



Visual Orbits of Spectroscopic Binaries with the CHARA Array. II. The Eclipsing Binary HD 185912

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Abstract

We present the visual orbit of the double-lined eclipsing binary, HD 185912, from long baseline interferometry with the CHARA Array. We also obtain echelle spectra from the Apache Point observatory to update the spectroscopic orbital solution and analyze new photometry from Burggraaff et al. to model the eclipses. By combining the spectroscopic and visual orbital solutions, we find component masses of $M_1 = 1.361 \pm 0.004 M_\odot$ and $M_2 = 1.331 \pm 0.004 M_\odot$, and a distance of $d = 40.75 \pm 0.30$ pc from orbital parallax. From the light-curve solution, we find component radii of $R_1 = 1.348 \pm 0.016 R_\odot$ and $R_2 = 1.322 \pm 0.016 R_\odot$. By comparing these observed parameters to stellar evolution models, we find that HD 185912 is a young system near the zero age main sequence with an estimated age of 500 Myr.

Unified Astronomy Thesaurus concepts: Binary stars (154); Eclipsing binary stars (444); Interferometric binary stars (806); Spectroscopic binary stars (1557); Fundamental parameters of stars (555)

1. Introduction

Eclipsing binary stars are important tools for testing models of stellar evolution and creating empirical mass–luminosity relationships, specifically when the masses and radii can be determined to within 3% uncertainty (Torres et al. 2010; Eker et al. 2015; Moya et al. 2018). For example, empirical mass–luminosity relationships are used to determine the masses of exoplanet host stars (Enoch et al. 2010), and binaries with A- and F-type components are used to test the treatment of convective core overshooting in evolutionary models (Claret & Torres 2018). However, eclipsing binaries are often close binary systems with orbital periods less than seven days, in which tidal interactions and tertiary companions can significantly affect the structure and evolution of the component stars (Hurley et al. 2002; Tokovinin et al. 2006). In order to expand the sample of binary stars to longer orbital periods where tidal interactions are negligible, long baseline interferometry must be used to measure the visual orbit to combine with the spectroscopic orbit. We began an observing campaign at the CHARA Array and the Apache Point Observatory (APO) to measure the visual and spectroscopic orbits of double-lined binaries (SB2) in order to measure their fundamental parameters. We presented the results for our first system, HD 224355, in Lester et al. (2019, Paper I).

The next spectroscopic binary in our sample is HD 185912,⁷ which consists of a pair of F5 V stars in a 7.6 day orbital period. The first spectroscopic solution was determined by Snowden & Koch (1969) and updated by Andersen et al. (1987) and Behr et al. (2011). In addition, Albrecht et al. (2007) presented precise radial velocities from high-resolution spectra as part of their study on the spin–orbit alignment using

the Rossiter–McLaughlin effect. HD 185912 is also an eclipsing binary (Snowden & Koch 1969; van Hamme & Wilson 1984; Andersen et al. 1987) showing slow apsidal motion with a significant relativistic component (e.g., Dariush et al. 2005; Wolf et al. 2010; Wilson & Raichur 2011). This system was included in the Torres et al. (2010) sample of stars with accurate fundamental parameters. HD 185912 therefore presents a rare opportunity to test the results from interferometry against those from photometry and to provide model-independent distances from orbital parallax to test against GAIA DR2 results (Stassun & Torres 2016, 2018).

We present interferometric observations and the first visual orbit for this system, as well as an updated spectroscopic and photometric analysis. In Section 2, we describe our spectroscopic observations from APO and radial velocity analysis. In Section 3, we present our interferometric observations from CHARA and the visual orbit. In Section 4, we describe the new photometry of Burggraaff et al. (2018) and our light-curve analysis. In Section 5, we present the resulting stellar parameters and a comparison to evolutionary models. Please note that we refer to the “primary” as the more massive, hotter star and the “secondary” as the less massive, cooler star. Due to the orientation of the orbit, the deeper eclipse actually occurs when the secondary star is behind the primary, so our notation is opposite that of van Hamme & Wilson (1984) and Andersen et al. (1987).

2. Spectroscopy

2.1. ARCES Observations

We observed HD 185912 thirteen times from 2015 August to 2019 June using the ARC echelle spectrograph (ARCES; Wang et al. 2003) on the APO 3.5 m telescope. ARCES covers 3500–10500 Å across 107 echelle orders at an average

⁷ V1143 Cyg, HR 7484, HIP 96620; $\alpha = 19: 38: 41.183$, $\delta = +54: 58: 25.642$, $V = 5.9$ mag.

Table 1
Radial Velocity Measurements for HD 185912

UT Date	HJD-2,400,000	Orbital Phase	V_{r1} (km s ⁻¹)	σ_1 (km s ⁻¹)	Residual (km s ⁻¹)	V_{r2} (km s ⁻¹)	σ_2 (km s ⁻¹)	Residual (km s ⁻¹)
2015 Aug 30	57264.6896	0.98	93.16	0.69	0.61	-127.84	1.04	0.73
2015 Dec 1	57357.5389	0.14	-70.32	0.57	-0.66	37.05	0.85	-0.16
2016 Sep 14	57645.7060	0.85	46.69	0.59	0.33	-80.74	0.89	0.62
2016 Nov 16	57708.5374	0.07	-42.82	0.55	0.25	10.32	0.85	0.29
2016 Dec 15	57737.5269	0.87	54.73	0.62	-0.34	-90.14	0.94	0.12
2017 Feb 16	57801.0539	0.18	-73.50	0.65	0.23	40.52	1.08	-0.84
2017 Oct 1	58027.6335	0.84	38.65	0.60	-0.94	-75.60	0.90	-1.17
2018 Jan 28	58147.0347	0.46	-48.94	0.57	-0.24	14.96	0.87	-0.82
2018 Jun 2	58271.8554	0.80	24.85	0.54	0.30	-59.13	0.83	-0.06
2018 Jun 25	58294.8097	0.80	26.72	0.59	0.65	-60.51	0.91	0.11
2018 Sep 27	58388.6182	0.08	-47.99	0.60	0.31	15.81	0.90	0.44
2019 Jun 19	58653.8670	0.80	23.32	0.56	-0.01	-57.86	0.85	-0.04
2019 Jun 20	58654.8837	0.93	89.71	0.60	-0.90	-126.12	0.91	0.46

