS* discovery of an additional transiting planet in the  $\pi$  Mensae system (Huang et al. 2018), which was already known to have a longer-period planet from earlier RV surveys. However, the large number of RV planets with orbital periods shorter than 10 days provides many opportunities to detect further transits among the known RV population (Kane & von

Braun 2008). This paper reports the detection of transits of HD 118203 b, a previously known giant planet ( $M_p \sin i = 2.13 M_J$ ) in a 6.13-day eccentric ( $e = 0.31$ ) orbit around a bright ( $V = 8.05$ ) star (da Silva et al. 2006b). The star was observed by *TESS* during Sector 15 of Cycle 2 observations of the northern ecliptic hemisphere.

The stellar brightness of HD 118203 combined with the eccentric nature of the orbit presents an important opportunity to study the atmospheres of exoplanets under tidal stress from the host star. HD 118203 b joins TOI-172 b (Rodriguez et al. 2019) and HD 2685 b (Jones et al. 2019) as *TESS*-detected giant planets in eccentric orbits close to their host stars. In Section 2 we describe the details of *TESS* observations and photometry, as well as ground-based observations that contribute to the analysis. Section 3 presents a detailed analysis of the photometry and RVs in order to determine the system characteristics. In Section 4 we discuss the discovery within the context of the known exoplanet population and the prospects for further observations.

## 2. *TESS* OBSERVATIONS

The star HD 118203 (see Table 1 for additional names) was observed by *TESS* in Sector 15 of the mission. The star was selected for 2-minute *TESS* observations for several reasons. It was included in the exoplanet candidate target list accompanying version 8 of the *TESS* Input Catalog of prime targets for *TESS* discovery of small exoplanets (Stassun et al. 2019) at a priority of 0.00282, placing it among the top 20% of targets selected for transit detection. In addition, the target was proposed for observations by a number of guest investigators<sup>1</sup>. Furthermore, HD 118203 was included in the Asteroseismic Target List (Schofield et al. 2019) of solar-like oscillators to be observed in 2-min cadence with *TESS*. The Asteroseismic Target List comprises of bright, cool main-sequence and subgiant stars and forms part of the larger target list proposed by the *TESS* Asteroseismic Science Consortium.

*TESS* obtained 17,839 observations of HD 118203 in 2-minute cadence from 15 August to 10 September 2019. As a 2-minute target, the light curve was processed by the SPOC data reduction pipeline (Jenkins et al. 2016), and released through the *TESS* page of the MAST

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archive<sup>2</sup>. The SPOC light curve clearly shows four complete transits, and one partial transit, at a period corresponding to the  $\sim 6.13$ d known planet orbital period detected by da Silva et al. (2006b). During the automated search for new planets, transits of HD 118203 were identified by the Science Processing Operations Center (SPOC) transit search pipeline (Jenkins 2002; Jenkins et al. 2010), and HD 118203 was identified as a promising transit candidate by the *TESS* vetting procedure (Guerrero, et al. in preparation) using *TESS* data validation tools (Twicken et al. 2018; Li et al. 2019) and assigned TOI number 1271.01.

The discovery paper by da Silva et al. (2006b) provides 43 individual RV observations from the ELODIE spectrograph (Baranne et al. 1996), acquired between May 2004 and July 2005. That paper reports an orbital period for the companion of  $P = 6.1335 \pm 0.0006$  days and an eccentricity of  $e = 0.309 \pm 0.014$ , with an additional acceleration of  $49.7 \pm 5.7 \text{ m s}^{-1}\text{yr}^{-1}$ , and an average radial velocity of  $-29.387 \pm 0.006 \text{ km s}^{-1}$ . We have included those RV observations in our analysis below in §3.

### 3. SYSTEM ANALYSIS

In addition to the *TESS* photometry and the RV data and system parameters reported by da Silva et al. (2006b), we have gathered various properties of HD 118203 from existing catalogs and archives. These include elemental abundances, spectroscopic parameters, other measures of photometric variability, and kinematic information. Those data and parameters are described below, in addition to the procedures we used to conduct a global fit of the system properties.

#### 3.1. Abundances and Effective Temperature

A total of 37 elements (including neutral and singly-ionized) were measured based on the spectrum of the host star HD 118203 by 8 different groups (Brugamyer et al. 2011; Gonzalez et al. 2010; Gonzalez et al. 2010; Maldonado et al. 2013; Delgado Mena et al. 2015; Maldonado & Villaver 2016; Luck 2017; Maldonado et al. 2018). The star is, in general, metal rich compared with the Sun, such that only a few elemental abundance ratios fall below solar ratios ([Li/H], [Cr II/H], and [La II/H]). The median of all [Fe/H] measurements, including the determination by Sousa et al. (2015), yield a value of  $0.23 \pm 0.08$  dex, where the uncertainty represents the spread or range in abundance measurements by the different literature sources (see Hinkel et al. 2014 for more details). In terms of important planet forming

materials, the median values<sup>3</sup> for [C/H], [O/H], [Mg/H], and [Si/H] are listed in Table 1, which have been normalized to the solar values of Lodders et al. (2009). Also, the overall  $[\alpha/\text{H}]$  abundance for this planetary system, when utilizing the abundances from O, Mg, Si, Ca, and Ti, is  $0.25 \pm 0.10$  dex. Converting to molar fractions, we find that the C/O ratio for this system is 0.47.

In addition, we utilized the stellar atmospheric determinations from the previously cited spectroscopic studies to compile an estimate of the effective temperature of HD 118203. The median of the reported  $T_{\text{eff}}$  values is  $5816 \pm 90$  K, where again the uncertainty represents the spread in the effective temperature measurements. SIMBAD lists this star as a spectral type K0 dwarf based on the update of the Henry Draper Catalog (Cannon & Pickering 1993), and that spectral type appears to be repeated through a number of star catalogs. We find that the star is more appropriately considered as early G-type. Furthermore, as the global analysis below indicates, the surface gravity of the star places it closer to the subgiant than the dwarf regime.

#### 3.2. Global Analysis

We determined the parameters and uncertainties of the HD 118203 planetary system using the publicly available exoplanet fitting suite, EXOFASTv2 (Eastman et al. 2013, 2019). We conducted a preliminary fit of the system with EXOFASTv2 to obtain an approximate measure of the stellar surface gravity, and used a loose prior on the surface gravity of the host star of  $\log g = 4.0 \pm 0.25$ . We then fit the full range of available broadband photometry listed in Table 1, to a model spectral energy distribution (SED). For the SED fit, we placed a Gaussian prior on the metallicity using the value of [Fe/H] ( $0.23 \pm 0.08$  dex) from the available stellar spectra (see §3.1) and the corrected Gaia parallax (see §3.4). We also constrain the maximum line-of-sight extinction using the dust maps of Schlegel et al. (1998). The resulting SED fit provides values for  $T_{\text{eff}} = 5703$  K and  $R_{\star} = 2.113 R_{\odot}$ .

