THE ASTROPHYSICAL JOURNAL, **310**:354–359, 1986 November 1

THE ORBIT AND PROPERTIES OF THE HD 149162 SYSTEM

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Received 1985 August 22; accepted 1986 April 14

ABSTRACT

HD 149162 is classified photometrically single and SB1 except for Hα emission that departs widely from the radial velocity of the K0 dwarf. Ca II H and K and Mg II *h* and *k* also show emission components at low dispersion. The system is X-ray luminous although ostensibly old disk and a slow K dwarf rotator. The orbit and other observations lead to a secondary that is composed of a dMe star and a cool white dwarf or a pair of dM and dMe stars. Further observations of the emission lines should ultimately define the triple system.
Subject headings: stars: binaries — stars: individual — stars: late-type — ultraviolet: spectra

I. INTRODUCTION

A variety of connected observations made between 1981 and 1985 show that this spectroscopic binary or triple has very unusual properties despite the almost normal primary. It had been classified K0 with the photometric magnitude 9.1 in the Henry Draper catalog, dK0 by Joy (1947), and K1 by Kuiper in Jenkins (1963). By request Houk (1984) determined a preliminary type of K0 Vp from an objective prism survey plate. She noticed a peculiarity consisting of emission cores barely discernible in the strong but somewhat filled-in Ca II H and K lines. The absolute trigonometric parallax is 0″.038 ± 0″.007 p.e. (Jenkins 1963) or 0″.041 ± 0″.007 p.e. with different reduction precepts (Woolley *et al.* 1970). A preliminary revision to 0″.0436 ± 0″.0095 s.d. has been provided by van Altena (1984). Joy (1947) selected the star for radial velocity observations on the basis of rather large proper motion (0″.40 yr^{-1}), obtained a mean heliocentric velocity of -58 km s^{-1} from five plates, and called the star a spectroscopic binary with a range from -76 km s^{-1} to -39 km s^{-1}. HD 149162 is kinematically an old disk SB1 system.

We have made an X-ray observation with the *Einstein Observatory* imaging proportional counter (IPC) and an ultraviolet spectrographic observation with the *IUE* (Johnson 1983*a*). Subsequent Geneva CORAVEL observations and orbit have been briefly presented (Johnson and Mayor 1984). At our request Grenon (1984) made a Geneva photometric evaluation of the system, and we have obtained the first high-resolution spectrograms of the Hα region. All of the data acquired since 1981 are essential for a discussion of the system, and further observations are needed to decide whether the optically invisible secondary is a white dwarf and red dwarf close pair, and whether the X-rays originate entirely in the corona of the K0 dwarf or perhaps mostly elsewhere in the system.

II. OBSERVATIONS AND INTERPRETATIONS

a) The CORAVEL Orbit

Radial-velocity observations have been obtained with the scanner CORAVEL (Baranne, Mayor, and Poncet 1979; Mayor 1985) mounted on the 1 m Swiss telescope at Haute-Provence Observatory. This echelle grating spectrograph realizes the cross-correlation of the stellar spectrum and a mask located in the focal surface. About 1500 absorption lines are simultaneously used to derive the velocity. The wavelength coverage is from 3600 Å to 5200 Å with a mean dispersion of 2 Å mm^{-1}. For HD 149162 only 2 or 3 min are needed to derive one radial velocity measurement.

CORAVEL radial-velocity observations were started in 1983 and completed in 1984 to provide a good distribution through the phases of the first orbit of 1983. The heliocentric radial velocity v_r data appear in Table 1 as a function of ϕ in the final orbit, together with the uncertainty ϵ of each measure-

TABLE 1

CORAVEL RADIAL VELOCITY OBSERVATIONS OF HD 149162

Phase ϕ	Julian Date	v_r (km s^{-1})	ϵ (km s^{-1})	$O-C$ (km s^{-1})
0.010.........	5735.739	−22.82	0.16	+0.19
0.047.........	5518.398	−29.07	0.19	−0.09
0.100.........	5530.390	−40.27	0.30	+0.16
0.134.........	5763.675	−47.57	0.27	−0.23
0.170.........	5771.671	−53.51	0.20	−0.04
0.198.........	5552.385	−57.57	0.20	−0.11
0.242.........	5562.354	−62.01	0.28	+0.20
0.322.........	5580.318	−67.07	0.20	+0.15
0.348.........	5586.304	−68.08	0.21	+0.02
0.413.........	5826.498	−69.09	0.28	−0.09
0.585.........	5865.446	−64.53	0.31	−0.05
0.672.........	5433.609	−58.60	0.13	−0.09
0.685.........	5436.606	−57.45	0.19	−0.11
0.703.........	5440.614	−55.52	0.15	+0.13
0.718.........	5895.446	−54.16	0.17	−0.10
0.749.........	5902.402	−50.59	0.23	−0.04
0.776.........	5908.400	−47.08	0.23	+0.05
0.804.........	5463.536	−42.79	0.15	+0.26
0.862.........	5476.510	−33.67	0.19	+0.15
0.902.........	5485.533	−27.65	0.22	−0.32
0.979.........	5728.744	−20.92	0.19	−0.02