resolving power of $R \sim 30,000$. Each observation was reduced in IRAF using the standard echelle procedures, including bias subtraction, one-dimensional flat-fielding, wavelength calibration using ThAr lamp exposures, and correction from a barycentric to heliocentric logarithmic frame. We removed the blaze function of each echelle order using the procedure of Kolbas et al. (2015).

2.2. Radial Velocities

We calculated the radial velocities (V_r) of HD 185912 using TODCOR, the two-dimensional cross-correlation algorithm of Zucker & Mazeh (1994), extended to multiorder spectra as described in Zucker et al. (2003). Template spectra for each component were taken from BLUERED⁸ model spectra (Bertone et al. 2008) with atmospheric parameters from Andersen et al. (1987). These models use solar metallicity with an abundance mixture from Anders & Grevesse (1989). The radial velocities from each night are listed in Table 1, along with the rescaled uncertainties from Section 2.3 and the residuals from the orbital solution found in Section 3.4. The monochromatic flux ratio near H α estimated from TODCOR is $f_2/f_1 = 0.91 \pm 0.12$.

2.3. Spectroscopic Orbit

We used the adaptive simulated annealing code RVFIT⁹ (Iglesias-Marzoa et al. 2015) to solve for the spectroscopic orbital parameters: the orbital period (P), epoch of periastron (T), eccentricity (e), longitude of periastron of the primary star (ω_1), systemic velocity (γ), and the velocity semiamplitudes (K_1 , K_2). We first found separate solutions for the ARCES velocities, Albrecht et al. (2007) velocities, and Behr et al. (2011) velocities, in order to rescale the uncertainties by factors of 1.3, 1.4, and 2.4, respectively, so the reduced $\chi^2 = 1$ for each data set. Offsets of 0.1 km s⁻¹ and -0.23 km s⁻¹ were also added to the ARCES velocities and Behr et al. (2011) velocities, respectively, to match $\gamma = -16.81$ km s⁻¹ from Albrecht et al. (2007). Finally, we combined all data sets and refit for the spectroscopic orbital solution. The results are listed in the first column of Table 2, where the uncertainties in each parameter were determined using the Monte Carlo Markov Chain feature of RVFIT. Figure 1 shows the radial velocities from all data sets.

3. Interferometry

3.1. ‘Alopeke Observations

The presence of a third companion would greatly bias our results if not taken into account in our analyses, specifically affecting the resulting flux ratios, radial velocities, and orbital inclination. In order to search for the presence of a tertiary companion, HD 185912 was observed with the ‘Alopeke speckle imager (Scott et al. 2018) on the Gemini North telescope¹⁰ in 2018 October. A set of 1000 60 ms exposures were taken in the 562 nm and 716 nm bands simultaneously and reduced using the speckle team’s pipeline (Howell et al. 2011). Figure 2 shows a plot of the background sensitivity limit found using the method described in Horch et al. (2017). No tertiary companions were found within 1''5 down to a contrast of $\Delta m = 4.0$ mag. Any more distant companions would be beyond the fields of view of our spectroscopic and interferometric observations.

3.2. CLIMB Observations

We observed HD 185912 with the CHARA Array (ten Brummelaar et al. 2005) 11 times from 2016 June to 2019 April, using the CLIMB (ten Brummelaar et al. 2013) beam combiner to combine the K' -band light from three telescopes. Table 3 lists the observation dates, the telescopes and calibrator stars used, the number of data points measured, and the average Fried parameter (r_0) for each night. Our data were reduced with the pipeline developed by J. D. Monnier, using the general method described in Monnier et al. (2011) and extended to three beams (e.g., Kluska et al. 2018), resulting in squared visibilities (V^2) for each baseline and closure phases (CP) for each closed triangle. Instrumental and atmospheric effects on the observed visibilities were measured using observations of stars with known angular diameters (HD 178207, 184170, 186760, and 187748) taken before and after the target. One calibrator-target-calibrator sequence is referred to as a “bracket.” The respective K' -band angular diameters from SearchCal¹¹ are 0.260 ± 0.007 mas, 0.592 ± 0.014 mas, 0.445 ± 0.011 mas, and 0.374 ± 0.009 mas (Chelli et al. 2016).

