HIPPARCOS ASTROMETRIC ORBIT AND EVOLUTIONARY STATUS OF HR 6046

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ABSTRACT

The previously known, 6 yr single-lined spectroscopic binary HR 6046 has been speculated in the past to contain a compact object as the secondary. A recent study has redetermined the orbit with great accuracy and shown that the companion is an evolved but otherwise normal star of nearly identical mass to the primary, which is also a giant. The binary motion was detected by the Hipparcos mission but was not properly accounted for in the published astrometric solution. Here we use the Hipparcos intermediate data in combination with the spectroscopic results to revise that solution and establish the orbital inclination angle for the first time, and with it the absolute masses $M_A = 1.38^{+0.09}_{-0.03} M_{\odot}$ and $M_B = 1.36^{+0.07}_{-0.02} M_{\odot}$. Aided by other constraints, we investigate the evolutionary status and confirm that the primary star is approaching the tip of the red giant branch, while the secondary is beginning its first ascent.

Key words: astrometry — binaries: general — binaries: spectroscopic — methods: data analysis — stars: fundamental parameters — stars: individual (HR 6046)

1. INTRODUCTION

Since the publication of the first preliminary orbits in the 1930s by Christie (1934, 1936), the bright giant star HR 6046 (HD 145849, HIP 79358, $\alpha = 16^h11^m48.05^s$, $\delta = +36^\circ25^\prime30.3^\prime$ [J2000.0]; spectral type K3 II, $V = 5.63$) has been known as a highly eccentric ~6 yr period single-lined spectroscopic binary of particular interest. The relatively large minimum mass inferred early on for the companion ($>3 M_{\odot}$), along with the fact that it was not visible to early observers, led to the speculation that the secondary was a collapsed star (Trimble & Thorne 1969), more commonly referred to nowadays as a black hole. Very recently Scarfe et al. (2007) have dispelled this notion by detecting the secondary spectroscopically and showing that it is merely an evolved late-type star, with nothing particularly out of the ordinary in its properties other than the fact that it is faint. On the basis of extensive radial velocity measurements carried out over more than 26 years, these authors presented an accurate double-lined orbit for the system yielding minimum masses considerably smaller than previously thought. They also found the components to be nearly identical in mass to within 1%, even though they are substantially different in brightness ($\Delta V \approx 3$). They relied on the Hipparcos parallax of the system (Perryman et al. 1997) to construct a plausible photometric model of the stars (individual magnitudes and colors), but cautioned that the distance could be vitiated by unmodeled photocentric motion.

As described by Scarfe et al. (2007), HR 6046 has never been spatially resolved despite repeated attempts over the years using speckle interferometry and other techniques. However, Jancart et al. (2005) were able to obtain an estimate of the inclination angle by reconsidering the Hipparcos Intermediate Astrometric Data in conjunction with the spectroscopic orbit of Christie (1936) to account for the binary motion. With this the absolute masses of the components can in principle be obtained, although the resulting values are somewhat high for late-type giants ($\sim 3.6 M_{\odot}$), possibly because of the use of outdated spectroscopic elements.

The main motivation for the present work is to revisit the Hipparcos astrometric solution in the light of the accurate orbit of Scarfe et al. (2007) and to examine the effect on the published parallax. In addition, we investigate the evolutionary status of the system with our newly determined masses, aided by current stellar evolution models. We also report a spectroscopic determination of the effective temperature of the primary star that supports the general picture outlined by other constraints in showing the evolved state of the binary.

2. HIPPARCOS OBSERVATIONS AND REVISED ASTROMETRIC SOLUTION

Given the 6 yr orbital period of HR 6046, which is of the same order as the duration of the Hipparcos mission (slightly more than 3 yr), it may be expected that the orbital motion would be detectable in the satellite measurements, and that if not properly accounted for it could bias either the trigonometric parallax, the proper motions, or both. Indeed, proof that a signal of this nature is detectable is given by the fact that the Hipparcos team found it necessary to include acceleration terms in the astrometric solution, representing the first derivatives of the proper motions. These terms, $d\mu_\alpha^*/dt = -9.08 \pm 1.23$ mas yr$^{-2}$ and $d\mu_\delta^*/dt = -6.98 \pm 1.53$ mas yr$^{-2}$, are statistically significant. It is unclear why a full orbital model was not applied originally to this system, since the binary nature of the object has been known for a long time. In any case, this has been done more recently by Jancart et al. (2005), as mentioned earlier.

