THE ASTRONOMICAL JOURNAL, 132:1490–1495, 2006 October


# HR 1613: A SLOWLY ROTATING A DWARF SPECTROSCOPIC BINARY WITH SOLAR ABUNDANCES

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*Received 2006 May 10; accepted 2006 June 17*

## ABSTRACT

From two sets of radial velocities we have obtained the orbital elements of HR 1613. This single-lined binary has an orbital period of 8.11128 days and a nearly circular orbit. The primary has an A9 V spectral type and a $v \sin i$ value of 11 km s$^{-1}$, while the unseen secondary is likely a K or M dwarf. Spectral classifications and spectrum synthesis analysis indicate that the abundances of the primary are normal. We reject the possibility that the primary of HR 1613 is seen nearly pole-on and instead argue that its rotational inclination is at least 20°, resulting in an equatorial rotational velocity of 30 km s$^{-1}$ or less. Slowly rotating A stars almost always have spectrum peculiarities, being classified as either Ap or Am stars, but HR 1613, with its essentially solar abundances, appears to be an exception.

*Key words:* binaries: spectroscopic — stars: fundamental parameters — stars: individual (HR 1613)

## 1. INTRODUCTION

HR 1613 (= HD 32115 = HIP 23296; $\alpha = 05^{\rm h}00^{\rm m}39\overset{\rm s}{.}9$, $\delta = -02°03'57\overset{''}{.}0$ [J2000.0], $V = 6.31$ mag) is a slowly rotating, late-A star in the constellation of Orion. Its spectrum has been classified as A8 IV (Cowley et al. 1969) and A9 V (Abt & Morrell 1995), while determinations of its projected rotational velocity have ranged from 9 (Bikmaev et al. 2002) to 15 km s$^{-1}$ (Abt & Morrell 1995). From an abundance analysis of over 30 elements, Bikmaev et al. (2002) found HR 1613 to have essentially solar abundances. Nordström & Andersen (1985) included HR 1613 in their radial velocity survey of 551 bright A and F stars in the southern hemisphere. Their three radial velocities have a range of 37 km s$^{-1}$, resulting in the discovery that HR 1613 is a binary.

The paper by Nordström & Andersen (1985) is not listed in SIMBAD as a reference for HR 1613, and so we did not initially know of its velocity variability. Thus, its low $v \sin i$, combined with a normal, as opposed to an Am or Ap, spectral type (Abt & Morrell 1995), caused us to observe HR 1613 as a possible constant radial velocity and spectral type standard for some of our projects. We soon independently discovered the velocity variability of HR 1613 and continued observing it to determine its orbit and basic parameters. Buggs et al. (2004) presented preliminary results of our work.

## 2. SPECTROSCOPIC OBSERVATIONS AND REDUCTIONS

From 2001 April to 2006 April we obtained 21 high-resolution spectrograms of HR 1613 (Table 1) with the Kitt Peak National Observatory (KPNO) coudé feed telescope, coudé spectrograph, and a TI CCD detector. Eighteen spectrograms are centered in the red at 6430 Å, cover a wavelength range of about 80 Å, and have a resolution of 0.21 Å. The other three are centered in the blue at 4500 Å, cover a wavelength range of 85 Å, and have a resolution of 0.22 Å. Typical signal-to-noise ratios are 150–200. At both red (Fig. 1) and blue wavelengths (Fig. 2), only a single set of lines has been detected.

From 2004 January to 2006 April we acquired 50 additional radial velocities with the Tennessee State University 2 m automatic spectroscopic telescope (AST), fiber-fed echelle spectrograph, and a 2048 × 4096 SITe ST-002A CCD. The echelle spectrograms have 21 orders, covering the wavelength range 4920–7100 Å with an average resolution of 0.17 Å. The typical signal-to-noise ratio of these observations is about 30. Eaton & Williamson (2004) have given a more extensive description of the telescope, situated at Fairborn Observatory near Washington Camp in the Patagonia Mountains of southeastern Arizona, and its operation.