⁸ <http://www.inaoep.mx/~modelos/bluered/bluered.html>

⁹ <http://www.cfca.es/people/~riglesias/rvfit.html>

¹⁰ <https://www.gemini.edu/sciops/instruments/alopeke-zorro/>

¹¹ <http://www.jmmc.fr/searchcal>

Table 2
Orbital Parameters for HD 185912

Parameter	SB2 Solution	VB + SB2 Solution	LC Solution
P (days)	7.640735 ± 0.000004	7.640735 ± 0.000004	7.640735^a
T (HJD-2,400,000)	54598.1928 ± 0.0010	54598.1930 ± 0.0008	54598.2053 ± 0.0053
e	0.5380 ± 0.0004	0.5386 ± 0.0004	0.5396 ± 0.0012
ω_1 (deg)	49.10 ± 0.08	49.11 ± 0.10	49.87 ± 0.09
i (deg)	...	86.73 ± 0.76	86.90 ± 0.10
a (mas)	...	2.57 ± 0.03	...
Ω (deg)	...	50.9 ± 0.6	...
γ (km s $^{-1}$)	-16.81 ± 0.04	-16.81 ± 0.04	...
K_1 (km s $^{-1}$)	88.09 ± 0.05	88.15 ± 0.06	...
K_2 (km s $^{-1}$)	90.01 ± 0.09	90.08 ± 0.08	...

Note.

^a Fixed to spectroscopic solution.

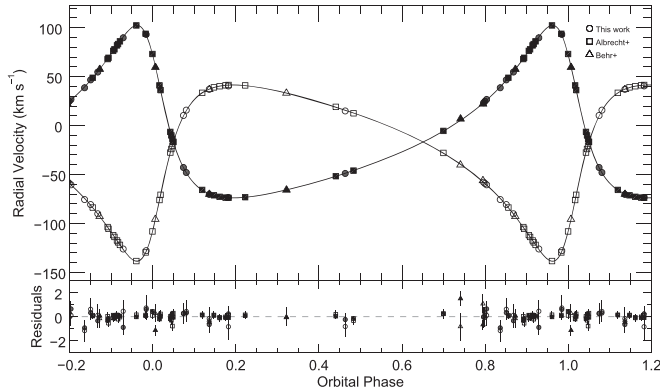


Figure 1. Radial velocity curve for HD 185912 from the combined VB+SB2 solution. The filled and open points correspond to the observed velocities for the primary and secondary components, including the velocities from ARCES (circles), Albrecht et al. (2007; squares), and Behr et al. (2011; triangles). The solid lines represent the model curves, and the residuals are shown in the bottom panel.

3.3. Binary Positions

Binary positions were measured using the grid search code¹² of Schaefer et al. (2016). We estimated the angular diameters of both components to be 0.26 mas using the *GAIA* DR2 parallax (Gaia Collaboration et al. 2016, 2018) and the radii from Andersen et al. (1987). Both stars are smaller than the 0.6 mas angular resolution of CLIMB and therefore unresolved, so we held the angular diameters fixed and fit only for the relative position of the secondary component and the flux ratio, as described in Paper I. Table 4 lists the separation and position angle of the secondary component (measured east of north) for each night, the major axis, minor axis, and position angle of the error ellipse, and the best-fit flux ratio at 2.13 μ m. The weighted average flux ratio from all nights is $f_2/f_1 = 0.97 \pm 0.06$. The sizes of the error ellipses depend on several factors, including the number of brackets obtained, the telescope combination used, the seeing, and the data quality. Figure 3 shows the observed relative positions, as well as the best-fit visual orbit found in the next section.

3.4. Combined Visual + Spectroscopic Solution

From the visual orbit alone, one can determine the orbital inclination (i), angular semimajor axis (a), and longitude of the

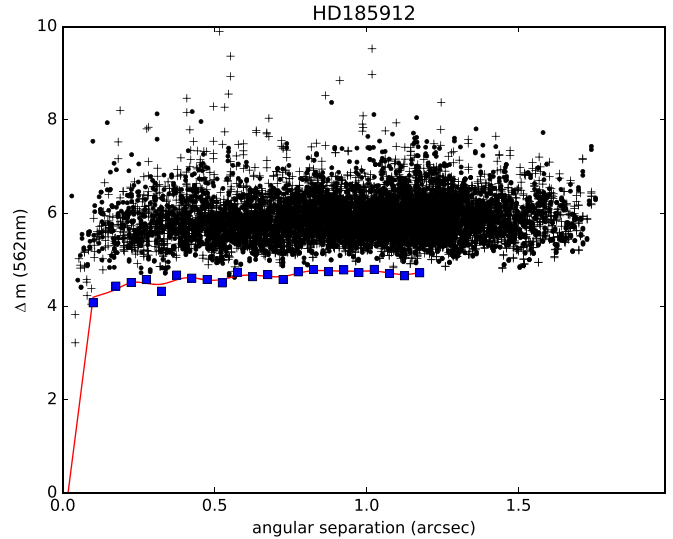


Figure 2. Background sensitivity as a function of radius from the center for the reconstructed speckle image from ‘Alopec’. The black points represent the local maxima (crosses) and minima (dots). The blue squares mark the 5σ background sensitivity limit within 0.05 bins, and the red line corresponds to a spline fit. No points fall below the contrast limit, therefore no tertiary companions were detected.

ascending node (Ω). By combining the interferometric and spectroscopic data, we can fit for all 10 orbital parameters (P , T , e , i , a , ω_1 , Ω , γ , K_1 , K_2) using the method of Schaefer et al. (2016), described in detail in Paper I. The best-fit orbital parameters for this combined (VB+SB2) solution are listed in the third column of Table 2, along with the uncertainties calculated using a Monte Carlo error analysis. The best-fit model radial velocity curves are shown in Figure 1 and model visual orbit is shown in Figure 3.