A total of 78 astrometric measurements were made by Hipparcos from 1989 December to 1993 February, covering about 53% of an orbital cycle. Each measurement consisted of a one-dimensional observation ("abscissa," $\nu$) along a great circle representing the scanning direction of the satellite, tied to the absolute frame of reference known as the International Celestial Reference System. The measurements available for our analysis are published in the form of "abscissa residuals" ($\Delta\nu$, see Table 1), which are the residuals from the standard five-parameter solution reported in the catalog (Perryman et al. 1997). The five standard parameters are the position ($\alpha_0^\nu$, $\delta_0^\nu$) and proper-motion components ($\mu_\alpha^*\nu$, $\mu_\delta^\nu$) of the barycenter at the reference epoch 1991.251$^1$ and the trigonometric parallax, $\pi_\nu$. The nominal errors of these measurements have a median value of 2.5 mas.

We incorporated orbital motion into a new astrometric solution following the formalism of van Leeuwen & Evans (1998), Pourbaix & Jorissen (2000), and Jancart et al. (2005), including the correlations between measurements from the two independent

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$^1$ Following the practice in the Hipparcos catalog we define $\alpha^* = \alpha \cos \delta$ and $\mu_\alpha^* = \mu_\alpha \cos \delta$. 

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data-reduction consortia that processed the original *Hipparcos* observations (Northern Data Analysis Consortium [NDAC] and Fundamental Astrometry by Space Techniques [FAST]; Perryman et al. 1997). Details of this modeling along with another example of an application may also be seen in Torres (2007b). In the most general case the adjustable quantities of the fit (a total of 12) are the corrections to the five standard *Hipparcos* parameters ($\Delta \Omega$, $\Delta \lambda$, $\Delta \mu_{\alpha}^\ast$, $\Delta \mu_{\delta}^\ast$, and $\Delta \pi$), and the seven usual elements of the binary orbit: the period $P$, the semimajor axis of the photocenter $a_{\text{phot}}$, the eccentricity $e$, the inclination angle $i$, the longitude of periastron for the primary $\omega_1$, the position angle of the ascending node $\Omega$ (equinox J2000.0), and the time of periastron passage $T$. For HR 6046 the *Hipparcos* measurements do not constrain $P$, $e$, and $\omega_1$, or $T$ sufficiently well, so those elements were held fixed at their spectroscopic values as reported by Scarfe et al. (2007). We solved for the remaining eight parameters simultaneously using standard nonlinear least-squares techniques (Press et al. 1992, p. 650). The reduced $\chi^2$ of the solution is 0.9895, indicating that the internal errors of the abscissa residuals are realistic.

We list the results in Table 2, where they are compared with those obtained by Jancart et al. (2005). Significant differences are seen in the semimajor axis and inclination angle, which reflect the spectroscopic constraints used in each case. Jancart’s value of $a_{\text{phot}}$ is nearly twice as large as ours, and while their inclination angle is substantially smaller than 90°, we obtain an orientation that is essentially edge-on. The smaller $i$-value of Jancart et al. (2005) would lead to much larger absolute masses for the stars when combined with the minimum masses of Scarfe et al. (2007), as noted in § 1. There is little doubt that the recent orbital elements by Scarfe et al. (2007) supersede the provisional values of Christie (1936) adopted by Jancart et al., which suggests our solution should be closer to the truth.\(^2\) An external check on our results is provided by the absolute proper motions we obtain, listed in the bottom section of Table 2. These are different from the values reported in the *Hipparcos* catalog, which are likely to be affected also by the unmodeled orbital motion. They agree well, however, with the motions given in the Tycho-2 catalog (Høg et al. 2000), as shown in Table 3. The latter are based on the position from the Tycho experiment aboard the *Hipparcos* satellite (epoch ∼1991.25) combined