We then placed Gaussian priors on  $T_{\text{eff}}$ , [Fe/H], and  $R_{\star}$  for the full EXOFASTv2 analysis using the values listed above. The error limits for stellar effective temperature and thus radius are set by the accuracy of interferometric angular diameters, which show systematic differences in excess of 3% (e.g. White et al. 2018). We therefore adopted fractional errors of 1.5% for  $T_{\text{eff}}$  and 3.5% for stellar radius, yielding priors of  $T_{\text{eff}} = 5703 \pm 86$

<sup>2</sup> <https://archive.stsci.edu/tess/>

<sup>3</sup> Individual abundance measurements can be found in the Hypatia Catalog: [www.hypatiacatalog.com](http://www.hypatiacatalog.com).

$K$  and  $R_{\star} = 2.113 \pm 0.74 R_{\odot}$  for the input to the global EXOFASTv2 fit.

We used EXOFASTv2 to simultaneously model the archival ELODIE RVs, *TESS* photometry, and constraints on the stellar parameters from spectroscopy. Within the fit, the stellar parameters of HD 118203 were determined using the MESA Isochrones and Stellar Tracks (MIST) stellar evolution models (Dotter 2016; Choi et al. 2016; Paxton et al. 2011, 2013, 2015).

We fit the *TESS* light curve processed by the SPOC pipeline’s Presearch Data Conditioning (PDC) module, which removes common-mode instrumental systematics from light curves (Stumpe et al. 2012; Smith et al. 2012; Stumpe et al. 2014). The PDC light shows some low-frequency variability (likely originating from the rotation modulations in the light curve, see Section 3.3), which must be accounted for in transit modeling. It is particularly challenging to remove the low-frequency variability from the HD 118203 light curve because not all of the transits have sufficient out-of-transit coverage to determine and extrapolate the variability. One of the five transits ended less than two hours before the end of Sector 15, and *TESS* only observed the second half of another transit after a gap in observations when the spacecraft downlinked data during its perigee passage. We chose to model the low-frequency variability with a basis spline.

We started by fitting a basis spline to the full *TESS* light curve, while iteratively identifying and excluding  $3\sigma$  outliers (Vanderburg & Johnson 2014). We determined the optimal spacing between spline knots to be about 0.3 days by calculating the Bayesian Information Criterion for a series of splines fit with different knot spacings (Shallue & Vanderburg 2018). Then, we followed a procedure similar to that of Vanderburg et al. (2016), wherein we simultaneously fit the shape of the transits and the low-frequency variability (though we did not also model spacecraft systematics as is commonly done for *K2* data). In brief, we performed a preliminary fit of the un-flattened HD 118203 light curve with a Mandel & Agol (2002) model. Inside the fit, after each evaluation of the Mandel & Agol (2002) model, we fit a spline to the residuals (light curve - transit model) and subtracted it before calculating  $\chi^2$ , which we minimized with a Levenberg-Marquardt algorithm (Markwardt 2009). After convergence, we retrieved the best-fitting spline and subtracted it from the *TESS* light curve, yielding a flattened light curve for the EXOFASTv2 analysis.

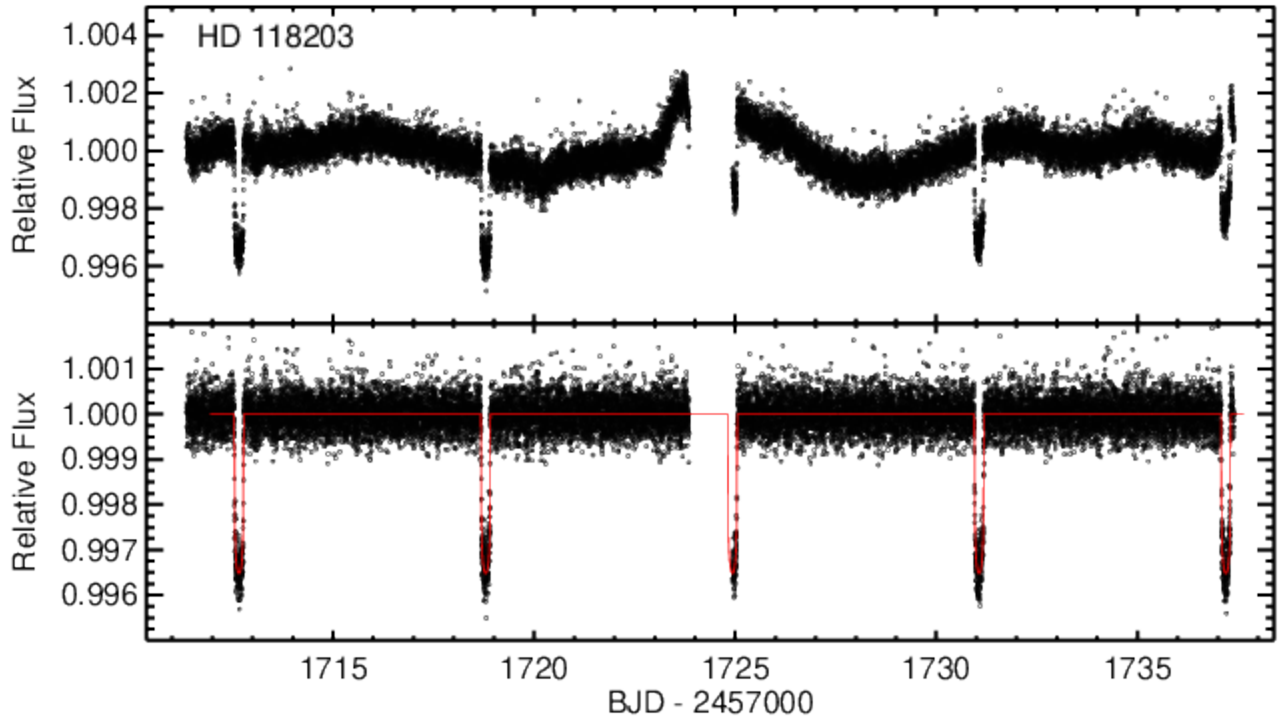
The SPOC PDC lightcurve before and after the flattening procedure is shown in Figure 1. A phase-folded zoom-in on the transit in the flattened light curve is

shown in Figure 2. We show the full and phase-folded RV curve in Figure 3.