4. Photometry

4.1. MASCARA Light Curve

HD 185912 was recently observed by the Multi-site All-Sky CAmERA (MASCARA¹³) photometric survey of Burggraaff et al. (2018), who completed V-band relative photometry of bright stars in search of exoplanets. The observations spanned 10 orbital cycles, but the primary and secondary eclipses were

¹² <http://chara.gsu.edu/analysis-software/binary-grid-search>

¹³ <http://mascara1.strw.leidenuniv.nl/>

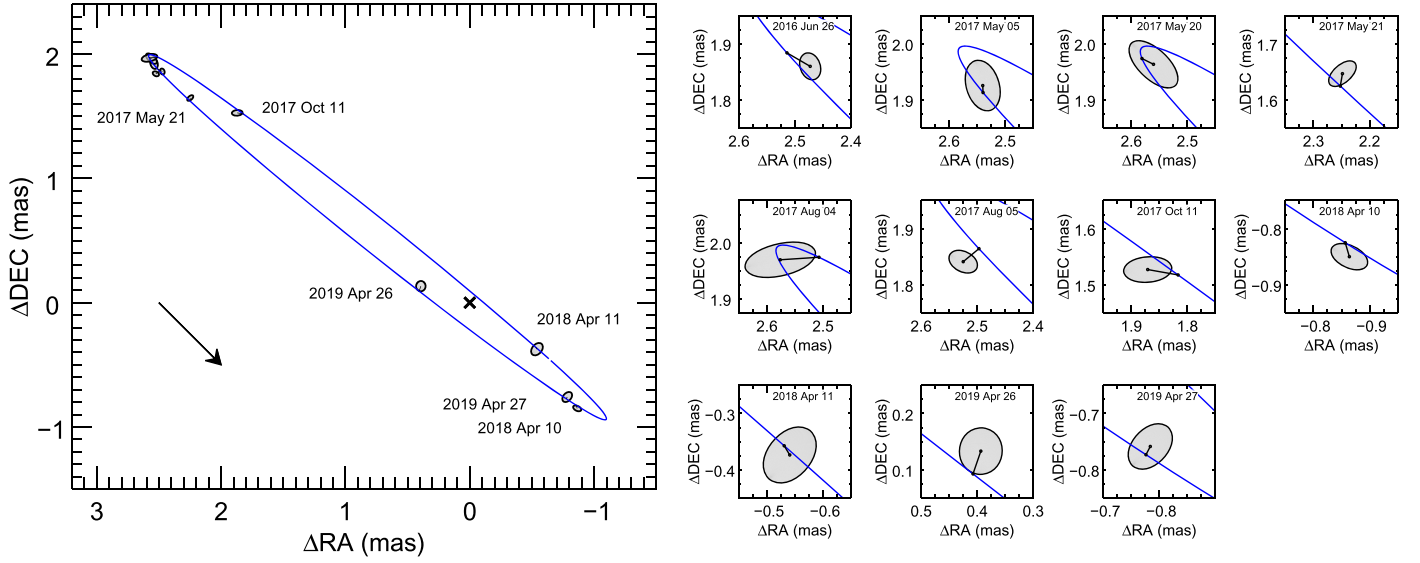


Figure 3. Left: visual orbit for HD 185912 from the combined VB+SB2 solution. The primary star is located at the origin (black cross). The relative positions of the secondary are plotted as the filled ovals corresponding to the sizes of the error ellipses, along with a line connecting the observed and predicted positions. The solid blue line shows the full model orbit, and the arrow shows the direction of orbital motion. Right: plots of individual data points in chronological order and on the same 0.2×0.2 mas scale.

Table 3
CHARA/CLIMB Observing Log for HD 185912

UT Date	HJD-2,400,000	Telescope Configuration	Calibrators	Number of V^2	Number of CP	r_0 (cm)
2016 Jun 26	57565.7877	S1-W1-E1	HD 178207, 187748	12	4	9.8
2017 May 5	57878.9577	S2-W1-E1	HD 184170, 186760	9	3	9.3
2017 May 20	57893.9517	S2-W1-E1	HD 184170, 186760	21	7	9.1
2017 May 21	57894.9542	S2-W1-E1	HD 184170, 186760	21	7	11.6
2017 Aug 4	57969.7870	S1-W1-E1	HD 184170, 186760	6	2	10.0
2017 Aug 5	57970.8065	S1-W1-E1	HD 184170, 186760	15	5	8.3
2017 Oct 11	58037.6580	S1-W1-E1	HD 184170, 186760	12	4	10.6
2018 Apr 10	58219.0089	S1-W1-E1	HD 184170	9	3	11.3
2018 Apr 11	58219.9480	S1-W1-E1	HD 184170, 186760	9	3	9.5
2019 Apr 26	58599.9298	S1-W1-E1	HD 184170, 186760	21	7	9.8
2019 Apr 27	58600.9608	S1-W1-E1	HD 184170, 186760	24	8	8.3

Table 4
Relative Positions for HD 185912

UT Date	HJD-2,400,000	Orbital Phase	ρ (mas)	θ (deg)	σ_{maj} (mas)	σ_{min} (mas)	ϕ (deg)	f_2/f_1
2016 Jun 26	57565.7877	0.39	3.094	53.1	0.049	0.036	19.8	0.82 ± 0.00
2017 May 5	57878.9577	0.38	3.187	412.8	0.093	0.059	17.1	0.96 ± 0.16
2017 May 20	57893.9517	0.34	3.226	52.5	0.109	0.053	46.6	0.93 ± 0.09
2017 May 21	57894.9542	0.47	2.787	53.8	0.031	0.018	131.1	0.96 ± 0.01
2017 Aug 4	57969.7870	0.27	3.243	412.6	0.128	0.057	103.1	0.93 ± 0.34
2017 Aug 5	57970.8065	0.40	3.125	413.9	0.054	0.036	63.1	0.99 ± 0.03
2017 Oct 11	58037.6580	0.15	2.415	50.8	0.086	0.045	94.5	0.94 ± 0.08
2018 Apr 10	58219.0089	0.88	1.212	225.5	0.070	0.040	64.3	0.98 ± 0.02
2018 Apr 11	58219.9480	0.01	0.657	235.3	0.113	0.078	139.5	0.92 ± 0.11
2019 Apr 26	58599.9298	0.74	0.415	431.3	0.083	0.076	175.1	0.83 ± 0.18
2019 Apr 27	58600.9608	0.87	1.091	225.9	0.094	0.063	137.2	0.98 ± 0.02