\(^2\) A preliminary version of the Scarfe et al. (2007) work had been published in 2004 (Scarfe et al. 2004), but was perhaps not yet available to Jancart and collaborators.
TABLE 2

Astrometric Orbital Solutions for HR 6046

| Parameter | Jancart et al. (2005)* | This Work b |
|-----------|------------------------|-------------|
| Adjusted Quantities | | |
| $P$ (days) | 2150 (fixed) | 2200.77 (fixed) |
| $a_{\text{ph}}$ (mas) | 16.5 ± 2.3 | 9.69 ± 0.85 |
| $e$ | 0.6 (fixed) | 0.6797 (fixed) |
| $i$ (deg) | 46.4 ± 3.5 | 91.4 ± 9.7 |
| $\omega$ (deg) | 340 (fixed) | 9.73 (fixed) |
| $\Omega_{2000}$ (deg) | 305.4 ± 6.7 | 50.5 ± 6.6 |
| $T$ (HJD - 2,400,000) | 50,699 (fixed)* | 50,760.4 (fixed) |
| $\Delta \alpha$ (mas) | ... | -4.41 ± 0.76 |
| $\Delta \delta$ (mas) | ... | -3.77 ± 0.95 |
| $\Delta \mu_\alpha$ (mas yr$^{-1}$) | ... | -3.57 ± 0.91 |
| $\Delta \mu_\delta$ (mas yr$^{-1}$) | ... | -3.13 ± 1.23 |
| $\Delta \pi$ (mas) | ... | +0.27 ± 0.51 |

| Derived Quantities | | |
| $\mu_\alpha$ (mas yr$^{-1}$) | ... | -12.46 ± 0.91 |
| $\mu_\delta$ (mas yr$^{-1}$) | ... | -31.13 ± 1.23 |
| $\pi$ (mas) | ... | 5.61 ± 0.51 |
| $M_1$ ($M_\odot$) | ... | 1.38 ± 0.08 |
| $M_2$ ($M_\odot$) | ... | 1.38 ± 0.07 |

* $P$, $e$, $\omega$, and $T$ adopted from Christie (1936). Other Hipparcos-related parameters were not reported.

b $P$, $e$, $\omega$, and $T$ adopted from Scarfe et al. (2007).

c Projected forward from the original epoch 2,424,290 (HJD) using the more accurate period from the present paper, for easier comparison with our new results.

with ground-based catalog positions, going back nearly a century in some cases. This long baseline tends to average out any orbital motion that has a period of a few years, as in the case of HR 6046, and therefore yields a more accurate estimate than Hipparcos. Finally, we note that our revised Hipparcos solution did not change the value of the parallax significantly, which was one of the concerns of Scarfe et al. (2007). This parallax corresponds to a distance of 178 pc.

As a way of visualizing the effect of accounting for the orbital motion in the Hipparcos solution, we show in Figure 1a the abscissa residuals $\Delta \alpha$ resulting from the standard five-parameter solution as a function of orbital phase. Some systematic patterns are apparent, but they largely disappear after the orbital motion is incorporated into the model. This is shown by the $O - C$ residuals from the 12 parameter fit in Figure 1b.

The projection of the photocentric orbit on the plane of the sky along with a schematic representation of the Hipparcos measurements is seen in Figure 2, where the axes are parallel to the right ascension and declination directions. Because these measurements are one-dimensional in nature, their exact location on the plane of the sky cannot be shown graphically. The filled circles represent the predicted location on the computed orbit (see also Fig. 3). The dotted lines connected to each filled circle indicate the scanning direction of the Hipparcos satellite for each measurement and show which side of the orbit the residual is on. The length of each