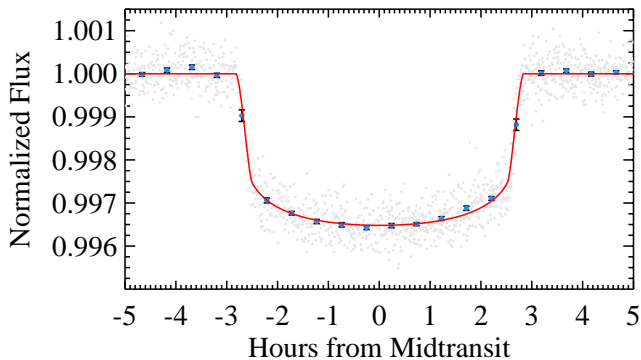
The results of the EXOFASTv2 global fit are listed in Tables 2 and 3. We note that the mass and age of the HD 118203 are bimodal in our probability distribution function (PDF, see Figure 4). The two peaks in the PDF are centered at a host star mass of  $1.26 M_{\odot}$  and  $1.48 M_{\odot}$  corresponding to ages of 5.23 Gyr and 2.89 Gyr, respectively. In order to arrive at distinct solutions, we split the host star mass PDF at the valley between the two peaks,  $1.38 M_{\odot}$ , and extract two separate solutions that are presented in Tables 2 and 3. We adopt the peak at  $1.26 M_{\odot}$  since it is significantly more probable than the  $1.48 M_{\odot}$  solution (89.6% compared to 10.4%). However both solutions are provided in Tables 2 and 3 for future work on HD 118203. We note that the host star mass and age solutions are based on single model grid and thus do not account for systematic errors due to different input physics, which can be substantial for evolved stars (Tayar et al., in prep). Therefore, the uncertainties in mass and age reported in Table 2 are likely underestimated.

As an additional check on the system parameters, we employed the Bayesian code PARAM (da Silva et al. 2006a; Rodrigues et al. 2014, 2017) to determine fundamental properties of HD 118203 following a grid-based approach, whereby observed quantities (namely,  $T_{\text{eff}}$ ,  $[\text{Fe}/\text{H}]$ ,  $\pi$ , and apparent magnitudes) were matched to a well-sampled grid of stellar evolutionary tracks. The optimization method we adopted, the so-called 1-step approach, takes into account the entire set of input parameters at once in order to compute the PDFs for the stellar properties. This method is an updated version of the Rodrigues et al. (2014) implementation, in which the code considers both the apparent and model-derived absolute magnitudes, as part of an additional step, to derive the extinction and distance to the star (2-step approach). The underlying grid of stellar evolutionary tracks (and relevant physical inputs) on which we ran PARAM is described in Section 2 of Rodrigues et al. (2017). Element diffusion has, however, now been included (leading to a different He-enrichment ratio of  $\Delta Y/\Delta Z = 1.33$ , where  $Y$  and  $Z$  are respectively the initial helium and metal mass fractions). We note that the PARAM output is consistent with the adopted EXOFASTv2 solution.

In addition to using EXOFASTv2 to model the system, we performed an additional analysis of the *TESS* light curve and ELODIE RV data using *allesfitter* (Günther & Daylan 2019, and in prep.). *allesfitter* is an analysis framework that allows the orbital and dynamical parameters of a multi-body system to be in-



**Figure 1.** (Top) The *TESS* 2-minute cadence light curve of HD 118203. (Bottom) The flattened *TESS* light curve used in the EXOFASTv2 fit. The observations are plotted in open black circles, and the best fit model from EXOFASTv2 is plotted in red.



**Figure 2.** The *TESS* SPOC PDC light curve of HD 118203 phase-folded to the best fit period of 6.135 days. The blue points are showing the *TESS* photometry in 24 minute bins. The EXOFASTv2 model is plotted in red.

ferred given some RV and photometric data. In this work, we omit a complete discussion of *allesfitter* and we refer the reader to Günther et al. (2019a,b); Daylan et al. (2019) for its implementation details. Using a Gaussian process to model the background as part of this analysis, we find a radius ratio of  $5.53\% \pm 0.03$  and an eccentricity of  $0.30 \pm 0.03$ . Although we select the EX-

OFASTv2 results as the final system solution, the fact that the system parameters found by *allesfitter* are in agreement is additional verification of the robustness of the global fit.

### 3.3. Stellar Variability

To search for signs of stellar variability, we visually inspected the SPOC Simple Aperture Photometry (SAP) version (Twicken et al. 2010; Morris et al. 2017) of the *TESS* lightcurve from Sector 15 and found a potentially periodic signal with an amplitude of around 0.6% and an estimated period of 20–25 days. The spectroscopically measured projected rotational velocity of the host star of  $4.7 \text{ km s}^{-1}$  (da Silva et al. 2006b), coupled with the newly obtained stellar radius of  $2.1 R_{\odot}$  (see Table 2), implies a stellar rotational period of 22 days under the assumption that the stellar rotation axis is orthogonal to the line of sight. This suggests that the observed variability could be caused by the stellar rotation and the presence of starspots. With the pending release of

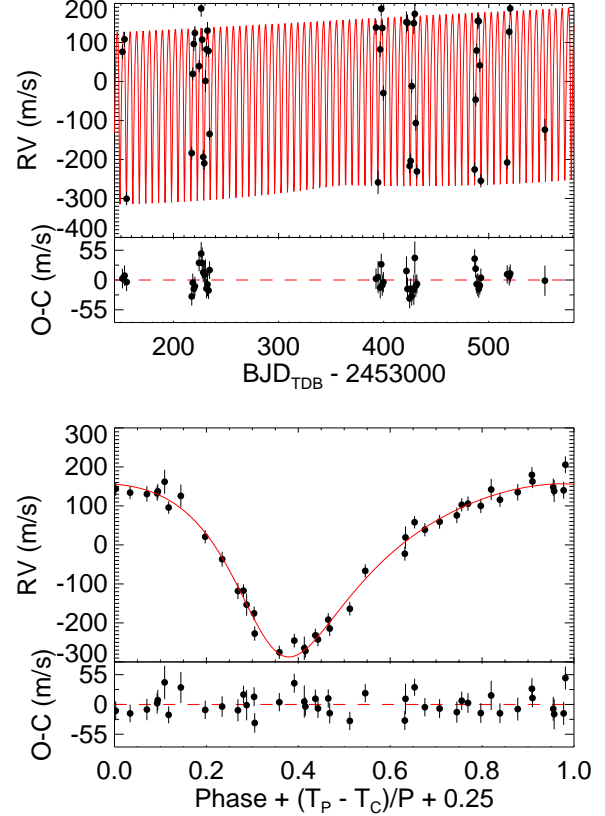
**Table 1.** Literature and Measured Properties for HD 118203