observed fully in only two. We first removed the systematic effects as a function of lunar phase and sidereal time as described in their paper and folded the data using the orbital period from the spectroscopic solution. We then removed

outlier points by calculating the residuals against a model light curve with parameters from Andersen et al. (1987) and discarding all of the points outside three times the standard deviation. The folded light curve is shown in Figure 4.

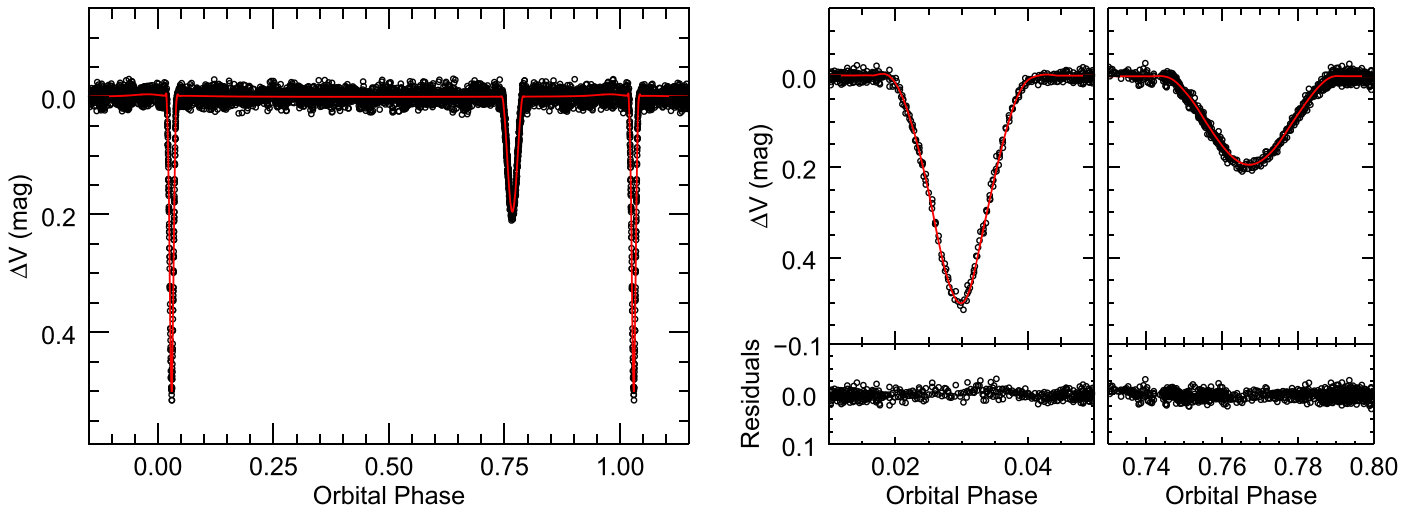


Figure 4. Light curve of HD 185912 from Burggraaff et al. (2018) photometry. The full, phased light curve is shown in the left panel, with detailed views of the primary and secondary eclipses in the right panels. Phase 0 corresponds to the time of periastron. The best-fit ELC model is shown as the solid red line, which was used to calculate the residuals shown in the right-hand panels.

4.2. Light-curve Modeling

We modeled the light curve using the Eclipsing Light Curve code of Orosz & Hauschildt (2000). We held the orbital period fixed to the spectroscopic solution and used ELC’s genetic optimizer to fit for T , e , i , and ω_1 , as well as the relative radius of each component (R_1/a , R_2/a) and the temperature ratio ($T_{\text{eff } 2}/T_{\text{eff } 1}$). We found that T , e , and ω_1 were well constrained by the optimizer and are listed in Table 2. The inclination, relative radii, and temperature ratio were not well constrained, because it is difficult to determine the individual radii directly from the light curve in partially eclipsing systems with very similar components. There exists a family of solutions that fit the observations equally well, so that only the value of $(R_1 + R_2)/a$ can be determined accurately.

To show this more clearly, we calculated the χ^2 goodness-of-fit statistic across the primary and secondary eclipses for model light curves over a grid of R_1/a and R_2/a values, fitting for the inclination and temperature ratio at each grid point. In order to weight equally the primary and secondary eclipses, we divided the χ^2 values for each eclipse by the number of points within each eclipse (124 and 458) before adding the χ^2 values together. Figure 5 shows the χ^2 contour as a function of relative radius, where the valley of possible solutions is easily visible.

Solving the problem of partially eclipsing systems therefore requires additional constraints; for example, Andersen et al. (1987) used the luminosity ratio from their spectroscopic analysis to inform their results. We used the observed flux ratios and model surface fluxes to estimate a radius ratio (see Section 5.3), plotted as the solid line in Figure 5. We found the minimum χ^2 value along this line to correspond to $i = 86.9 \pm 0.1$ deg, $R_1/a = 0.0594 \pm 0.0011$, $R_2/a = 0.0582 \pm 0.0011$, and $T_{\text{eff } 2}/T_{\text{eff } 1} = 0.99 \pm 0.01$. The uncertainties correspond to where $\chi^2 \leq \chi^2_{\text{min}} + 1$. This inclination is consistent with that from the visual orbit; however, this value does depend on the relative radii and surface flux models while the visual orbit is independent of models.