TABLE 3

Comparison of the Proper Motion and Parallax Results for HR 6046

| Parameter | Hipparcos | Tycho-2 | This Work |
|-----------|-----------|---------|-----------|
| $\mu_\alpha$ (mas yr$^{-1}$) | -8.89 ± 0.58 | -13.3 ± 1.4 | -12.46 ± 0.91 |
| $\mu_\delta$ (mas yr$^{-1}$) | -28.00 ± 0.60 | -30.8 ± 1.4 | -31.13 ± 1.23 |
| $\pi$ (mas) | 5.34 ± 0.60 | ... | 5.61 ± 0.51 |

Fig. 1.—(a) Abscissa residuals of HR 6046 from the Hipparcos mission as a function of orbital phase. These are the residuals from the standard five-parameter solution as published in the catalog (Perryman et al. 1997). The systematic patterns are due to the unmodeled motion of the center of light. (b) $O - C$ residuals of the Hipparcos measurements from our new 12 parameter fit that accounts for the orbital motion.

Fig. 2.—Motion of the photocenter of HR 6046 relative to the center of mass of the binary (plus sign) as seen by Hipparcos. The one-dimensional abscissa residuals are shown schematically with filled circles at the predicted locations, dotted lines representing the scanning direction of the satellite, and short perpendicular line segments indicating the undetermined location of the measurement on that line (see text). The lengths of the dotted lines represent the magnitude of the $O - C$ residual from the computed location. Three measurements with residuals larger than 5 mas were omitted for clarity. Also indicated on the plot is the location of periastron (open circle near the top).
The dotted line represents the magnitude of the $O - C$ residual.\(^3\) The short line segments at the end of and perpendicular to the dotted lines indicate the direction along which the actual observation lies, although the precise location is undetermined. Occasionally, more than one measurement was taken along the same scanning direction, in which case two or more short line segments appear on the same dotted lines. The orbit is formally clockwise (retrograde), although the orientation is so close to edge-on ($i = 91.4^\circ \pm 9.7^\circ$) that the motion on the plane of the sky may well be direct.

The phase coverage of the Hipparcos observations is seen more clearly in Figure 3, in which we have deprojected the orbit and represented it as if it were viewed with an inclination angle of $0^\circ$. The measurements happen to cover the periastron passage of 1991.83 (indicated with an open circle), but not apastron. The path of HR 6046 on the plane of the sky as seen by Hipparcos is shown in Figure 4. The irregular pattern is the result of the combination of annual proper motion (indicated by the arrow), parallactic motion, and orbital motion.

The detection of the photocentric motion by Hipparcos offers an independent way of estimating the brightness difference between the stars, in the passband of the satellite ($B$ band), from the relation between the semimajor axis of the photocentric orbit and that of the relative orbit in angular units (e.g., van de Kamp 1967): $\alpha_{\text{phot}} = a_{\text{rel}}(B - \beta)$. Here $a_{\text{rel}}$ can be obtained from the spectroscopic minimum masses, the inclination angle, and the parallax through Kepler’s Third Law; $B$ represents the mass fraction $M_B/(M_A + M_B)$, and $\beta$ is the light fraction given by $L_B/(L_A + L_B) = (1 + 10^{0.4 \Delta M_B})^{-1}$. The magnitude difference is then

\[
\Delta H_p = 2.5 \log \left( \frac{q - \alpha_{\text{phot}}}{1 + q - \alpha_{\text{phot}}} \right) - 1 ,
\]

in which $q \equiv M_B/M_A$. We obtain $\Delta H_p = 2.1 \pm 0.6$ mag, somewhat smaller but still broadly consistent with the values in the Johnson $B$ and $V$ bands reported by Scarfe et al. (2007) (see below), considering the difference in the passbands.

