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STUDY OF SPECTROSCOPIC BINARIES WITH TODCOR. II. THE HIGHLY ECCENTRIC BINARY HD 2909[1]

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ABSTRACT

TODCOR is a new two-dimensional correlation technique for analyzing observed spectra of double-lined spectroscopic binaries in order to extract the radial velocities of both components. In this paper we apply TODCOR for the first time to a real system—the highly eccentric binary HD 2909. TODCOR has derived successfully the velocities of the two components, even at phases when the velocity difference between the primary and the secondary was very small. We present an orbital solution which shows that HD 2909 is the second most eccentric spectroscopic binary known, with an eccentricity of 0.949 ± 0.002.

We discuss the tidal history of HD 2909 and show that neither the semimajor axis and the eccentricity of the orbit nor the stellar rotation have been changed by tidal interaction throughout the system lifetime.

Subject headings: binaries: spectroscopic — stars: individual (HD 2909) — stars: rotation

1. INTRODUCTION

In a recent paper (Zucker & Mazeh 1994, the first of this series), we intoduced TODCOR—a new technique for deriving the radial velocities of both components of double-lined spectroscopic binaries. TODCOR correlates an observed spectrum against a combination of *two* selected templates, calculating the correlation for all possible velocity shifts of the two templates. The velocity shifts for which maximum correlation is attained correspond to the velocities of the two stellar components. So far, we have demonstrated the potential of TODCOR with various simulations (Mazeh & Zucker 1992, 1994; Zucker & Mazeh 1994). The present paper is devoted to the analysis of a real double-lined system—HD 2909 (= BD + 27°82 = G69-1)—demonstrating TODCOR's utility.

HD 2909 is a high proper motion star, with $\mu = 0\farcs21$ yr^{-1} (see Carney et al. 1994, hereafter CLLA). It was therefore selected for the original Carney-Latham photometric and spectroscopic survey of high proper motion stars (Carney & Latham 1987). After a few years of monitoring the stellar radial velocity, we discovered that the star is a double-lined spectroscopic binary, with a period of a few years and a *very high eccentricity*. We therefore monitored the stellar velocity carefully, in order to catch the fast motion of the two components through the orbital periastron passage. This was done by solving the orbital parameters for the data as they were being accumulated, predicting the next periastron passage, and adopting an observational strategy accordingly. In 1993 November we monitored the most recent passage, as a result of which we now have in hand good coverage of all orbital phases. Utilizing TODCOR and the complete phase coverage, we have derived a double-lined orbital solution. The observations and the analysis are reported in § 2.

The orbital solution yields an eccentricity of 0.949 ± 0.002. This value is second only to the highest eccentricity known for a spectroscopic binary: 0.9752 ± 0.0003, which was recently found by Duquennoy et al. (1992) for Gl 586A. The discovery of the high eccentricities of Gl 586A and HD 2909 raises some interesting questions with regard to the tidal evolution of such systems. These questions and the tidal history of HD 2909 are discussed in § 3, where we show that the tidal interaction of HD 2909 has not been strong enough to produce any substantial change of its orbit. In the last section our work is briefly discussed.

2. OBSERVATIONS, ANALYSIS, AND RESULTS

The radial velocity observations were made with the Digital Speedometers (Latham 1985, 1992) operated by the Center for Astrophysics (CfA), mainly with the 1.5 m Wyeth Reflector at the Oak Ridge Observatory in Harvard, MA, and occasionally with the 1.5 m Tillinghast Reflector at the Whipple Observatory and the Multiple Mirror Telescope, both on Mount Hopkins, AZ. Alltogether, we have secured 110 spectra of HD 2909, spanning over 3000 days.

To derive the radial velocity of the two components of HD 2909, each observed spectrum was correlated with TODCOR against a combination of *two* selected templates. We selected the templates out of a library of synthetic spectra calculated from a new grid of Kurucz model atmospheres (Kurucz 1992a, b), derived by Jon Morse (see Nordström et al. 1994) following the precepts of Carney et al. (1987). CLLA derived the effective temperature and metallicity for HD 2909 using the stellar colors ($B-V = 0.65$ and $U-B = 0.08$) and a metallicity analysis of the CfA spectra and found $T_{\rm eff} = 5438$ K and $[{\rm m/H}] = -0.65$. The estimation of metallicities for double-lined systems is difficult, but CLLA have shown that when the velocities of the primary and the secondary overlap, the enhanced strengths of the absorption lines are matched to a good degree by the redder colors for the combined light. Since cooler temperatures tend to produce stronger lines, the effects compensate, and CLLA estimate that they can derive mean metallicities to an internal precision of 0.1–0.2 dex. For the

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[1] Some of the observations reported here were obtained with the Multiple Mirror Telescope, a joint facility of the Smithsonian Institution and the University of Arizona.