Other identifiers			
HIP 66192, Gaia 1560420854826284928			
2MASS J13340254+5343426, TYC 3850-458-1			
BD+54 1609, TIC 286923464, TOI 1271.01			
Parameter	Description	Value	Source
$\alpha_{J2000}$	Right Ascension (RA)	13:34:02.3894	1
$\delta_{J2000}$	Declination (Dec)	+53:43:41.4752	1
$l$	Galactic Longitude	109.3442934°	2
$b$	Galactic Latitude	+62.2614278°	2
$NUV$	GALEX $NUV$ mag.	14.0481 $\pm$ 0.0059	3
$FUV$	GALEX $FUV$ mag.	20.16 $\pm$ 0.20	3
$B_T$	Tycho $B_T$ mag.	8.903 $\pm$ 0.03	4
$V_T$	Tycho $V_T$ mag.	8.135 $\pm$ 0.03	4
$G$	Gaia $G$ mag.	7.8925 $\pm$ 0.05	1
$J$	2MASS $J$ mag.	6.861 $\pm$ 0.021	5
$H$	2MASS $H$ mag.	6.608 $\pm$ 0.038	5
$K_S$	2MASS $K_S$ mag.	6.543 $\pm$ 0.023	5
$WISE1$	$WISE1$ mag.	6.472 $\pm$ 0.078	6
$WISE2$	$WISE2$ mag.	6.450 $\pm$ 0.023	6
$WISE3$	$WISE3$ mag.	6.501 $\pm$ 0.016	6
$WISE4$	$WISE4$ mag.	6.438 $\pm$ 0.054	6
$\mu_\alpha$	Gaia DR2 proper motion in RA (mas yr <sup>-1</sup> )	-85.877 $\pm$ 0.052	1
$\mu_\delta$	Gaia DR2 proper motion in DEC (mas yr <sup>-1</sup> )	-78.913 $\pm$ 0.038	1
$\pi$	Gaia Parallax (mas)	10.810 $\pm$ 0.027 <sup>†</sup>	1
$RV$	Systemic radial velocity	-29.387 $\pm$ 0.006	7
$d$	Distance (pc)	92.26 $\pm$ 0.24 <sup>†</sup>	2
Spec. Type	Spectral Type		
$A_V$	Visual extinction (mag)		§3
[Fe/H]	Iron abundance (dex)	0.23 $\pm$ 0.08	8
[C/H]	Carbon abundance (dex)	0.31 $\pm$ 0.22	8
[O/H]	Oxygen abundance (dex)	0.30 $\pm$ 0.17	8
[Mg/H]	Magnesium abundance (dex)	0.24 $\pm$ 0.12	8
[Si/H]	Silicon abundance (dex)	0.22 $\pm$ 0.14	8
[ $\alpha$ /H]	$\alpha$ -element (O, Mg, Si, Ca, and Ti) abundance (dex)	0.25 $\pm$ 0.10	8
$U^*$	Space Velocity (km s <sup>-1</sup> )	4.87 $\pm$ 0.03	§3.4
$V$	Space Velocity (km s <sup>-1</sup> )	-45.00 $\pm$ 0.12	§3.4
$W$	Space Velocity (km s <sup>-1</sup> )	1.62 $\pm$ 0.06	§3.4

**NOTES:** † Values have been corrected for the -0.82  $\mu$ s offset as reported by Stassun et al. (2019).

\*  $U$  is in the direction of the Galactic center.

References are: <sup>1</sup>Gaia Collaboration et al. (2018), <sup>2</sup>Stassun et al. (2019), <sup>3</sup>Bianchi et al. (2017), <sup>4</sup>Høg et al. (2000), <sup>5</sup>Cutri et al. (2003), <sup>6</sup>Cutri & et al. (2014), <sup>7</sup>da Silva et al. (2006b), <sup>8</sup>Hypatia Catalog (Hinkel et al. 2014), www.hypatiacatalog.com



**Figure 3.** (Top) Radial velocity measurements from ELODIE of HD 118203 (da Silva et al. 2006b). (Bottom) The radial velocity measurements phase-folded to the best determined period by EXOFASTv2, 6.135 days. The EXOFASTv2 best-fit model is shown in red and the residuals of the model are shown below each plot.

the *TESS* light curves from Sector 16, it should be possible to confirm the astrophysical origin as well as the periodic nature of this signal.

HD 118203 was also observed by the KELT-North Telescope (Pepper et al. 2007) between 2012 February 19 and 2014 December 30, which provided a total of 4221 photometric data points. We performed a Lomb–Scargle analysis on KELT photometry and did not detect any periodic astrophysical signals with a semi-amplitude upper limit of 24 ppt, equal to the standard deviation of the raw KELT lightcurve. Given that the apparent variability amplitude from the *TESS* photometry is smaller than the detection threshold for KELT, the non-detection of both the rotation signal and the transit in KELT is unsurprising.

### 3.4. Location and Kinematics in the Galaxy

HD 118203 is labeled as a high-proper motion star by SIMBAD. This could be due to the fact that it is relatively close, or it could be because it has higher-

**Table 2.** Median values and 68% confidence intervals for the global model of HD 118203

Parameter	Units	Values (Adopted Solution)	Values (Secondary Solution)
Stellar Parameters:			
Probability		89.6%	10.4%
$M_*$ . . . . .	Mass ( $M_\odot$ ) . . . . .	$1.257^{+0.051}_{-0.056}$	$1.477^{+0.045}_{-0.043}$
$R_*$ . . . . .	Radius ( $R_\odot$ ) . . . . .	$2.103^{+0.055}_{-0.054}$	$2.168^{+0.053}_{-0.051}$
$L_*$ . . . . .	Luminosity ( $L_\odot$ ) . . . . .	$4.18^{+0.35}_{-0.33}$	$4.66^{+0.36}_{-0.34}$
$\rho_*$ . . . . .	Density ( $\text{g cm}^{-3}$ ) . . . . .	$0.190 \pm 0.012$	$0.205 \pm 0.012$
$\log g$ . . . . .	Surface gravity ( $\text{g cm}^{-2}$ ) . . . . .	$3.891^{+0.019}_{-0.020}$	$3.936^{+0.016}_{-0.017}$
$T_{\text{eff}}$ . . . . .	Effective Temperature (K) . . . . .	$5692 \pm 83$	$5761^{+77}_{-78}$
[Fe/H] . . . . .	Metallicity (dex) . . . . .	$0.223 \pm 0.073$	$0.265^{+0.070}_{-0.068}$
[Fe/H] $_0^\dagger$ . . . . .	Initial Metallicity . . . . .	$0.225^{+0.069}_{-0.071}$	$0.285^{+0.062}_{-0.058}$
Age . . . . .	Age (Gyr) . . . . .	$5.23^{+0.90}_{-0.70}$	$2.89^{+0.33}_{-0.32}$
EEP $^\ddagger$ . . . . .	Equal Evolutionary Phase . . . . .	$457.0^{+3.9}_{-3.7}$	$407.7^{+5.4}_{-6.8}$
$\dot{\gamma}$ . . . . .	RV slope (m/s/day) . . . . .	$0.139^{+0.026}_{-0.027}$	$0.138^{+0.026}_{-0.027}$