3. EVOLUTIONARY STATUS

From the analysis of their high-resolution spectra of HR 6046, Scarfe et al. (2007) estimated the spectral types and luminosity classes of the components to be K3 II and K0 IV, and the brightness differences to be $\Delta B \approx 2.5$ mag and $\Delta V \approx 3.0$ mag. They then made use of the Hipparcos parallax (which we now know is substantially correct) and the combined system brightness to infer absolute visual magnitudes of $M_V = -0.68$ for the primary and $M_V = 2.32$ for the secondary, ignoring extinction. The $U - B$ and $B - V$ color indices were computed by making use of standard tabulated values for spectral types and luminosity classes close to what they derived, along with the magnitude differences. The photometry synthesized in this way provides a very good match to the observed $B - V$ color of the system, and enabled Scarfe et al. (2007) to claim that both stars are evolved, with the primary being near the tip of the giant branch. They also pointed out that evolutionary models by Pols et al. (1998) allow the brightness difference to be as large as observed in HR 6046 for component masses that differ by as little as they do in this system (~1%), at least for masses in the most probable range for HR 6046, which they estimated to be $2.0 - 3.5 M_\odot$. This provided a natural explanation for a set of properties that had intrigued earlier investigators.

The minimum masses from the spectroscopic work of Scarfe et al. (2007) combined with our inclination angle give absolute masses for HR 6046 of $M_A = 1.38^{+0.09}_{-0.09} M_\odot$ and $M_B = 1.36^{+0.07}_{-0.02} M_\odot$ (Table 2), in which the uncertainties are currently dominated by the error in $i$. These masses are considerably smaller than assumed by those authors. We have therefore reexamined the consistency with the evolutionary models by making use of these values along with slightly revised absolute magnitudes for the stars based on our new parallax. Given a distance approaching 200 pc,
a small amount of extinction would not be unexpected for the system, and in fact the dust maps of Schlegel et al. (1998) indicate a total reddening in the direction of HR 6046 of $E(B - V) \approx 0.03$ mag. We tentatively adopt $E(B - V) \sim 0.02 \pm 0.01$ mag, which corresponds to $A_V \sim 0.06 \pm 0.03$ mag. With this adjustment to the apparent magnitude $V = 5.63 \pm 0.01$ (Håggkvist & Oja 1987), and taking into account the magnitude difference from Scarfe et al. (2007) (to which we assign, somewhat arbitrarily, an uncertainty of 0.3 mag), we infer individual magnitudes of $M_V = -0.62 \pm 0.20$ and $M_B = 2.38 \pm 0.34$. These are not changed much from the original estimates of Scarfe et al. (2007). The $B - V$ colors proposed by them rely on an external tabulation and are quite sensitive to the luminosity class adopted, so we have preferred to proceed without them here, although they may well be accurate. The models by Girardi et al. (2000) are a convenient choice for a comparison with the observations, since they reach the late evolutionary stages needed for the primary and are tabulated for a wide range of chemical compositions and ages. They also incorporate mass loss due to winds in the giant phase, which turns out to be only a 1%–2% effect for HR 6046.

In Figure 5 we show several isochrones for different metallicities from this series of models that produce the best simultaneous matches to the absolute magnitudes of both components at their current masses (accounting for mass loss). In each case (except for the middle isochrone) the age is the one providing the best agreement among the values tabulated by Girardi et al. (2000), which come in steps of 0.05 in log $t$. The locations of the stars in these models are indicated with open circles. The combined color and magnitude predicted for the system in each case is shown by a plus sign, and the filled circle represents the measured values of $M_V$ and $B - V$ for HR 6046. The system color we have adopted is $B - V = 1.34 \pm 0.01$ (Håggkvist & Oja 1987), which we have then reddened as indicated above. Properties of the stars inferred from these models are listed in Table 4. If we now impose the additional requirement that the isochrones match the measured system color within its uncertainty, a very good correspondence may be obtained by interpolation for a metallicity of $Z = 0.011 \pm 0.002$ (corresponding to $[\text{Fe/H}] = -0.24 \pm 0.07$ for the assumed $Z_\odot = 0.019$ in these models) and a logarithmic age of log $t = 9.49_{-0.04}^{+0.04}$ (or 3.1$^{+0.5}_{-0.5}$ Gyr). This model is shown with the thick line in Figure 5 and indicates that the primary is indeed approaching the tip of the giant branch, whereas the secondary is beginning its first ascent of the giant branch. We infer from this best-fitting isochrone that the primary star has a radius of $R_\star = 30_{-15}^{+30}$ and a surface gravity of $\log g = 1.60_{-0.08}^{+0.04}$ and an effective temperature ($T_{\text{eff}}$) of 4211$^{+10}_{-23}$ K, and the secondary has $R = 4.20_{-0.13}^{+0.07} R_\odot$, log $g = 3.33_{-0.04}^{+0.07}$, and $T_{\text{eff}} = 5010_{-178}^{+142}$ K. These uncertainties account for all observational errors but exclude possible systematics in the models. Other properties of the stars are listed in Table 4.