5. Stellar Parameters

5.1. Masses and Distance

By combining the results from spectroscopy with those of interferometry, we found the component masses of HD 185912 to be $M_1 = 1.361 \pm 0.004 M_\odot$ and $M_2 = 1.332 \pm 0.004 M_\odot$. By combining the angular and physical sizes of the orbit, we found the distance to be $d = 41.02 \pm 0.22$ pc. This is consistent with the *Hipparcos* distance of $d = 40.88 \pm 0.48$ pc (Perryman et al. 1997; van Leeuwen 2007) and the *GAIA* DR2 distance of $d = 40.47 \pm 0.08$ pc (Gaia Collaboration et al. 2016, 2018).

5.2. Effective Temperatures and Rotational Velocities

We first used the Doppler tomography algorithm of Bagnuolo et al. (1992) to reconstruct the individual spectrum of each component for all echelle orders between 4000 and 7000 Å, shown in Figure 6. We then cross-correlated the reconstructed spectra with BLUERED models of different effective temperatures to find the best-fit temperature for each echelle order. The maximum correlation for each order was used to calculate the weighted average temperature for each component, where better correlated orders were more highly weighted, and the uncertainty corresponding to the standard deviation of the temperatures from all orders. We found the effective temperatures to be $T_{\text{eff } 1} = 6620 \pm 190$ K and $T_{\text{eff } 2} = 6570 \pm 220$ K.

These values are higher than those determined by Smalley et al. (2002) from the Balmer line profiles ($T_{\text{eff } 1} = 6441 \pm 201$ K and $T_{\text{eff } 2} = 6393 \pm 136$ K), but consistent with the values determined by Wilson & Raichur (2011) from absolute photometry ($T_{\text{eff } 1} = 6653 \pm 11$ K and $T_{\text{eff } 2} = 6558 \pm 5$ K). However, the latter uncertainties are rather underestimated; the authors included internal uncertainties from the least squares fitting procedure and calibration of the filter passbands in their code, but did not incorporate uncertainties in the observations from comparison star magnitudes nor uncertainties in the fixed model parameters.

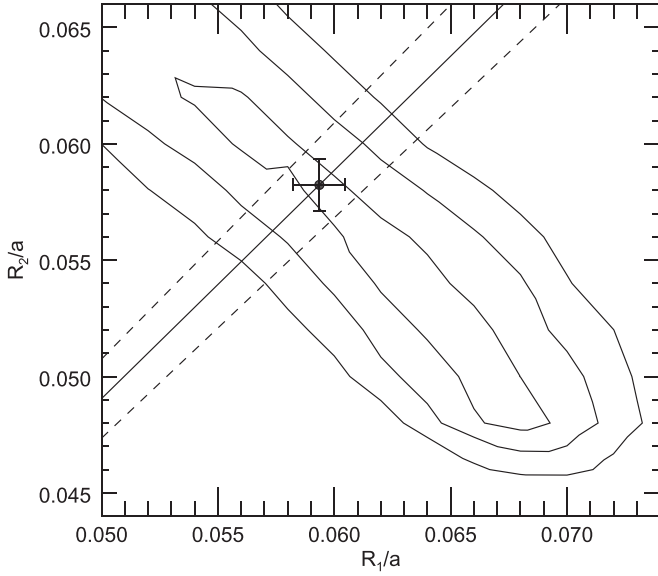


Figure 5. Contour plot of χ^2 as a function of relative radius (R/a), corresponding to the 1-, 2-, and 3- σ levels. The solid line corresponds to the mean radius ratio from Section 5.3 and the dashed lines correspond to the uncertainty. The best-fit pair of relative radii is marked with the black point.

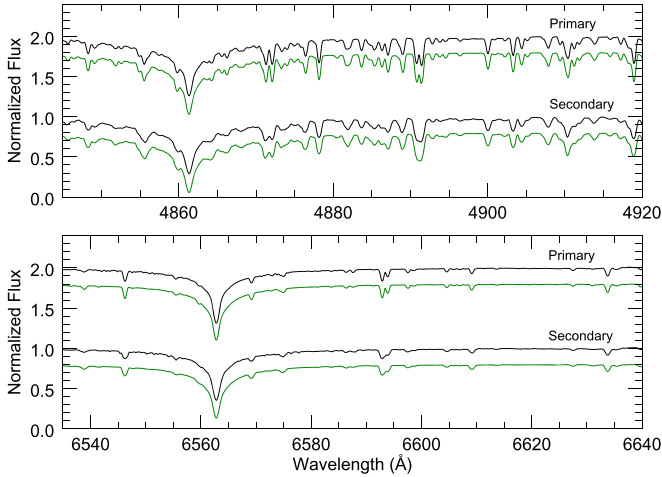


Figure 6. Reconstructed spectra of HD 185912 (black) and best-fit model spectra (green) near $H\alpha$ and $H\beta$ using the atmospheric parameters in Table 5. The model spectra are offset by -0.2 for clarity.

We used a similar method as described above to determine the projected rotational velocity ($V \sin i$) of each component by cross-correlating model spectra of different $V \sin i$ with the reconstructed spectra. We found $V_1 \sin i = 19.1 \pm 0.6 \text{ km s}^{-1}$ and $V_2 \sin i = 27.9 \pm 1.2 \text{ km s}^{-1}$. The best-fit model spectrum for each component is shown in Figure 6. These rotational velocities are consistent with the more precise values found by Albrecht et al. (2007; $19.6 \pm 0.1 \text{ km s}^{-1}$ and $28.2 \pm 0.1 \text{ km s}^{-1}$). Both components are also rotating slower than the projected pseudo-synchronous velocities of 31.1 and 30.5 km s^{-1} .