For the KPNO spectrograms we determined radial velocities with the IRAF cross-correlation program FXCOR (Fitzpatrick 1993), fitting a Gaussian function to the cross-correlation peak. The IAU radial velocity standard star 10 Tau was used as the cross-correlation reference star for the red-wavelength spectrograms. Its velocity of 27.9 km s$^{-1}$ was adopted from Scarfe et al. (1990). Lines in the wavelength region redward of 6445 Å are not particularly suitable for measurement because most features are blends, and there are a number of modest-strength water vapor lines. Thus, the radial velocities were determined from lines in the region 6385–6445 Å. However, this 60 Å portion of the spectrum is so small that a spectrum mismatch, caused by the varying strength of line blends with temperature, between HR 1613 (spectral type A9 V; Abt & Morrell 1995) and that of the cross-correlation standard 10 Tau (spectral type F9 IV–V; Keenan & McNeil 1989), can significantly alter the measured velocity. Thus, instead of cross-correlating this entire 60 Å wavelength region, only the wavelength regions around the five strongest and least-blended lines, the Fe I lines at 6394, 6412, 6421, and 6431 Å plus the Ca I line at 6439 Å, were cross-correlated. For the three blue-wavelength spectrograms the full observed spectral region was cross-correlated, and 68 Tau, with a velocity of 39.0 km s$^{-1}$ adopted from Fekel (1999), was used as the reference star.

For the Fairborn Observatory AST spectra, we chose approximately 100 relatively strong, mostly Fe I lines that were not obvious blends. Lines at the ends of each echelle order were not used because of their lower signal-to-noise ratios. A Gaussian function was fitted to each line to determine its observed wavelength. The difference between the observed wavelength and that given in the solar line list of Moore et al. (1966) was used to

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TABLE 1
RADIAL VELOCITIES OF HR 1613

| Hel. Julian Date (HJD − 2,400,000) | Phase | Velocity (km s$^{-1}$) | $O-C$ (km s$^{-1}$) | Observatory |
|---|---|---|---|---|
| 52,014.618 | 0.976 | 4.9 | 0.1 | KPNO |
| 52,326.610 | 0.440 | 41.0 | −0.2 | KPNO |
| 52,327.612 | 0.564 | 45.0 | −0.1 | KPNO |
| 52,328.578 | 0.683 | 37.9 | 0.2 | KPNO |
| 52,329.717[a] | 0.823 | 20.3 | 0.1 | KPNO |
| 52,330.583 | 0.930 | 7.6 | −0.5 | KPNO |
| 52,390.607 | 0.330 | 29.9 | 0.4 | KPNO |
| 52,536.974 | 0.375 | 35.1 | 0.1 | KPNO |
| 52,537.973 | 0.498 | 44.3 | −0.2 | KPNO |
| 52,541.913[a] | 0.984 | 4.6 | 0.2 | KPNO |
| 52,542.992 | 0.117 | 5.0 | −0.5 | KPNO |
| 52,705.663 | 0.172 | 10.1 | 0.1 | KPNO |
| 52,706.659 | 0.295 | 24.7 | −0.2 | KPNO |
| 52,903.024 | 0.504 | 44.9 | 0.2 | KPNO |
| 52,903.970 | 0.620 | 42.4 | −0.4 | KPNO |
| 52,904.952 | 0.741 | 31.4 | 0.4 | KPNO |
| 53,017.841 | 0.659 | 40.5 | 0.5 | Fairborn |
| 53,052.751 | 0.963 | 5.3 | −0.3 | Fairborn |
| 53,274.004 | 0.240 | 17.2 | −0.6 | KPNO |
| 53,276.008 | 0.487 | 44.0 | −0.1 | Fairborn |
| 53,278.028 | 0.736 | 31.5 | −0.2 | KPNO |
| 53,278.969[a] | 0.852 | 16.8 | 0.2 | KPNO |
| 53,284.020 | 0.475 | 43.5 | 0.0 | Fairborn |
| 53,290.816 | 0.313 | 27.4 | 0.1 | Fairborn |
| 53,296.959 | 0.070 | 3.4 | 0.0 | Fairborn |
| 53,297.962 | 0.194 | 12.9 | 0.7 | Fairborn |
| 53,302.944 | 0.808 | 21.8 | −0.5 | Fairborn |
| 53,309.937 | 0.670 | 39.0 | 0.0 | Fairborn |
| 53,314.915 | 0.284 | 23.5 | 0.1 | Fairborn |
| 53,320.896 | 0.021 | 2.9 | −0.3 | Fairborn |
| 53,327.967 | 0.893 | 11.9 | 0.1 | Fairborn |
| 53,334.882 | 0.745 | 30.3 | −0.2 | Fairborn |
| 53,335.874 | 0.868 | 14.6 | −0.1 | Fairborn |
| 53,336.868 | 0.990 | 4.1 | 0.0 | Fairborn |
| 53,342.853 | 0.728 | 32.8 | 0.1 | Fairborn |
| 53,347.841 | 0.343 | 30.8 | −0.3 | Fairborn |
| 53,348.832 | 0.465 | 43.1 | 0.2 | Fairborn |
| 53,349.845 | 0.590 | 44.3 | 0.0 | Fairborn |
| 53,355.741 | 0.317 | 27.8 | 0.0 | Fairborn |
| 53,383.857 | 0.783 | 25.3 | −0.3 | Fairborn |
| 53,389.824 | 0.519 | 44.6 | −0.5 | Fairborn |
| 53,404.661 | 0.348 | 31.5 | −0.2 | Fairborn |
| 53,425.724 | 0.945 | 6.7 | −0.2 | Fairborn |
| 53,438.715 | 0.546 | 45.5 | 0.2 | Fairborn |
| 53,639.014 | 0.240 | 17.5 | −0.3 | KPNO |
| 53,642.007 | 0.609 | 43.0 | −0.5 | Fairborn |
| 53,655.022 | 0.214 | 14.5 | 0.0 | Fairborn |
| 53,667.970 | 0.810 | 22.0 | 0.0 | Fairborn |
| 53,680.945 | 0.410 | 39.0 | 0.4 | Fairborn |
| 53,693.909 | 0.008 | 3.8 | 0.3 | Fairborn |
| 53,725.859 | 0.947 | 6.6 | −0.1 | Fairborn |
| 53,740.879 | 0.799 | 23.7 | 0.2 | Fairborn |
| 53,753.760 | 0.387 | 36.2 | 0.0 | Fairborn |
| 53,766.759 | 0.989 | 5.0 | 0.8 | Fairborn |
| 53,779.680 | 0.582 | 44.8 | 0.2 | Fairborn |
| 53,800.675 | 0.171 | 9.7 | −0.1 | Fairborn |
| 53,808.663 | 0.155 | 8.8 | 0.4 | Fairborn |
| 53,810.622 | 0.397 | 37.3 | 0.0 | Fairborn |
| 53,811.615 | 0.519 | 45.3 | 0.2 | Fairborn |
| 53,812.605 | 0.641 | 41.3 | −0.1 | Fairborn |
| 53,816.598 | 0.134 | 6.4 | −0.2 | Fairborn |
| 53,817.598 | 0.257 | 20.1 | 0.2 | Fairborn |
| 53,818.601 | 0.381 | 35.5 | −0.1 | Fairborn |
| 53,820.601 | 0.627 | 42.4 | 0.0 | Fairborn |
| 53,823.602 | 0.997 | 3.7 | −0.2 | Fairborn |
| 53,827.611 | 0.491 | 44.3 | 0.1 | Fairborn |
| 53,832.609 | 0.108 | 5.2 | 0.3 | Fairborn |
| 53,837.611 | 0.724 | 33.1 | 0.0 | Fairborn |
| 53,838.612 | 0.848 | 17.5 | 0.4 | Fairborn |
| 53,843.615 | 0.464 | 42.7 | −0.2 | Fairborn |
| 53,851.612 | 0.450 | 42.2 | 0.2 | KPNO |