### 3.1. Additional Spectroscopic Constraints

With the goal of providing a check on the temperature of the primary star, we obtained a high-resolution spectrum of HR 6046 on UT 2007 July 5 using the HIRES instrument (Vogt et al. 1994) on the Keck I telescope. The spectrometer slit was 0.86", giving a resolving power of $\lambda/\Delta \lambda \approx 55,000$. The signal-to-noise ratio of this spectrum is $\sim 120$ pixel$^{-1}$. The spectral region 6200–6300 Å was used to measure a number of temperature-sensitive lines mainly of Fe i and V i, and also a few of Ni i, Sc i, Si i, and Fe ii. As

## Table 4

**Properties for the Components of HR 6046 Inferred from the Models**

| Property          | Z = 0.004 | Z = 0.008 | Z = 0.011 | Z = 0.019 | Z = 0.030 |
|-------------------|-----------|-----------|-----------|-----------|-----------|
| log age (yr)       | 9.40      | 9.45      | 9.49      | 9.55      | 9.60      |
| $(B - V)_0$ (mag)  | 1.07      | 1.25      | 1.35      | 1.50      | 1.58      |
| $(B - V)_g$ (mag)  | 0.75      | 0.87      | 0.92      | 1.02      | 1.12      |
| $(B - V)_{\text{tot}}$ (mag) | 1.05 | 1.22 | 1.32 | 1.47 | 1.54 |
| $\Delta J$ (mag)   | 3.48      | 3.64      | 3.80      | 3.96      | 4.11      |
| $\Delta H$ (mag)   | 3.66      | 3.88      | 4.05      | 4.29      | 4.43      |
| $\Delta K$ (mag)   | 3.68      | 3.90      | 4.08      | 4.33      | 4.54      |
| $T_{\text{eff}}$ (K) | 4590     | 4311      | 4211      | 3947      | 3699      |
| $T_{\text{eff}}$ (K) | 5312     | 5079      | 5010      | 4819      | 4649      |
| $R_\star$ (R$_\odot$) | 23.1     | 29.3      | 30.9      | 42.1      | 56.7      |
| $R_g$ (R$_\odot$)   | 3.84      | 4.33      | 4.20      | 4.98      | 5.90      |

**Notes.**—The models used are those of Girardi et al. (2000), and the observational constraints are the measured masses and absolute magnitudes of the components (see text). The best-fitting model for $Z = 0.011$ satisfies the additional constraint that the combined colors of the components match the observed $B - V$ color.
described by Gray & Johanson (1991) and others, line-depth ratios (LDRs) of properly selected line pairs are an excellent diagnostic of effective temperature that allow for relative measurements with a precision as small as a few kelvins, not only in dwarfs but also in giants (Gray & Brown 2001). The conversion to an absolute temperature scale, however, necessarily depends on an external color-temperature calibration, since LDR variations are usually compared with corresponding changes in a color index such as $B - V$, which is an easier quantity to measure than temperature. Therefore, absolute temperatures are much less certain. We measured a total of 26 lines of the primary star4 from Table 1 by Biazzo et al. (2007) and used their calibrations appropriate for giants for 16 selected line pairs to derive an average temperature from the LDRs of $T_{\text{eff}} = 4340 \pm 20$ K (formal error). The scatter of the individual determinations is only 80 K. The color-temperature relation on which the above calibrations are based is that of Gray (2005), which combines dwarf and giant temperatures obtained by many different methods. For this work we have preferred to rely on a more sophisticated color-temperature relation such as that by Ramírez & Meléndez (2005), which accounts not only for luminosity class but also metallicity and is based on effective temperatures derived homogeneously by the infrared flux method. The conversion from the above LDR-based $T_{\text{eff}}$ back to an average color for the primary star was made using the same prescription by Gray (2005) and gives $B - V = 1.328 \pm 0.014$. The Ramírez & Meléndez (2005) calibration for an adopted metallicity of $[\text{Fe/H}] = -0.24$ (3) then yields $T_{\text{eff}} = 4210 \pm 60$ K, in which the error combines photometric uncertainties and the scatter of the calibration. This result is in virtually perfect agreement with the temperature predicted by the Girardi et al. (2000) models, supporting our overall conclusions from the previous section.