**NOTES:**  $^\dagger$ The initial metallicity is the metallicity of the star when it was formed.

$^\ddagger$ The Equal Evolutionary Point corresponds to static points in a stars evolutionary history when using the MIST isochrones and can be a proxy for age. See §2 in [Dotter \(2016\)](#) for a more detailed description of EEP.

than average space velocity for a typical thin disk star (which might imply that it is older than the typical age of the thin disk or a member of the thick disk), or some combination of the two. To determine the location and kinematics of HD 118203, we use the Gaia parallax (corrected for the  $82 \mu\text{as}$  systematic according to [Stassun & Torres 2018](#)), and the Gaia proper motions and parallax ([Gaia Collaboration et al. 2018](#)).

The corrected parallax is  $10.90201 \pm 0.0275$  mas, which implies a distance from the sun of  $91.7 \pm 0.2$  pc. <sup>4</sup> The Galactic coordinates of HD 118203 are  $(\ell, b) = (109.34^\circ, +62.3^\circ)$ , and thus the difference in the vertical position of HD 118203 from that of the sun is  $Z - Z_\odot = 81$  pc. Given the  $Z_\odot \simeq 30$  pc determined from giants in the local solar neighborhood ([Bovy 2017](#)), we find  $Z \simeq 120$  pc. This is comparable to the scale height of early G stars in the local Galactic disk as determined by [Bovy \(2017\)](#). Given the relatively small distance of HD 118203 from the Sun and the fact that it is located at roughly  $\ell \sim 90^\circ$ , we find that the Galactocentric distance of HD 118203 is essentially the same as that of the Sun (to within  $\lesssim 1\%$ ).

We determine the space velocity of HD 118203 to be  $(U, V, W) = (4.87 \pm 0.03, -45.00 \pm 0.12, 1.62 \pm 0.06)$   $\text{km s}^{-1}$ , correcting for the velocity of the Sun with respect to the local standard of rest as determined by [Coşkunoğlu et al. \(2011\)](#). Thus HD 118203 has relatively small  $U$  and  $W$  velocities relative the dispersion in the local disk, but a relatively high asymmetric drift. This generally indicates a relatively old (but

still thin disk) star, which would not be surprising given that it is a mid-type star. The classification scheme of [Bensby et al. \(2003\)](#) gives a 97.5% chance that this is a thin disk star. This is corroborated by the abundances,  $[\text{Fe}/\text{H}] = 0.23 \pm 0.08$  and  $[\alpha/\text{Fe}] = 0.25 \pm 0.10$ .

## 4. DISCUSSION

### 4.1. Demographic Properties

The fact that HD 118203 b orbits such a bright host star makes this an exciting representative of a transiting planet. Out of the 3074 confirmed planets listed on the NASA Exoplanet Archive<sup>5</sup> that are not labeled as “controversial”, that are known to transit, and that have a host star with a recorded optical magnitude, HD 118203 is brighter than all but 12 host stars, and is the 8th brightest transit host in the northern hemisphere.

Additionally, HD 118203 b is a massive transiting planet in a short-period, eccentric orbit. That combination of properties is shown in Figures 5 and 6, which display all known transiting planets in orbits with significant eccentricity ( $e > 0.05$ ). HD 118203 b is one of the few transiting planets in eccentric orbits with a bright host star.

### 4.2. Expectations for Transits of RV-detected Planets

By observing bright stars covering almost the entire sky, *TESS* offers a unique opportunity to search for transits of exoplanets that were discovered via RV variations of their host stars. Considering the geometric transit probability of each RV-detected system and the observational strategy of *TESS*, [Dalba et al. \(2019\)](#) predicted

<sup>4</sup> Given the very small (0.3%) fractional uncertainty in the parallax, we do not attempt to correct for Lutz-Kelker bias ([Lutz & Kelker 1973](#)).

<sup>5</sup> <https://exoplanetarchive.ipac.caltech.edu>, queried on 14 October 2019

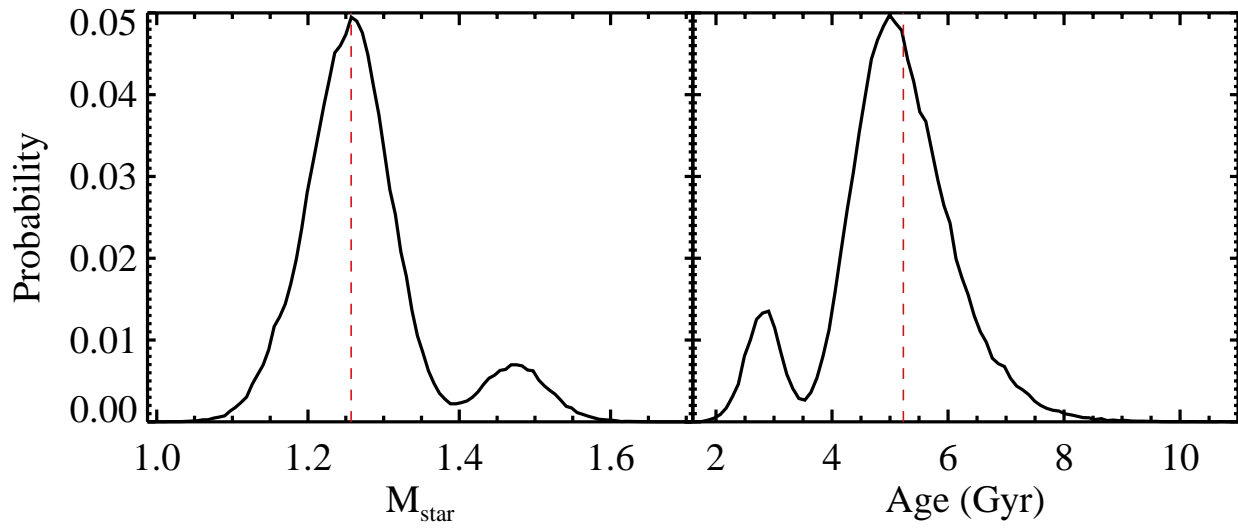
**Table 3.** Median values and 68% confidence intervals for the global model of HD 118203