[a] 4500 Å region.

compute the radial velocity with the Doppler formula, and this velocity was corrected for the Earth's motion. The individual velocities were averaged and an rms value computed. Then velocities of individual lines that differed from the average by more than 2 times the rms value were rejected, and the remaining velocities were averaged. Typically, 5–10 velocities were eliminated in such a process, and the final rms values are about 1 km s$^{-1}$. Our unpublished velocities of several IAU standard stars, as well as two late-A or early-F reference stars from Fekel (1999), indicate that the Fairborn Observatory velocities have a small zero-point offset of −0.3 km s$^{-1}$ relative to the velocities of Scarfe et al. (1990).

## 3. ORBIT

To determine the orbital period of HR 1613, a sine curve was fitted to the KPNO velocities for trial periods between 1 and 20 days with a step size of 0.001 days. For each period the sum of the squared residuals was computed, and a period of 8.111 days, which had the smallest value of that sum, was identified as the preliminary value of the orbital period. With this period adopted, initial orbital elements were computed with BISP (Wolfe et al. 1967), a computer program that implements a slightly modified version of the Wilsing-Russell method. The orbit was then refined with SB1 (Barker et al. 1967), a program that uses differential corrections. An orbit for the 50 Fairborn Observatory AST radial velocities was similarly computed. Comparing the variances of the two solutions, we assigned unit weights to the velocities of both observatories. Then, after 0.3 km s$^{-1}$ was added to each Fairborn velocity, a combined orbital solution was obtained with SB1.