4. DISCUSSION AND CONCLUDING REMARKS

The example of HR 6046 is one of a growing number of binaries in which the Hipparcos intermediate data have been brought to bear on the orbit of the system, providing information complementary to that afforded by other types of observations (see, e.g., Pourbaix et al. 2004; Fekel et al. 2005, 2007; Torres 2006, 2007a, 2007b). In this case the Hipparcos data yield the inclination angle and allow the absolute masses to be derived for the first time. In addition, they provide an estimate of the brightness difference.

Although the inclination we derive for the orbit is consistent with 90° and allows for the possibility of eclipses, chances are slim because of the long period compounded by the relatively large uncertainty in $i$. No photometric variability was found by Percy (1993), who, however, apparently did not observe during the eclipse phases, or with the Hipparcos satellite (scatter $\sigma_{\text{Hip}} = 0.007$ mag). The latter observations do straddle two of the eclipses, which can be predicted very accurately from the spectroscopic orbit of Scarfe et al. (2007) with errors of only 1.0 days for primary eclipse (HJD 2,448,652.4) and 1.4 days for the secondary (HJD 2,448,419.3). If central, the eclipses would last approximately 18 and 22 days, respectively. Examination of the epoch photometry from Hipparcos indicates that both of these eclipses were missed by just a few days. Future eclipses would be expected to occur at Julian dates 2,455,254.7 ± 1.2 and 2,457,455.5 ± 1.4 for the primary, and 2,455,021.6 ± 1.4 and 2,457,222.4 ± 1.6 for the secondary. The small separation of only 233 days (10.6% of a cycle) between the secondary eclipses and the primary events that follow is due to a combination of high eccentricity and a longitude of periastron near zero.

A second implication of the near edge-on orientation of HR 6046 is significantly lower component masses than previously assumed, which in turn leads to a linear semimajor axis for the relative orbit of 4.63 ± 0.11 AU, corresponding to 26.0 ± 2.4 mas. The maximum angular separation subtended by the binary is about 43 mas, also considerably smaller than has been suggested in the past (~70 mas; McAlister 1976; Halbwachs 1981). About two dozen unsuccessful attempts to detect the secondary have been made over the past three decades with the speckle technique. Some of them were made at phases in the orbit when the instrumental resolution should have allowed the observers to resolve the pair, suggesting the large disparity in brightness ($\Delta V \approx 3$) as the cause of those nondetections. In principle the expected separations make it a good target for long-baseline interferometry, except that in most cases these instruments observe in the near-infrared, where the brightness difference will be even more extreme. From our modeling we expect $\Delta V \sim 3.8$ mag and $\Delta K \sim 4.1$ mag. Still, some of these facilities may have the sensitivity required. They could also resolve the primary itself; the angular diameter should be approximately 1.6 mas, while that of the secondary is only 0.2 mas.

Double-lined spectroscopic binaries with two giant components are a relatively rare occurrence and usually imply the components must have nearly identical mass. HR 6046 is quite remarkable in that the stars have attained a large brightness difference that is near the maximum for this system, yet the secondary is still visible. Evolution proceeds very rapidly at this stage, and according to the models the difference in brightness may still increase by another half a magnitude or so in $V$ over the next 20 Myr, which represents only ~0.5% of its present age.

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