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primary template we chose the closest synthetic spectrum from our library, $T_{\rm eff} = 5500$ K and [m/H] = -0.5. Essentially all the stars in the Carney-Latham proper-motion survey are dwarfs, so we adopted $\log g = 4.5$.

The second template was more difficult to estimate, as it is less evident in the observed colors of the system. We chose the secondary template in two stages: The first, coarse stage consisted of searching for a secondary template which would yield, in combination with the primary template, the highest correlation against the best observed spectra of HD 2909. In the second, fine stage we searched for the template which would yield radial velocities with the best fit to the double-lined orbital solution. We chose for the secondary of HD 2909 a spectrum calculated for a temperature of 5000 K, and we assumed the metallicity and gravity of the primary. The temperature choice is supported by the mass ratio of the system derived from the orbital solution (see below), which indeed implies a temperature of 5000 K for the secondary.

Another parameter to choose for the two templates was the stellar rotation. It turned out that the highest values of the correlation were attained when the templates had low $V_{\rm rot} \sin i$, of the order of a few km s^{-1}. The best fit to the orbital solution was reached with a stellar rotation of 4 km s^{-1} for both the primary and the secondary. The last parameter to be chosen for the analysis was the relative brightness of the two components. We found that when the luminosity of the secondary template was 0.6 of that of the primary template, we obtained the best fit. This value is consistent with the mass ratio found in the orbital solution, as explained below. The two synthetic templates are plotted in Figure 1.

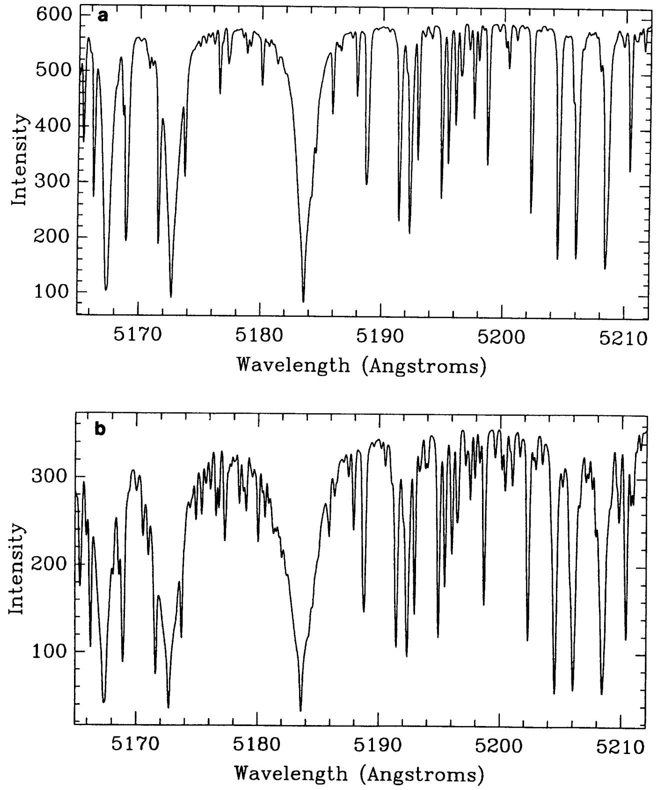

FIG. 1.—Calculated spectra used as templates in the analysis. (*a*) $T = 5500$, [m/H] = -0.5, $\log g = 4.5$, $V_{\rm rot} \sin i = 4$ km s^{-1}. (*b*) $T = 5000$, [m/H] = -0.5, $\log g = 4.5$. $V_{\rm rot} \sin i = 4$ km s^{-1}.

In highly eccentric binaries, the velocity difference between the two components is small for most of the orbital phases; hence, many of the observations of HD 2909 were obtained when the difference between the velocities of the primary and the secondary was quite small relative to the width of the lines of the two components. In such cases, the original one-dimensional correlation technique (e.g., Tonry & Davis 1979; Wyatt 1985; Kurtz et al. 1992) could not resolve the two sets of lines. To demonstrate this point, we show in Figure 2 two different spectra of HD 2909—(*a*) case A, observed on JD 2,447,188.50, when the velocity difference was relatively large, and (*b*) case B, observed on JD 2,448,645.57, when the velocity difference was small (so the major lines appear narrow). In Figure 3 we present the *one-dimensional* correlations for both spectra against the primary synthetic template, showing that this correlation technique was easily able to extract the two velocities in the first case, while it was not able to derive either of the two velocities in the second case.