Since the eccentricity of that solution is so low, 0.0076 ± 0.0023, a circular-orbit solution was computed with SB1C

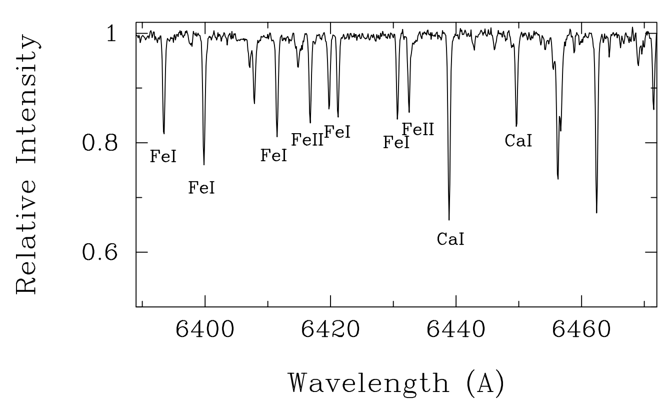


FIG. 1.—Spectrum of HR 1613 in the 6430 Å region. The element and ionization stage of several lines are identified. Compared to the blue region shown in Fig. 2, the lines in the red are weaker and predominantly from neutral species.

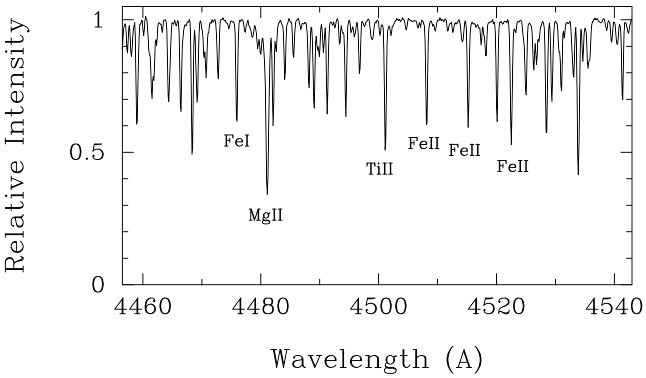


FIG. 2.—Spectrum of HR 1613 in the 4500 Å region. The element and ionization stage of several lines are identified.

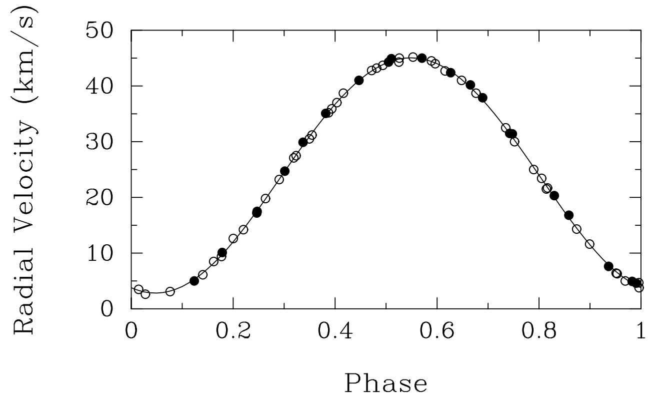


FIG. 3.—Computed radial velocity curve of HR 1613 compared with our KPNO and Fairborn Observatory radial velocities. Filled circles represent KPNO velocities, and open circles represent Fairborn velocities. Zero phase is a time of periastron passage.

(D. Barlow 1998, private communication), which also uses differential corrections to determine the elements. The tests of Lucy & Sweeney (1971) indicated that the eccentric-orbit solution is to be preferred, and so its elements, along with the mass funciton $f(m)$ and other parameters derived from the values of those elements, are given in Table 2.

Additional velocities of HR 1613 are available from three other sources. As noted earlier, Nordström & Andersen (1985) obtained three velocities of HR 1613. In addition, Grenier et al. (1999) acquired a single velocity, and Bikmaev et al. (2002) obtained two. We are uncertain of the zero points of the three velocity systems, so we included those six velocities in an orbital solution of our KPNO and Fairborn velocities but gave them zero weight. In that solution the velocities of Grenier et al. (1999) and Bikmaev et al. (2002) each had residuals of less than 0.5 km s$^{-1}$. However, the three velocities of Nordström & Andersen (1985) had an average residual of 1.5 km s$^{-1}$. Those three observations were obtained in 1974 and 1975, and so they extend our 5 yr baseline by a factor of 5. With the three velocities given weights of 0.25, the orbital period is reduced from 8.11128 to 8.11119 days, a difference slightly greater than the sum of the uncertainties of the two periods. Nevertheless, we have retained our KPNO and Fairborn solution because of the previously noted zero-point uncertainties in the older velocities.