Parameter	Description (Units)	Values (Adopted Solution)	Values (Secondary Solution)
Probability ..		89.6%	10.4%
$P$ .....	Period (days) .....	$6.134980^{+0.000038}_{-0.000037}$	$6.134993^{+0.000038}_{-0.000037}$
$R_P$ .....	Radius ( $R_J$ ) .....	$1.133^{+0.031}_{-0.030}$	$1.167^{+0.029}_{-0.028}$
$M_P$ .....	Mass ( $M_J$ ) .....	$2.173^{+0.077}_{-0.080}$	$2.417^{+0.073}_{-0.068}$
$T_C$ .....	Time of conjunction (BJD <sub>TDB</sub> ) .....	$2458712.66156^{+0.00023}_{-0.00025}$	$2458712.66155^{+0.00022}_{-0.00023}$
$T_0^\dagger$ .....	Optimal conjunction Time (BJD <sub>TDB</sub> ) .....	$2458724.93152^{+0.00022}_{-0.00024}$	$2458724.93154 \pm 0.00021$
$a$ .....	Semi-major axis (AU) .....	$0.07082^{+0.00095}_{-0.0011}$	$0.07474 \pm 0.00074$
$i$ .....	Inclination (Degrees) .....	$88.75^{+0.86}_{-1.0}$	$89.12^{+0.62}_{-0.85}$
$e$ .....	Eccentricity .....	$0.316 \pm 0.021$	$0.303 \pm 0.021$
$\omega_*$ .....	Argument of Periastron (Degrees) .....	$153.6^{+3.5}_{-3.6}$	$156.1^{+3.6}_{-3.7}$
$T_{eq}$ .....	Equilibrium temperature (K) .....	$1496 \pm 26$	$1496^{+26}_{-25}$
$\tau_{circ}$ .....	Tidal circularization timescale (Gyr) .....	$12.7^{+1.5}_{-1.4}$	$13.6^{+1.5}_{-1.4}$
$K$ .....	RV semi-amplitude (m/s) .....	$218.3^{+5.2}_{-5.1}$	$217.0 \pm 5.0$
$R_P/R_*$ .....	Radius of planet in stellar radii .....	$0.05538^{+0.00023}_{-0.00022}$	$0.05534^{+0.00021}_{-0.00020}$
$a/R_*$ .....	Semi-major axis in stellar radii .....	$7.24 \pm 0.15$	$7.42 \pm 0.15$
$\delta$ .....	Transit depth (fraction) .....	$0.003067^{+0.000026}_{-0.000024}$	$0.003063^{+0.000023}_{-0.000022}$
$\tau$ .....	Ingress/egress transit duration (days) .....	$0.01259^{+0.00052}_{-0.00019}$	$0.01249^{+0.00034}_{-0.00011}$
$T_{14}$ .....	Total transit duration (days) .....	$0.23516^{+0.00069}_{-0.00062}$	$0.23508^{+0.00061}_{-0.00058}$
$T_{FWHM}$ .....	FWHM transit duration (days) .....	$0.22246^{+0.00054}_{-0.00052}$	$0.22249 \pm 0.00053$
$b$ .....	Transit Impact parameter .....	$0.125^{+0.10}_{-0.086}$	$0.092^{+0.089}_{-0.065}$
$b_S$ .....	Eclipse impact parameter .....	$0.17^{+0.13}_{-0.11}$	$0.119^{+0.11}_{-0.084}$
$\tau_S$ .....	Ingress/egress eclipse duration (days) .....	$0.01698^{+0.00091}_{-0.00075}$	$0.01617^{+0.00073}_{-0.00065}$
$T_{S,14}$ .....	Total eclipse duration (days) .....	$0.309 \pm 0.012$	$0.299^{+0.012}_{-0.011}$
$T_{S,FWHM}$ .....	FWHM eclipse duration (days) .....	$0.292 \pm 0.012$	$0.283 \pm 0.011$
$\delta_{S,3.6\mu m}$ .....	Blackbody eclipse depth at $3.6\mu m$ (ppm) .....	$227.2^{+8.9}_{-8.5}$	$223.0^{+8.5}_{-8.1}$
$\delta_{S,4.5\mu m}$ .....	Blackbody eclipse depth at $4.5\mu m$ (ppm) .....	$308.7^{+10.1}_{-9.4}$	$303.3^{+9.5}_{-9.0}$
$\rho_P$ .....	Density ( $g\ cm^{-3}$ ) .....	$1.85 \pm 0.13$	$1.89^{+0.13}_{-0.12}$
$logg_P$ .....	Surface gravity .....	$3.622 \pm 0.021$	$3.644 \pm 0.020$
$\Theta$ .....	Safronov Number .....	$0.2160^{+0.0074}_{-0.0072}$	$0.2093^{+0.0067}_{-0.0065}$
$\langle F \rangle$ .....	Incident Flux ( $10^9\ erg\ s^{-1}\ cm^{-2}$ ) .....	$1.031^{+0.071}_{-0.067}$	$1.039^{+0.071}_{-0.066}$
$T_P$ .....	Time of Periastron (BJD <sub>TDB</sub> ) .....	$2458707.116^{+0.048}_{-0.045}$	$2458707.163^{+0.050}_{-0.048}$
$T_S$ .....	Time of eclipse (BJD <sub>TDB</sub> ) .....	$2458708.495 \pm 0.082$	$2458708.521 \pm 0.082$
$T_A$ .....	Time of Ascending Node (BJD <sub>TDB</sub> ) .....	$2458710.981^{+0.060}_{-0.062}$	$2458710.942^{+0.059}_{-0.062}$
$T_D$ .....	Time of Descending Node (BJD <sub>TDB</sub> ) .....	$2458707.344^{+0.041}_{-0.040}$	$2458707.376^{+0.041}_{-0.040}$
$e \cos \omega_*$ .....		$-0.282 \pm 0.022$	$-0.276 \pm 0.022$
$e \sin \omega_*$ .....		$0.140 \pm 0.019$	$0.123^{+0.019}_{-0.018}$
$M_P \sin i$ .....	Minimum mass ( $M_J$ ) .....	$2.173^{+0.077}_{-0.080}$	$2.417^{+0.073}_{-0.068}$
$M_P/M_*$ .....	Mass ratio .....	$0.001653^{+0.000044}_{-0.000042}$	$0.001563^{+0.000036}_{-0.000037}$
$d/R_*$ .....	Separation at mid transit .....	$5.71^{+0.26}_{-0.25}$	$6.00 \pm 0.26$
$P_T$ .....	A priori non-grazing transit prob .....	$0.1654^{+0.0076}_{-0.0071}$	$0.1574^{+0.0071}_{-0.0065}$
$P_{T,G}$ .....	A priori transit prob .....	$0.1848^{+0.0085}_{-0.0079}$	$0.1758^{+0.0079}_{-0.0072}$
$P_S$ .....	A priori non-grazing eclipse prob .....	$0.1246^{+0.0031}_{-0.0027}$	$0.1230^{+0.0028}_{-0.0024}$
$P_{S,G}$ .....	A priori eclipse prob .....	$0.1392^{+0.0035}_{-0.0030}$	$0.1374^{+0.0031}_{-0.0027}$
Wavelength Parameters:		TESS	
$u_1$ .....	linear limb-darkening coeff .....	$0.294 \pm 0.028$	$0.290 \pm 0.028$
$u_2$ .....	quadratic limb-darkening coeff .....	$0.206 \pm 0.043$	$0.212^{+0.044}_{-0.043}$
Telescope Parameters:		ELODIE	
$\gamma_{rel}$ .....	Relative RV Offset (m/s) .....	$-29339.4^{+3.4}_{-3.3}$	$-29339.5 \pm 3.3$
$\sigma_J$ .....	RV Jitter (m/s) .....	$16.3^{+3.5}_{-3.0}$	$16.2^{+3.5}_{-3.1}$
$\sigma_J^2$ .....	RV Jitter Variance .....	$267^{+130}_{-90}$	$263^{+130}_{-90}$
Transit Parameters:		TESS UT 2019-S1-5. (TESS)	
$\sigma^2$ .....	Added Variance .....	$0.000000169^{+0.0000000036}_{-0.0000000035}$	$0.000000170 \pm 0.0000000036$
$F_0$ .....	Baseline flux .....	$1.0000022 \pm 0.0000080$	$1.0000021 \pm 0.0000079$