To demonstrate the advantage of TODCOR, we show in Figures 4 and 5 the results of its application to the more demanding spectrum of Figure 2*b*, the one with the small velocity difference between the two components. Figure 4 shows the contour map of the two-dimensional correlation, where a clear maximum can be seen. The velocities corresponding to the peak of the correlation are 1.71 and -2.81 km s^{-1} for the primary and secondary, respectively. To estimate the success of TODCOR, we note that the calculated velocities of this spectrum, based on the derived orbital solution, are 1.97 and -3.55, respectively. Figure 4 indicates a steep decrease from the maximum as a function of the primary velocity, and only a very moderate slope along the secondary velocity. This is due to the fact that the secondary contributes only about

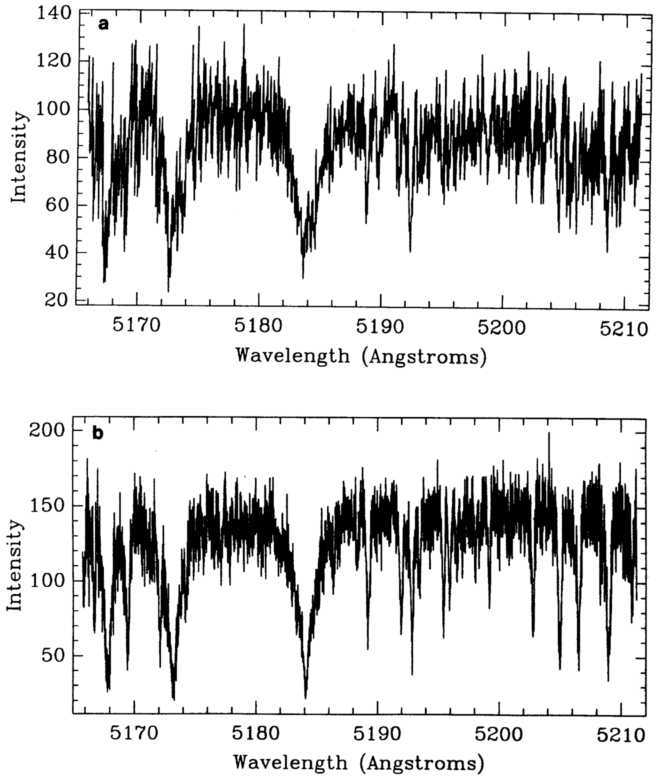

FIG. 2.—Two typical spectra of HD 2909

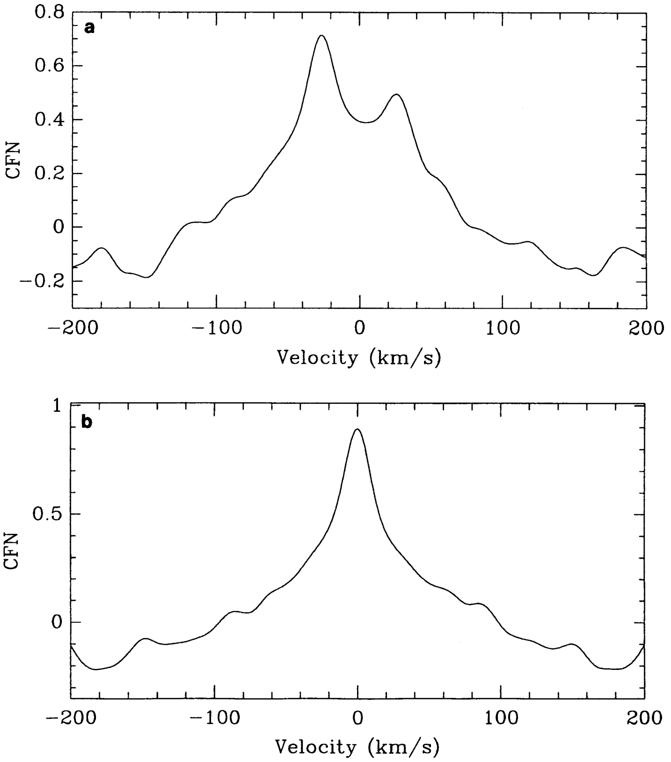

FIG. 3.—One-dimensional correlations of the spectra of Fig. 2, using template (*a*) of Fig. 1. The two velocities can be resolved in (*a*) but *cannot* be resolved in (*b*).