The phases of our observations and the velocity residuals to the computed curve are included in Table 1. Our observed velocities and the computed velocity curve are compared in Figure 3, where zero phase is a time of periastron passage.

## 4. SPECTRAL TYPE AND $v \sin i$

Cowley et al. (1969) determined spectral classifications of about 1700 bright A stars using spectrograms with a dispersion of 125 Å mm$^{-1}$. In their survey they classified HR 1613 as A8 IV. More recently, Abt & Morrell (1995) included HR 1613 in a spectral classification survey of about 2000 mostly northern A-type stars listed in the Bright Star Catalogue (Hoffleit & Jaschek 1982). They noted that the higher dispersion of their spectrograms, 39 Å mm$^{-1}$, enabled them to see faint lines better and resulted in the detection of a significantly greater number of peculiar stars than Cowley et al. (1969) had found. Nevertheless, for HR 1613 Abt & Morrell (1995) detected no abundance peculiarities and determined a spectral type of A9 V, quite similar to that given by Cowley et al. (1969).

For HR 1613 Bikmaev et al. (2002) performed a spectroscopic abundance analysis of over 30 elements and found the star to have essentially solar abundances. In particular, both calcium and iron have solar abundances, confirming the classifications of Cowley et al. (1969) and Abt & Morrell (1995), who found no Am-star spectrum peculiarities. We adopt the spectral type of Abt & Morrell (1995).

Measurements of the projected rotational velocity of HR 1613 range from 9 to 15 km s$^{-1}$. Abt & Morrell (1995) found $v \sin i =$ 15 km s$^{-1}$ from measurement of two lines, the Fe I line at 4476 Å and the Mg II close doublet at 4481 Å. Royer et al. (2002) derived a value of 12 km s$^{-1}$ using the Fourier transform of several lines in the 4200–4500 Å region, while Bikmaev et al. (2002) determined $9 \pm 2$ km s$^{-1}$ from synthetic spectrum calculations. Finally, from several of our spectra Fekel (2003) determined $v \sin i = 12 \pm 1$ km s$^{-1}$. Averaging the latter three results, we adopt a value of 11 km s$^{-1}$.

TABLE 2
ORBITAL ELEMENTS OF HR 1613

| Parameter | Value |
|---|---|
| $P$ (days) | 8.111283 ± 0.000054 |
| $T$ (HJD) | 2,452,542.04 ± 0.41 |
| $\gamma$ (km s$^{-1}$) | 24.319 ± 0.035 |
| $K$ (km s$^{-1}$) | 21.109 ± 0.050 |
| $e$ | 0.0077 ± 0.0023 |
| $\omega$ (deg) | 165.1 ± 18.0 |
| $a \sin i$ (10$^6$ km) | 2.3544 ± 0.0055 |
| $f(m)$ ($M_\odot$) | 0.007922 ± 0.000056 |
| Standard error of an observation of unit weight (km s$^{-1}$) | 0.29 |

## 5. BASIC PROPERTIES

In agreement with Bikmaev et al. (2002), we detect only lines of the primary, component A, in our red-wavelength spectrograms, so the secondary, component B, is at least 2.5 mag fainter (Stockton & Fekel 1992). From the *Hipparcos* catalog (Perryman et al. 1997), the $V$ magnitude and $B - V$ color of HR 1613 are 6.31 and 0.293, respectively. Its *Hipparcos* parallax of 0\.″02017 ± 0\.″00087 (Perryman et al. 1997) corresponds to a distance of $49.6 \pm 2.2$ pc. Because HR 1613 is such a nearby star, we have assumed that it is unaffected by interstellar reddening. As a result, the parallax plus the $V$ magnitude produce an absolute magnitude $M_V = 2.8 \pm 0.1$ mag for the primary. We then used its $B - V$ color of 0.293 from *Hipparcos* (Perryman et al. 1997) in conjunction with Table 3 of Flower (1996) to obtain a bolometric correction of 0.035 mag and an effective temperature of 7251 K. This temperature is essentially identical to the value of 7250 K