5.3. Radii and Surface Gravities

We created surface flux models of each component from ATLAS9 model atmospheres (Castelli & Kurucz 2004) using the temperatures found in the previous section. By comparing the observed flux ratios and model surface fluxes, we calculated the radius ratio to be $R_2/R_1 = 0.96 \pm 0.08$ near $H\alpha$ from the

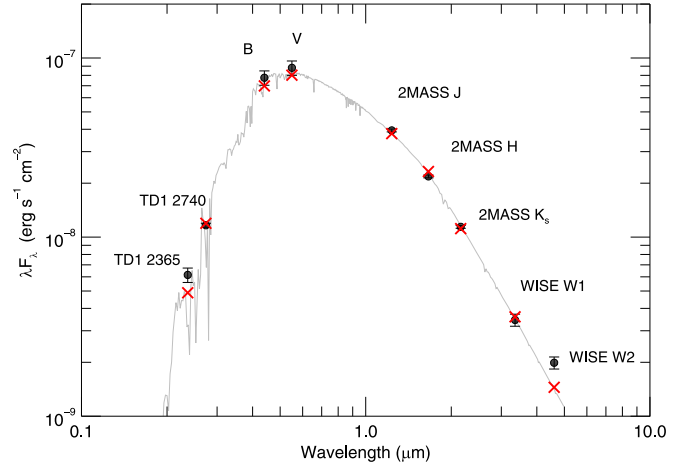


Figure 7. Observed photometry of HD 185912 (black filled circles) and best-fit model fluxes (red crosses). A full binary model SED is shown in gray for reference.

Table 5
Stellar Parameters of HD 185912

Parameter	Primary	Secondary
Mass ($M_\odot$)	1.361 ± 0.004	1.332 ± 0.004
Radius ($R_\odot$)	1.348 ± 0.016	1.322 ± 0.016
T_{eff} (K)	6620 ± 190	6570 ± 220
Luminosity ($L_\odot$)	3.35 ± 0.44	3.13 ± 0.50
$\log g$ (cgs)	4.31 ± 0.03	4.32 ± 0.04
$V \sin i$ (km s^{-1})	19.1 ± 0.6	27.9 ± 1.2
Semimajor axis ($R_\odot$)	22.71 ± 0.03	
Distance (pc)	41.02 ± 0.22	
$E(B - V)$ (mag)	0.08 ± 0.01	

spectroscopic flux ratio and $R_2/R_1 = 0.99 \pm 0.04$ in K' -band from the interferometric flux ratio. The weighted average radius ratio is $R_2/R_1 = 0.98 \pm 0.04$. We then used this radius ratio to determine the individual stellar radii from two methods; spectral energy distribution (SED) fitting and light-curve fitting.

For the first method, we took broadband photometry from the literature to create the SED for HD 185912 shown in Figure 7, which includes ultraviolet data from TD1 (Thompson et al. 1978), optical data from Egret et al. (1992), and infrared data from 2MASS (Skrutskie et al. 2006) and *Wide-field Infrared Survey Explorer* (Wright et al. 2010). We then created a binary SED model to compare to the observed SED by integrating the surface flux models across each photometric passband, and then fit for the primary angular diameter and reddening (see Section 5.2 of Paper I). We found angular diameters of $\theta_1 = 0.32 \pm 0.01 \text{ mas}$ and $\theta_2 = 0.31 \pm 0.01 \text{ mas}$, which correspond to stellar radii of $R_1 = 1.39 \pm 0.04 R_\odot$, $R_2 = 1.37 \pm 0.06 R_\odot$, and a reddening value of $E(B - V) = 0.08 \pm 0.01 \text{ mag}$.

For the second method, we used the orbital parameters found in Section 3.4 and the relative radii found in Section 4.2 to calculate the individual stellar radii. We found $R_1 = 1.348 \pm 0.016 R_\odot$ and $R_2 = 1.322 \pm 0.016 R_\odot$, corresponding to surface gravities of $\log g_1 = 4.31 \pm 0.03$ and $\log g_2 = 4.32 \pm 0.04$ as listed in Table 5. Both methods provide consistent results, but this is expected since they depend on the same model fluxes and radius ratio. Using these radii from the light-curve solution and the effective temperatures, we calculated the luminosities of each component to be $L_1 = 3.35 \pm 0.44 L_\odot$ and $L_2 = 3.13 \pm 0.50 L_\odot$ from the Stefan-Boltzmann law.