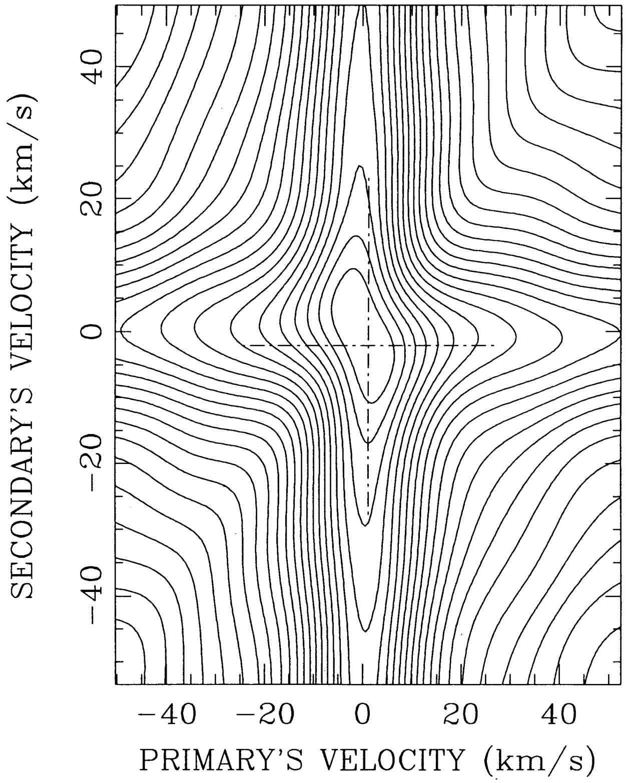

FIG. 4.—Contour map of the two-dimensional correlation of spectrum (*b*) of Fig. 2, where the one-dimensional correlation could not resolve the two velocities. The templates used are those of Fig. 1. The correlation maximum is clearly seen. The location of the peak indicates that the primary velocity is positive while the secondary velocity is negative.

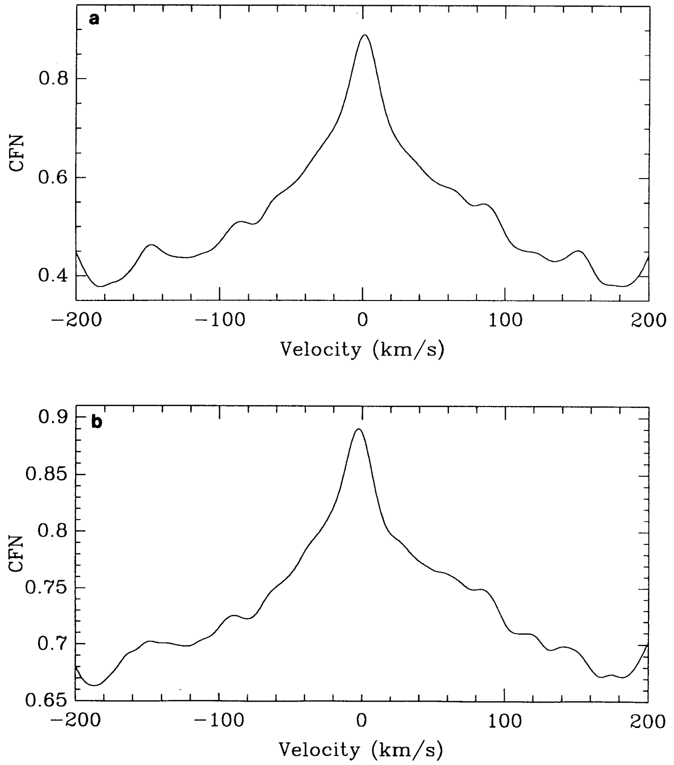

FIG. 5.—Cross sections of the two-dimensional correlation function, taken at the maximum. The observed spectrum and the templates are the same as in Fig. 4. (*a*) Cross section taken parallel to the primary's velocity axis; (*b*) cross section taken parallel to the secondary's velocity axis. The velocity difference between the primary and the secondary is clearly seen.

one-third of the light of the observed spectrum. Figure 5 shows the one-dimensional cuts of the two-dimensional function. The peaks of Figures 5*a* and 5*b* correspond to the primary and secondary velocities; the velocity difference, although small, can be seen clearly.

The derived velocities and the times of observation of all spectra are given in Table 1. To solve for the orbital motion of HD 2909 we use ORB18 (Mazeh, Krymolowski, & Latham 1993), a code which takes special care to find the global minimum of the χ^2 statistic in the parameter space, an important feature for highly eccentric orbits. To estimate the precision of the derived orbital parameters, we assumed that all velocities of the primary have the same uncertainty, the value of which was found by ORB18 from the averaged residuals of the primary velocities. The same goes for the uncertainty of the secondary velocities, which we allowed to be different from that of the primary, because of the different templates and brightness of the two components. The elements of the double-lined solution of HD 2909 are given in Table 2. The derived solution, together with the radial velocities of both components, are plotted in Figure 6 as a function of the orbital phase.

In order to check that there is no systematic difference between the primary's velocities and those of the secondary, we solved each component as a single-lined binary. We found that the elements of both orbits are similar to each other and are the same as the double-lined solution, within the estimated errors.