TABLE 3
Fundamental Properties of HR 1613

| Parameter | Value | Reference |
|---|---|---|
| $V$ (mag) | 6.31 | 1 |
| $B - V$ (mag) | 0.293 | 1 |
| Parallax (arcsec) | 0.02017 ± 0.00087 | 1 |
| Spectral type of A | A9 V | 2 |
| Spectral type of B | K or M dwarf | 3 |
| $v_A \sin i$ (km s$^{-1}$) | 11 ± 1.0 | 3 |
| $M_v$(A) (mag) | 2.8 ± 0.1 | 3 |
| $L_A$ ($L_\odot$) | 5.7 ± 0.5 | 3 |
| $R_A$ ($R_\odot$) | 1.5 ± 0.1 | 3 |
| $M_A$ ($M_\odot$) | 1.5 | 3 |

References.—(1) Perryman et al. 1997; (2) Abt & Morrell 1995; (3) this work.

adopted for HR 1613 by Bikmaev et al. (2002) after computing values with several different methods. The resulting luminosity and radius of the primary are $L_A = 5.7 \pm 0.5\ L_\odot$ and $R_A = 1.5 \pm 0.1\ R_\odot$, respectively. The uncertainties in the computed quantities are dominated by the parallax and, to a lesser extent, the effective temperature, the latter having an estimated uncertainty of ±200 K. The above properties are summarized in Table 3.

Comparison with the solar-abundance evolutionary tracks of Girardi et al. (2000) places the primary close to the zero-age main sequence with a mass of 1.5 $M_\odot$ and an age of about 600 million years. These values are similar to those estimated by Bikmaev et al. (2002). The mass function value of 0.00792 $M_\odot$, an adopted mass of 1.5 $M_\odot$ for the primary, and an orbital inclination of 90° combine to produce a minimum mass of 0.29 $M_\odot$ for the secondary, resulting in a spectral type of about M4 V (Delfosse et al. 2000). Decreasing the inclination to 30° increases the mass of the secondary to 0.67 $M_\odot$, corresponding to a spectral type of K5 V (Gray 1992). Thus, component B is most likely a late-K or early-M dwarf.

## 6. PULSATION?

The $B - V$ color and computed value of $M_V$ put the A9 V primary of HR 1613 just inside the red edge of the instability strip for $\delta$ Sct variables, and the star is also in the region of the H-R diagram in which the $\gamma$ Dor pulsators (e.g., Henry et al. 2005) are found. Is there any evidence that HR 1613 has light variability? From 74 observations the *Hipparcos* team did not detect it as variable (Perryman et al. 1997). However, they cautioned that a star might have variability below the *Hipparcos* detectability threshold, which for HR 1613 is a peak-to-peak amplitude of ~0.015 mag (see Fig. 2.1.1 of Perryman et al. 1997). Since some $\delta$ Sct and $\gamma$ Dor stars have been found to have their largest peak-to-peak amplitudes below this threshold (e.g., Henry & Fekel 2002, 2003), it remains possible that HR 1613 is a low-amplitude pulsating variable. There has been no extensive ground-based search for light variability.

In $\gamma$ Dor and $\delta$ Sct variable stars, pulsation also produces line profile variations (e.g., Mathias et al. 2004). One such star, HR 6844, is a short-period, single-lined spectroscopic binary and a $\gamma$ Dor pulsator. Fekel & Henry (2003) found that a circular-orbit fit to the velocities of HR 6844 produced relatively large residuals. They showed that those residuals have a period that is identical to the pulsation period with the largest light amplitude. For their orbital solution of HR 6844 the standard error of an observation of unit weight is 1.4 km s$^{-1}$, over 4 times larger than that for HR 1613. The standard error of an observation of unit weight for HR 1613 (Table 2) is, instead, similar to the best values, 0.2–0.3 km s$^{-1}$, obtained for our solutions of late-type dwarfs (e.g., Fekel 2004; Fekel et al. 2004). Thus, we conclude that, unlike HR 6844, HR 1613 has no obvious excess velocity variability indicative of pulsation.

## 7. CIRCULARIZATION AND SYNCHRONIZATION

It is well known (e.g., Tassoul & Tassoul 1996) that tidal interactions affect the rotational and orbital characteristics of close binaries, causing them to tend toward a state in which the rotational axes of the components are parallel to the orbital axis and their rotational velocities are synchronized with the orbital period. In addition, tidal dissipation of energy causes a binary to circularize its orbit. Indeed, observational results indicate that many binaries partially or fully accomplish these feats. Two prominent theories have been developed to account for tidal friction in binary stars with radiative envelopes such as the primary of HR 1613. Zahn (1977) investigated the effects of radiative damping on synchronization and circularization, while Tassoul (1987, 1988) explored the theory that binary synchronization and circularization result from distortions that cause large-scale hydrodynamic currents. Both theories predict that synchronization will occur before circularization.