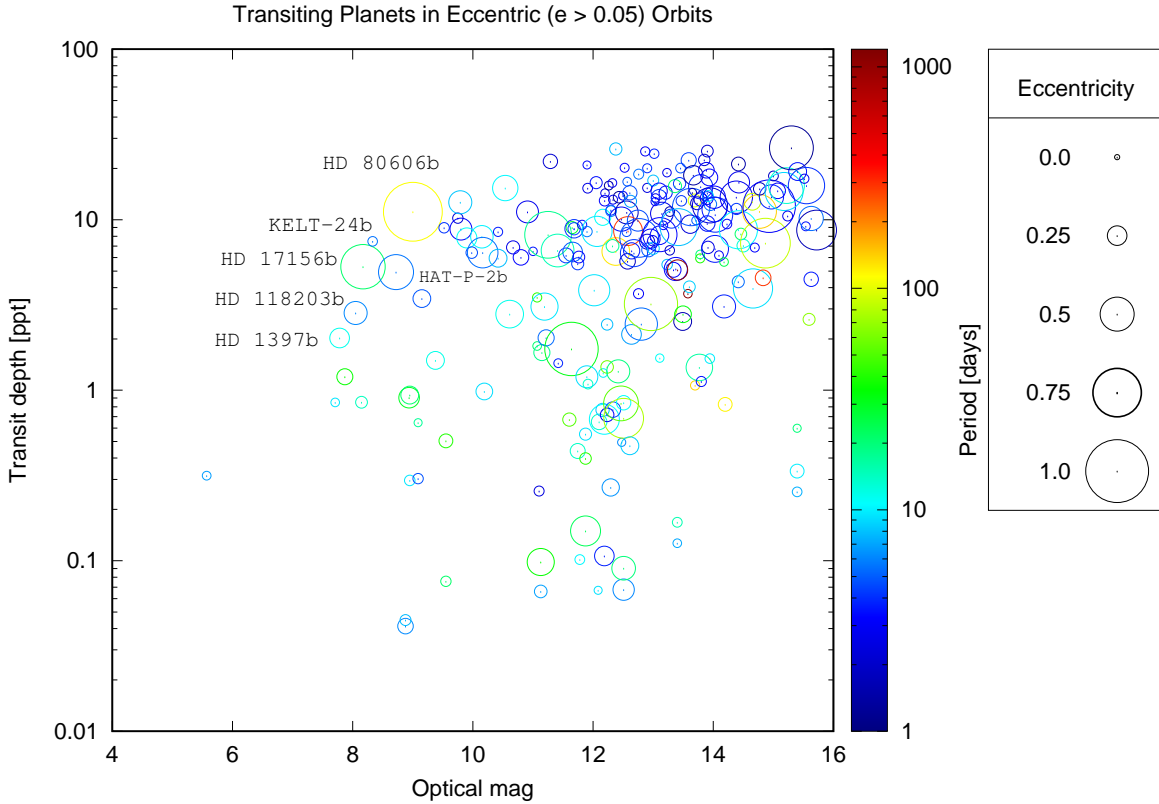
**NOTES:** See Table 3 in Eastman et al. (2019) for a list of the derived and fitted parameters in EXOFASTv2.

$\dagger$ Minimum covariance with period. All values in this table for the secondary eclipse of HD 118203 b are predicted values from our global analysis.





**Figure 4.** The probability distribution function for  $M_*$  (Left) and Age (Right). The red line shows the median value for each parameter from the adopted solution (see §3.2).