It is gratifying to see that TODCOR could indeed extract the two velocities of HD 2909, even for cases where the difference between the two was very small. This is so despite two

TABLE 1

Derived Radial Velocities of HD 2909

HJD (−2,440,000)	V_1 (km s^{-1})	V_2 (km s^{-1})	HJD (−2,440,000)	V_1 (km s^{-1})	V_2 (km s^{-1})
5,934.851……	−2.8	−0.6	7,879.531……	−2.6	1.6
5,953.720……	−3.0	3.4	7,895.510……	−2.9	1.5
6,005.626……	−3.7	5.0	7,910.474……	−3.1	0.0
6,279.821……	3.8	−2.0	7,922.460……	−3.3	3.2
6,306.730……	0.7	−0.9	7,941.462……	−2.6	−1.3
6,337.803……	4.0	−2.9	8,078.819……	−3.3	0.1
6,627.853……	5.3	−2.3	8,087.850……	−2.5	0.9
6,662.812……	2.5	−4.8	8,088.846……	−1.8	0.6
7,019.691……	8.5	−10.4	8,101.799……	−0.6	0.0
7,040.809……	9.4	−10.5	8,138.851……	−0.1	−0.8
7,069.691……	9.5	−12.7	8,143.858……	−1.3	−1.1
7,094.646……	11.4	−14.3	8,167.772……	−1.5	−2.8
7,104.708……	10.1	−13.6	8,194.768……	0.8	−2.1
7,114.653……	12.8	−14.6	8,221.496……	−1.1	−1.7
7,128.431……	14.6	−15.5	8,235.606……	−0.5	−0.6
7,139.634……	16.0	−18.2	8,259.510……	−1.1	0.8
7,141.616……	14.9	−18.7	8,267.494……	−0.1	−2.2
7,157.451……	18.6	−21.1	8,284.575……	−0.5	0.1
7,171.588……	23.6	−23.3	8,285.568……	0.5	−2.2
7,185.454……	−25.8	28.6	8,287.576……	−0.4	−0.3
7,188.496……	−26.7	26.6	8,290.566……	−0.7	−1.4
7,198.458……	−22.0	25.2	8,465.858……	2.6	−1.2
7,227.499……	−16.2	16.6	8,469.831……	2.9	−2.5
7,344.950……	−10.5	7.6	8,482.840……	1.7	−4.0
7,368.829……	−9.1	8.1	8,502.880……	−0.7	−0.1
7,369.978……	−10.3	7.0	8,526.877……	0.5	−2.4
7,375.860……	−9.0	8.9	8,577.581……	0.2	−2.4
7,395.812……	−9.0	7.3	8,605.587……	1.9	−2.2
7,407.716……	−8.0	7.7	8,617.574……	1.7	−2.0
7,421.783……	−8.2	5.4	8,638.570……	1.0	−3.1
7,433.723……	−8.3	5.4	8,645.568……	1.7	−2.8
7,459.689……	−7.1	4.9	8,839.828……	6.0	−1.9
7,464.607……	−7.4	6.0	8,847.710……	3.1	−5.2
7,480.575……	−7.1	5.2	8,867.763……	3.0	−4.8
7,491.605……	−6.4	6.6	8,898.802……	4.6	−4.4
7,511.528……	−6.7	5.5	8,966.517……	4.7	−7.2
7,521.502……	−6.9	4.6	8,971.543……	5.3	−7.4
7,541.445……	−6.5	3.4	9,016.451……	5.8	−7.0
7,552.449……	−6.9	3.5	9,175.954……	9.5	−10.9
7,568.454……	−6.6	4.9	9,195.984……	8.6	−13.2
7,576.466……	−5.7	4.0	9,259.711……	13.7	−17.8
7,692.976……	−4.5	3.0	9,271.727……	15.3	−18.4
7,700.982……	−3.7	2.7	9,290.803……	20.3	−21.1
7,720.824……	−6.9	1.2	9,310.616……	−20.4	21.6
7,731.864……	−5.1	4.5	9,312.595……	−26.9	25.3
7,747.771……	−4.7	2.7	9,314.596……	−27.6	27.0
7,779.767……	−3.9	2.0	9,314.673……	−26.2	30.2
7,783.613……	−4.0	2.7	9,317.644……	−27.3	26.8
7,803.617……	−4.0	2.4	9,318.615……	−24.6	27.7
7,811.747……	−3.4	1.7	9,318.649……	−26.2	27.0
7,821.697……	−3.8	1.7	9,322.508……	−25.0	24.3
7,830.652……	−3.6	−0.3	9,324.677……	−22.6	26.3
7,848.546……	−3.1	1.1	9,325.607……	−22.8	23.2
7,854.537……	−2.2	0.8	9,325.622……	−23.4	23.6
7,864.564……	−3.5	2.1	9,330.518……	−22.0	21.4

features of this particular system which made the analysis more difficult. One feature has to be with the fact that the two templates differ only moderately in the observed spectral region, as can be seen in Figure 1. The other feature is the low S/N of some spectra, a few of which had S/N as low as 9:1 per resolution element. This implies a S/N of about 3:1 for the secondary, which contributes only one-third of the combined light. Nevertheless, TODCOR was able to derive velocities which are close to the calculated ones for all but one or two spectra, as can be seen from Figure 6.