Observationally, Matthews & Mathieu (1992) examined 62 spectroscopic binaries with A-type primaries and periods less than 100 days. They concluded that all systems with orbital periods $\lesssim$3 days have circular or nearly circular orbits. They also found that many binaries with periods in the range of 3–10 days have circular orbits. With an eccentricity less than 0.01, the 8.11 day orbit of HR 1613 is essentially circular and so is quite consistent with these observational results.

To determine whether the primary might be synchronously rotating, we combined the orbital period and our derived radius of 1.5 ± 0.1 $R_\odot$ from Table 3 and computed a synchronous rotational velocity of 9.4 ± 0.6 km s$^{-1}$. Our adopted $v \sin i$ value of 11 ± 1 km s$^{-1}$ is slightly faster than the predicted synchronous velocity, but the rotational inclination is unknown. Reducing the rotational inclination from 90° to 60° produces a very modest increase in the equatorial rotational velocity, from 11 to 12.7 km s$^{-1}$. Thus, although the primary is rotating faster than synchronous, for high or moderate inclinations its rotational velocity is still not very far from its synchronous value.

## 8. DISCUSSION

Classical Am stars have spectral classes of A4–F1 (Abt & Morrell 1995), determined from their hydrogen lines. Those stars are noted as having peculiar spectra because lines of their metallic elements, such as iron and strontium, are stronger than expected compared to the hydrogen classification, while elements such as calcium and scandium are weaker (Abt & Morrell 1995).

Theoretically, Michaud et al. (1983) found that diffusion, which is thought to produce the Am peculiarities, should occur in Am stars with rotational velocities less than about 120 km s$^{-1}$. Abt & Morrell (1995) determined spectral types and projected rotational velocities for over 1700 bright, northern A-type stars. They found that virtually all Am stars have rotational velocities less than 120 km s$^{-1}$, in agreement with the prediction of Michaud et al. (1983), while normal A-type stars usually have rotational velocities greater than 120 km s$^{-1}$. This apparent dichotomy was not clear-cut, since about 10%–20% of the normal A stars have rotational velocities less than 120 km $s^{-1}$. Abt & Morrell (1995) and Abt (2000) argued that the overlap in rotational velocities is not real but that the apparently normal stars with rotational velocities less than 120 km $s^{-1}$ are likely undetected, marginally abnormal stars. Thus, Abt (2000) concluded from statistical arguments that rotation alone determines whether a star's spectrum has normal or abnormal abundance patterns.

The primary of HR 1613 appears to be unusual because it is an apparently slowly rotating star with normal abundances. While a low rotational velocity, caused by tidal friction, for a late-A star in an 8 day binary is not rare (Abt 2004), such a star with solar abundances, rather than the peculiar abundance pattern of an Am-type star, is exceptional.

Does HR 1613 really have a normal spectral type or have abundance peculiarities been missed? As discussed in § 4, Cowley et al. (1969), and in particular Abt & Morrell (1995), who obtained relatively high-dispersion spectrograms for their classification work, found no evidence of abundance peculiarities. Even more importantly, Bikmaev et al. (2002) carried out an extensive spectroscopic abundance analysis of about 30 elements that fully confirmed the two spectral classification results. Thus, the primary of HR 1613 has normal solar abundances.

Abt & Morrell (1995) pointed out that the process that produces Am stars is very rapid, since Am stars have been found among members of the Orion OB1 association (Smith 1972), which has an age of about 5 million years. Thus, it is not possible that HR 1613, with an estimated age of 600 million years, has simply not had time to produce the Am peculiarities. Abt & Morrell (1995) also noted that the Am star peculiarities are lost after a star leaves the main-sequence region, but the surface gravity log $g$ value determined by Bikmaev et al. (2002) and the comparison with evolutionary tracks in § 5 clearly indicate that the primary of HR 1613 is a main-sequence star. Therefore, it is not possible that HR 1613 once had Am-star abundance peculiarities but lost them in the course of its evolution.

If the abundances are normal, then the conundrum is solved if the primary of HR 1613 is not really rotating slowly. While it has a very low $v \sin i$ value of 11 km $s^{-1}$, since its rotational inclination is unknown we do not know whether its equatorial rotational velocity is truly low.