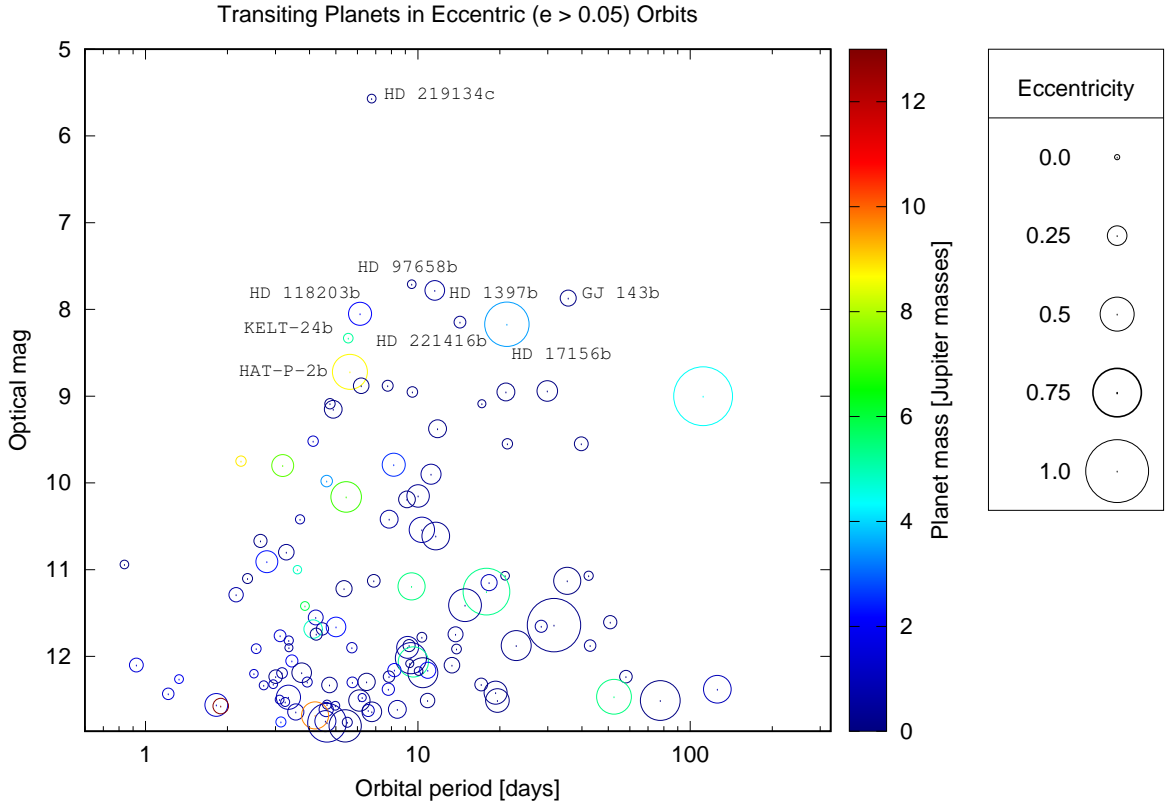
**Figure 5.** All known transiting planets in orbits with eccentricity greater than 0.05. HD 118203 b occupies a spot in the upper left of the distribution, along with a few other transiting planets orbiting bright stars with large transit depths. Data from the NASA Exoplanet Archive, retrieved 15 October 2019.

that *TESS* would observe transits for  $\sim 11$  RV-detected planets in its primary mission. However, only three of these detections were expected to be novel, such that the RV-detected planet was not previously known to transit.

The discovery of transits for HD 118203 b at approximately halfway through the *TESS* primary mission is consistent with this prediction. If the detection rate is (roughly) one per cycle, then we should expect one more discovery by the end of Cycle 2. As is the case with HD 118203 b, any other RV-detected planets found to transit are likely to have short-period orbits compared to the average RV-detected planet.

Since the orbital period of HD 118203 b is shorter than the duration of a *TESS* sector, its a priori transit probability is not reduced due to the observational baseline. The a priori geometric transit probability of HD 118203 b is  $0.21 \pm 0.02$  (Dalba et al. 2019), placing it in the 98th percentile among all RV-detected exoplanets.

The a posteriori transit probability (Stevens & Gaudi 2013) may be higher; however this depends on the true mass distribution of planets with masses within a factor of a few of HD 118203 b. Based on the fact that, from RV surveys, it is known that companions with minimum masses somewhat larger than that of Jupiter on relatively short period ( $P \lesssim$  a few years) orbits appear to have a mass function that decreases with increasing mass, at least until the ‘driest’ part of the brown dwarf desert (Grether & Lineweaver 2006), the a posteriori transit probability is likely to be higher for planets in this minimum mass regime than the naive a priori transit probability (Stevens & Gaudi 2013) would suggest. Indeed, the population synthesis models used by Stevens & Gaudi (2013) to determine the scale factor that relates the a posteriori and a priori transit probabilities suggest that HD 118203 b is right on the boundary of having a significant boost in the probability of transit relative to



**Figure 6.** All known transiting planets in orbits with eccentricity greater than 0.05. HD 118203 b occupies a spot near the top of the distribution, along with a few other transiting planets orbiting bright stars. Data from the NASA Exoplanet Archive, retrieved 15 October 2019.

the naive a priori estimate. In general, we follow [Stevens & Gaudi \(2013\)](#) and suggest that targeting RV-detected planets with minimum mass in the regime where the true mass function is likely decreasing sharply with increasing mass (super Jupiters, super Earths and Neptunes) may result in a higher yield of transiting planets than naive a priori transit estimates would imply. There are more than 30 RV-detected exoplanets with a priori transit probabilities as observed by *TESS* between 0.1 and 0.3 ([Dalba et al. 2019](#), their Table 1). Although some of these are already known to transit (e.g., 55 Cnc e), the next RV-detected exoplanet found to transit likely resides in this group, and is even more likely to be in the minimum mass regimes mentioned above. [Stevens & Gaudi \(2013\)](#) also provide a list of particularly promising systems with transit probabilities that are likely to be higher than naively expected (see their Table 3).

#### 4.3. Observing Prospects

HD 118203 was observed by *TESS* in Sector 15 (2019 Aug 15 to 2019 Sep 11) which is the data set we have analyzed here. The star was also observed in *TESS* Sector 16 (2019 Sep 11 to 2019 Oct 07), although that data is not yet available at the time of this writing. It is also expected to be observed in *TESS* Sector 22 (2020 Feb 18 to 2020 Mar 18). While we do not expect those data to lead to significant updates to the fundamental physical parameters of the system, the additional photometry can potentially provide a more precise measurement of the rotational period of the host star.

Another exciting prospect is that the additional photometry could allow the detection of solar-like oscillations in HD 118203 using asteroseismic analysis. That is primarily due to that star’s brightness of  $T = 7.45$  and the fact that it is slightly evolved (see §3.2). HD 118203 is therefore within the regime suitable for asteroseismology described by [Campante et al. \(2016\)](#). The actual observability of solar-like oscillations awaits a more de-

tailed analysis of the *TESS* photometry once the future sectors of observations are acquired.

The combination of a relatively short orbital period, bright host star, and eccentric orbit presents an opportunity for phase curve observations of the system. The secondary eclipse is predicted to take place 33 hours after periastron passage. Infrared observations of the system during and after periastron passage through the secondary eclipse could provide insight into the thermal properties of the planetary atmosphere and dynamics of heat transport, such as observed for HAT-P-2b (Lewis et al. 2013). Although *Spitzer* observations are no longer available, JWST presents an excellent opportunity for such observations.

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<sup>6</sup> <http://www.astropy.org>

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