From the orbital solution we find that the mass ratio of the system and the orbital inclination are

$$q = 0.936 \pm 0.026 \quad \text{and} \quad \sin i = (0.78 \pm 0.02) M_1^{-1/3} ,$$

where M_1 is the primary mass in units of solar masses. CLLA estimated the primary mass to be about 0.7 $M_\odot$, implying $\sin i \simeq 0.7$. Given the primary temperature and age, the derived mass ratio can be used to estimate the secondary temperature and relative brightness. As noted by CLLA, the 16 Gyr isochrones of VandenBerg & Bell (1985) indicate that, on average,

TABLE 2

ORBITAL ELEMENTS OF HD 2909

Element	Value
P (days)	2127.8 ± 0.8
γ (km s^{-1})	-0.70 ± 0.08
K_1 (km s^{-1})	24.7 ± 0.5
K_2 (km s^{-1})	26.4 ± 0.5
e	0.949 ± 0.002
ω (degrees)	94.7 ± 0.9
T (JD $-2,440,000$)	9308.3 ± 0.2
$a_1 \sin i$ (10^9 m)	228 ± 6
$a_2 \sin i$ (10^9 m)	244 ± 7
$M_1 \sin^3 i$ ($M_\odot$)	0.48 ± 0.04
$M_2 \sin^3 i$ ($M_\odot$)	0.45 ± 0.03
σ_1 (km s^{-1})	1.0
σ_2 (km s^{-1})	1.2
N	110

$L_\lambda \propto M^x$. For the V bandpass, $x \approx 8.3$, while for the B bandpass, $x \approx 9.8$, with a weak dependence of x on metallicity and age. At fixed age, the more metal-rich isochrones have shallower slopes in the relation, so x is smaller. At fixed metallicity, smaller ages also result in shallower slopes. Ignoring these hard-to-measure and secondary effects, the value of x at 5200 Å should be around 8.5. For a mass ratio of 0.935, the secondary-to-primary luminosity ratio would then be $0.935^{8.5}$, or 0.56, very close to the value found by our procedure. The temperature implied by these same isochrones would be about 5000 K, consistent with the temperature of the secondary template that gave the best correlation with TODCOR.

CLLA were not able to estimate the distance to HD 2909 since its mass ratio was not known when their paper was accepted for publication. According to the CLLA methodology, the q-value derived here yields a distance estimate of 61 pc. Combining this with the stellar proper motion and the system's mean radial velocity results in Galactic velocity vectors of $U = +45$, $V = -3$, and $W = +23$ km s^{-1}. The star thus appears to belong to the disk population, in spite of its rather low metallicity.

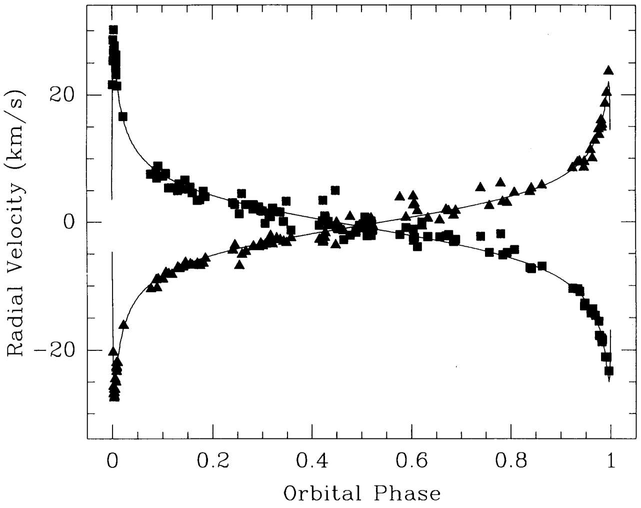

FIG. 6.—Orbital solution of HD 2909 as a function of the orbital phase. The triangles present the derived velocities of the primary, and the squares present the secondary velocities. The two continuous lines display the calculated radial velocity of both components.