Perhaps the primary of HR 1613 is one of those rare stars that is spinning almost pole-on and so has an inclination near 0°. For example, with $v \sin i = 21.8 \pm 0.2$ km $s^{-1}$ (Gulliver et al. 1994) Vega appears to be a slowly rotating early-A star. But Gulliver et al. (1991) found that it has two distinct types of line profiles, normal and flat-bottomed. Computing synthetic spectra, Gulliver et al. (1994) were able to reproduce both types of line profiles for Vega. They concluded that it is a rapidly rotating star seen pole-on with the unusual flat-bottomed profile caused by a temperature gradient over the photosphere due to the rapid rotation of the star. They determined an equatorial velocity of $245 \pm 15$ km $s^{-1}$ and a rotational inclination of $5.^\circ1 \pm 0.^\circ3$. Assuming that the rotational inclinations of stars are randomly oriented, a star such as Vega with a 5° inclination would occur in about 0.4% of the cases.

As noted earlier, from the work of Abt & Morrell (1995) the maximum rotational velocity of an Am star is 120 km $s^{-1}$. If that were the value of the equatorial rotational velocity of HR 1613, then its rotational inclination would be $5.^\circ3$, which is identical to that of Vega. Thus, if HR 1613 were actually a rapidly rotating star seen nearly pole-on, its weaker lines might also show flat-bottomed profiles. In the same paper in which Bikmaev et al. (2002) determined the abundances of HR 1613 they also computed abundances for HR 1940. Although they noted that the spectral lines of HR 1940 often looked peculiar and had V-shaped profiles, which Bikmaev et al. (2002) suggested were caused by pulsation, they stated that the line profiles of HR 1613 appeared normal. If we suppose that HR 1613 actually has a rotational velocity of 120 km $s^{-1}$, it is possible that flat-bottomed profiles are not detectable in the spectrum of HR 1613 because its primary is rotating only half as rapidly as Vega, 120 versus 245 km $s^{-1}$, with the slower rotation resulting in a significantly smaller temperature gradient. Of course, since HR 1613 is *not* an Am star, the maximum rotational velocity is not limited to the value of 120 km $s^{-1}$ but could be larger. However, as we discuss below, we believe that the rotational velocity of HR 1613 is substantially less than 120 km $s^{-1}$.

Abt (2004) investigated tidal effects in binaries with B- and A-type primaries that are dwarfs or subgiants. One of his three subgroups consisted of A6–F0 dwarfs. For apparently single stars with such spectral types, he determined a mean projected rotational velocity of 99 km $s^{-1}$, compared with mean values of 20 and 35 km $s^{-1}$ for binaries with periods ranging from 4 to 8 days and from 8 to 32 days, respectively. The mean projected rotational velocities of the two binary groups are substantially lower than those of the single stars, indicating that the rotational velocities of the binaries have been significantly decreased by tidal interactions. This suggests that the primary of HR 1613, with its spectral type of A9 V and orbital period of 8.11 days, has also had its rotational velocity greatly reduced by tidal interactions.

The mass function (Table 2), combined with a mass of 1.5 $M_\odot$ for the primary from § 5, can be used to determine the orbital inclination for various adopted masses of the secondary. If the secondary has a mass of 1.1 $M_\odot$, corresponding to a spectral type of G0 V (Gray 1992), the orbital inclination is 20°. According to Gray (1992), the $V$-magnitude difference for stars with A9 V and G0 V spectral types is 1.9 mag. Stockton & Fekel (1992) showed that in red-wavelength spectra the lines of a secondary star that is 2.5 mag fainter than the primary can be detected. Thus, the absorption features of a putative 1.1 $M_\odot$ main-sequence star should have been easily seen in our spectra. Since no lines of a secondary were found, the orbital inclination is greater than 20°. If the orbital and rotational axes are parallel, a condition generally expected and assumed for close binary stars, then the rotational inclination is also greater than 20°. Such inclinations result in equatorial rotational velocities of 30 km $s^{-1}$ or less, far below the maximum value of 120 km $s^{-1}$ for Am star peculiarities to occur. Thus, we argue that the A9 V primary of HR 1613 really is a slowly rotating, short-period binary with normal abundances. We note that HR 6844 with a spectral type of F1 V (Gray & Garrison 1989; Abt & Morrell 1995) is also, although just barely, within the classical Am star area of the H-R diagram. It appears to be another slowly rotating, short-period binary that has normal abundances (Fekel & Henry 2003).

The 2 m AST at Fairborn Observatory, built almost single-handedly by J. Eaton, has begun its valuable contribution to science. We acknowledge the dream, dedication, and hard work of J. Eaton and the support provided by M. Busby and L. Boyd, who together made our observations with the 2 m AST possible. We thank the referee, I. Bikmaev, for a careful reading of our paper. This research at Tennessee State University has been supported in part by NASA grant NCC5-511 and NSF grant HRD-9706268.

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