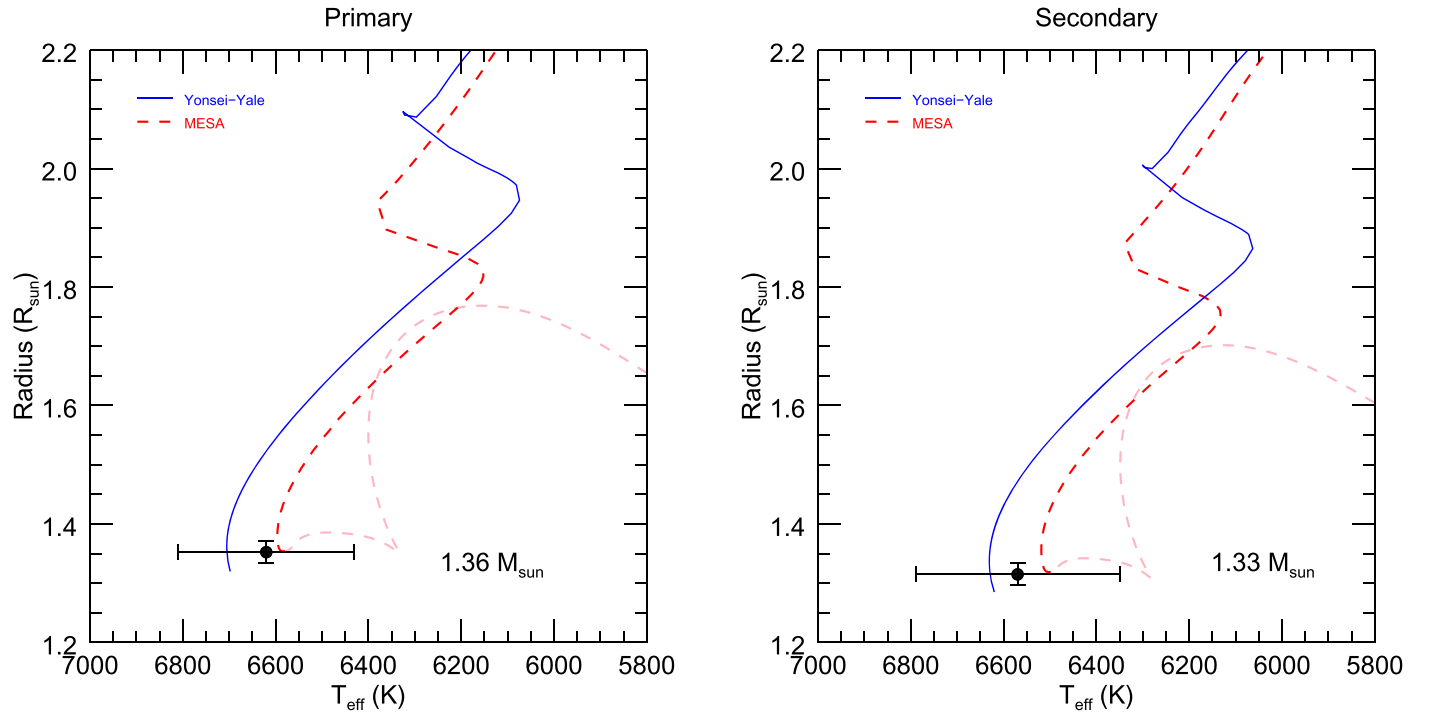


Figure 8. Evolutionary tracks for each component of HD 185912. The solid blue lines are the Yonsei-Yale models. The dashed red lines are the MESA models, with the pre-main-sequence portion shown in light red.

5.4. Comparison with Evolutionary Models

We created model evolutionary tracks for each component of HD 185912 using the Yonsei-Yale (Y^2) evolutionary models of Demarque et al. (2004) and the MESA stellar evolution code of Paxton et al. (2011, 2013, 2015, 2018, 2019), shown in Figure 8. The Yonsei-Yale models¹⁴ were created using the model interpolation program, and the MESA models¹⁵ were created using MESA release 10108 with overshooting parameters for each component taken from the empirical relationship of Claret & Torres (2018). Both sets of models are nonrotating and use solar metallicity. The Yonsei-Yale models use the solar abundance mixture from Grevesse et al. (1996), while the MESA models use the mixture of Grevesse & Sauval (1998).

As seen in Figure 8, HD 185912 lies very close to the zero age main sequence. We estimated the age of each component based on the portions of the evolutionary tracks that lie within the observed uncertainties, then took the average to estimate system ages of 550 Myr from the Yonsei-Yale models and 100 Myr from the MESA models. The individual ages of each component from their evolutionary tracks are consistent to within 5%. This young age is confirmed by the presence of the Li I 6708 Å absorption line in our spectra.

6. Discussion

We determined the first visual orbit for HD 185912 from long baseline interferometry with the CHARA Array, as well as updated spectroscopic orbits and photometric analysis. From the combined visual and spectroscopic solution, we found the component masses to within 0.3% and the distance to within 0.8%. We found the component radii to within 5% from SED

fitting and to within 1.2% from light-curve modeling, but these errors are likely underestimated in partially eclipsing systems. Therefore, more precise photometry during the eclipses is needed to determine the individual radii, such as the highly anticipated *TESS* observations currently underway in the northern hemisphere (Ricker et al. 2015).

By comparing our observed stellar parameters to evolutionary models, we found that HD 185912 is a young system located on the zero age main sequence and likely in the process of tidal circularization (Meibom & Mathieu 2005). We checked for membership in 29 nearby moving groups using the BANYAN¹⁶ website (Gagné et al. 2018), which compares the position, proper motion, radial velocity, and parallax to that of each moving group. BANYAN reported a membership probability of 0% for all associations, so HD 185912 is simply a young field star.

Eclipsing binaries like HD 185912 are important for comparing the results from interferometry and photometry. Specifically, the orbital inclination from interferometry is consistent with the results from photometry, providing a proof of concept for our project. We are continuing interferometric observations of several other longer period spectroscopic binaries to determine their visual orbits and their fundamental stellar parameters.

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¹⁴ <http://www.astro.yale.edu/demarque/yystar.html>

¹⁵ <http://www.mesa.sourceforge.net>

¹⁶ <http://www.exoplanetes.umontreal.ca/banyan/banyansigma.php>

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Facilities: CHARA, APO:3.5 m, Gemini:North.

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