3. TIDAL HISTORY OF HD 2909

The orbital eccentricity of HD 2909, 0.949 ± 0.002, is one of the highest values known for spectroscopic binaries. Ten years ago Griffin (1984; see also Griffin 1987) published an orbit for HD 210647 that had the highest eccentricity then known for a spectroscopic orbit, 0.904. In that paper he enumerated some of the practical difficulties militating against the discovery of spectroscopic binaries with very eccentric orbits. The eccentricity reported here for HD 2909, 0.949 ± 0.002, is now second only to the eccentricity of Gl 586A, 0.9852 ± 0.0003, that was found recently by Duquennoy et al. (1992). Those authors were concerned by the apparently impossible tidal history of such highly eccentric binaries. They pointed out that the primordial eccentricity of Gl 586A was probably even higher than the present value because tidal interaction tends to circularize the binary orbit throughout its lifetime. This is true despite the long orbital period of Gl 586A, 890 days, which implies quite a large average distance between the two stars. The tidal interaction was nevertheless effective enough in the case of Gl 586A, because the high eccentricity brings the two components close enough to strongly spur the tidal evolution. Duquennoy et al. therefore conjectured that the primordial periastron distance of Gl 586A was probably smaller than the present one and, if true, this would not have left enough room to accommodate the two main-sequence stars, let alone their pre–main-sequence progenitors. Similar concerns apply to any highly eccentric binary.

The seminal work of Duquennoy et al. (1992) inspired a theoretical study (Goldman & Mazeh 1994) of the tidal evolution of highly eccentric binaries. Goldman & Mazeh were able to show that under some reasonable assumptions, the semimajor axis of the orbit decreases on a timescale much shorter than does the eccentricity, while the periastron distance remains constant. If this is true, the primordial periastron distance was the same as the present one, and therefore there has always been enough room to accommodate the two stars.

Goldman & Mazeh (1994) also pointed out that the fast decrease of the semimajor axis through tidal evolution might nonetheless pose a new problem for the tidal theory of highly eccentric binaries. A very large primordial semimajor axis renders the binary unstable to tidal disruption by passing objects and the tidal force of the Galaxy. Their estimate of the primordial semimajor axis depends on the binary age and on the theory of turbulent viscosity. The latter dependence comes from the fact that the shear induced by the tidal interaction between the two components varies in some of the highly eccentric binaries on a timescale shorter than the convective timescale. As a result, the turbulent viscosity could be reduced, by an amount depending on the preferred theoretical approach (Zahn 1977, 1989, 1992; Goldman & Mazeh 1991, 1992). Goldman & Mazeh (1994) exploited this fact to suggest a new test for the different theories of viscosity reduction. They recommended a study of highly eccentric binaries and an estimation of the primordial semimajor axis for each system according to the different theoretical viscosity prescriptions. A theory which implies a primordial semimajor axis implausibly large could be discarded.

To see whether this test might be applied to HD 2909, we calculate the tidal shear timescale of this system and compare it to the convective timescale. The angular velocity at periastron in highly eccentric orbits is

$$\omega_p = \sqrt{2}(1 - e)^{-3/2}\omega \, ,$$

where e is the binary eccentricity and ω is the averaged angular velocity of the orbital motion. Goldman & Mazeh (1994) estimated the shear timescale for highly eccentric orbits to be $\sim 2/\omega_p$, which implies for an orbital period of 2125 days and an eccentricity of 0.95 a timescale of 5 days. This is only marginally smaller than the estimated convective timescale of 20 days for solar-type stars (Goldman & Mazeh 1991), as the latter is only an order-of-magnitude estimation.

To apply the proposed test to HD 2909, we use the Goldman & Mazeh (1994) equation for the timescale of evolution of the orbital semimajor axis, which can be approximated as

$$T_a \sim 5\eta^{-1} T_0 (P/P_0)^{16/3} (1-e)^{15/2} .$$

The factor η^{-1} depends on the theory of viscosity. It equals unity for nonreduced viscosity and increases for greater reductions. P is the binary period, and T_0 and P_0 are constants of the theory of tidal circularization. Using the values of 2×10^{10} yr and 20 days for T_0 and P_0, respectively (Goldman & Mazeh 1994), and the orbital parameters of HD 2909, we find that T_a is longer than the Hubble time. This is true even for the theory for which no reduction is assumed. We therefore conclude that the semimajor axis of HD 2909 has not changed substantially during the lifetime of the system. The orbital eccentricity has not changed either, as its timescale for tidal evolution is longer than that of the semimajor axis. Thus, the tidal orbital evolution of HD 2909 cannot help us to distinguish between the different viscosity theories.

Another test suggested by Goldman & Mazeh (1994) is associated with the rotation of the two stellar components. It is expected that in some eccentric binaries the stellar rotation would be pseudosynchronized with the orbital angular velocity at periastron (Hut 1981). The expected pseudosynchronization timescale depends again on the different theories of viscosity. If the stellar rotation can be measured and the age of the system can be estimated, the state of pseudosynchronization of the system may be compared with the predictions of the different theories.

To estimate the pseudosynchronization timescale for HD 2909 we use Goldman & Mazeh equations and find

$$T_{\rm ps} \sim \eta^{-1} \times 10^{10} \text{ yr} .$$

This estimate of the pseudosynchronization timescale is probably not shorter than the age of the system, even if η^{-1} is unity. For the other theories of viscosity, if indeed the viscosity in HD 2909 is reduced and η^{-1} is larger than unity, the pseudosynchronization timescale is even longer. We therefore conclude that all three theories predict that HD 2909 is not pseudosynchronized.

The pseudosynchronized stellar rotation period (Hut 1981; Goldman & Mazeh 1994) of HD 2909 is about 20 days. This yields a rotational velocity of somewhat less than 2 km s^{-1}, if the stellar radius is 0.7 $R_\odot$. Assuming alignment between the stellar rotation and the orbital revolution, and using the orbital inclination derived in the previous section, we obtain $V_{\rm rot} \sin i \simeq 1$ km s^{-1}. In our analysis we found that the best fit to the orbital solution is attained when we used $V_{\rm rot} \sin i$ of 4 km s^{-1} for both templates. This is a very crude estimate of the stellar rotation; nevertheless, it indicates that HD 2909 probably has not yet reached pseudosynchronization.

4. DISCUSSION

We have demonstrated the ability of TODCOR to extract the radial velocity of both components of a double-lined spectroscopic binary, even when the velocity difference between the primary and the secondary is small, even when the spectra of the two components are similar, and even for low-S/N observed spectra. This has been done here for HD 2909, a binary for which the secondary emits about half of the visual luminosity of the primary and is only slightly cooler. Those features of TODCOR enable us to derive the two velocities for most of the observed spectra, rendering the use of telescope time more efficient.

In principle, TODCOR can turn many single-lined binaries into double-lined binaries, even if the secondary is much fainter than the primary. In such systems, the secondary spectrum is likely to differ from the primary. Consequently, the correlation of the observed spectra with a combination of two *different* templates is highly advantageous, to the measurement of the radial velocity of the secondary in particular. TODCOR will find even greater application to high-resolution infrared spectra, where the flux difference between main-sequence stars with very different temperatures will be diminished (Mazeh & Zucker 1994). For example, a Hyades dwarf with solar temperature will have $V \approx 7.9$ and $V-K \approx 1.5$ (Carney 1982). A fainter dwarf, say 4 mag fainter at V, will be only 1.9 mag fainter at H or at K.

The measurement of the radial velocity of the secondary is important for understanding the nature of the unseen companion. It is crucial, for example, in the study of eclipsing binaries, where the inclination angles are known from the observed light curves. Using the radial velocities of the two components, we can estimate directly the masses and the absolute dimensions of both components (e.g., Maxted, Hill, & Hilditch 1994; Andersen, Clausen, & Gimenez 1991). Measuring the radial velocity of the secondaries is also important to the study of the mass-ratio distribution of short-period binaries and of the mass distribution of the secondaries (Mazeh & Goldberg 1992; Mazeh et al. 1992; Goldberg & Mazeh 1994).

The templates used in the correlation procedure were calculated with the Kurucz (1992a, b) models and therefore might differ from the real underlying spectrum. One way to improve our procedure might be to derive the templates directly from the observed spectra, using a tomography technique (Bagnuolo & Gies 1991; Hill & Khalesseh 1993) or the singular-value decomposition technique suggested by Simon & Sturm (1994). However, both techniques require an estimate of the velocities of the two components, which might be accomplished using TODCOR in the first step of the analysis. Iteration involving alternating applications of TODCOR and tomography may improve the results, but is deferred to a later study.

HD 2909 is the second system discovered recently with a highly eccentric orbit. The discovery of the high eccentricities of both HD 2909 and Gl 586A (Duquennoy et al. 1992) was possible because of the long operation of the very precise and stable stellar radial velocity spectrometers operated by the CfA and the Geneva Observatory. These binaries are difficult to detect and then difficult to obtain the orbital elements for, because of their necessarily long periods and their very small acceleration through most of the orbital period. Indeed, the two components in both systems have nearly equal masses and large inclinations, which made their discovery somewhat easier. It is too early to speculate on the frequency of highly eccentric orbits, but we certainly expect more systems of this kind to be discovered in the future if the monitoring of the radial velocity of large samples of stars continues. Applying TODCOR to digitized spectra can enhance the effectiveness of such large systematic studies.

The extremely small but growing group of highly eccentric binaries gives us a rare opportunity to study the tidal interaction of stars near periastron passage, where the tidal forces vary on short timescales. Such an environment raises interesting astrophysical questions about such matters as viscosity reduction, tidal evolution of the semimajor axis, and pseudosynchronization. When enough of these systems have been detected, we may also study the true eccentricity distribution of binaries and possibly learn more about binary formation.

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