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[1] X-ray data have been obtained with the *Einstein Observatory* and ultraviolet data with the *International Ultraviolet Explorer* (*IUE*).

[2] 1985 March 22 coudé-feed data have been obtained under the Observing Service Program of the Kitt Peak National Observatory, National Optical Astronomy Observatories, operated by the Association for Research in Astronomy, Inc., under contract with the National Science Foundation.

[3] Radial velocities have been obtained at the Haute-Provence Observatory.

ment, the observed less the calculated velocity in the orbit, $O-C$, and the Julian Date (modulo 2,440,000). These velocities are in the system defined by the faint IAU standard stars. The final orbit elements are listed below.

$$P = 225.7 \pm 0.1 \text{ days};$$
$$T = 5282.1 \pm 0.3 \text{ (periastron)};$$
$$e = 0.282 \pm 0.002;$$
$$v_0 = -51.4 \pm 0.1 \text{ km s}^{-1};$$
$$\omega = 17\overset{\circ}{.}6 \pm 0\overset{\circ}{.}5;$$
$$k_1 = 24.1 \pm 0.1 \text{ km s}^{-1};$$
$$\sigma_{O-C} = \pm 0.17 \text{ km s}^{-1};$$
$$a_1 \sin i = (71.7 \pm 0.3) \times 10^6 \text{ km};$$
$$f_1(M) = 0.289 \pm 0.003.$$

Radial-velocity measurements and the fitted orbit are illustrated in Figure 1. The extremely small residues, σ_{O-C}, appear to exclude orbital dissymmetries that might be induced by the secondary component. The mass function, $f_1(M)$, leads to $M_2 \geq 0.97 \pm 0.01\ M_\odot$ if $M_1 = 0.80\ M_\odot$, or to $M_2 \geq 1.02 \pm 0.01\ M_\odot$ if $M_1 = 0.90\ M_\odot$, where the inequality depends on the unknown inclination i of the orbit. The mass of the K0 dwarf (called the primary in the rest of this paper) is probably large enough to conclude that the mass of the secondary is at least $1\ M_\odot$. Thus the invisible secondary may be (1) degenerate, (2) a pair of red dwarfs whose mass totals at least $1\ M_\odot$ but whose joint magnitude is too faint to perturb the K0 dwarf continuum, (3) a degenerate paired with a red dwarf. One may also imagine a pair of degenerate stars.

b) Geneva Photometric System Analysis

HD 149162 has been measured in the seven-color photometric system of the Geneva Observatory. These measurements were kindly given to us in advance of publication by Rufener. A definition of the wavelength and characteristics of the filters is given in Rufener's (1981) catalog. Let us only recall that their spectral coverage is from 3400 to 5800 Å.

According to the calibrations for analysis of the Geneva colors (Grenon 1978), the following hypotheses lead to the given results. (1) If we assume that the colors are a result of one single star only (i.e., the contribution of the secondary component is considered to be insignificant), we obtain for the primary the following parameters: $T_{\text{eff}} = 5070$ K, photometric parallax = 0″029, $V = 8.839 \pm 0.003$ mag, $M_v = 6.13$ mag, metallicity [M/H] = −0.04, and mass $M = 0.76\ M_\odot$. The colors are absolutely normal. The determined metallicity is slightly deficient with respect to the Sun. The photometric parallax is a little less certain than the trigonometric parallax. (2) Pursuing a second hypothesis we represent the colors of this system as the sum of three stars $(a + b + c)$ where the masses $M_b = M_c = 0.50$ or $0.55\ M_\odot$. This is a rather complex process, considering that the effective temperature, the metallicity, and the absolute magnitude of the primary star can be modified in order to reproduce the colors of the whole system. The results of this analysis are shown in Table 2. The resulting colors of this system $(a + b + c)$ are perfectly consistent with the six observed colors. The hypothesis that the observed colors result from the combined flux of the three stars $(a + b + c)$ has in particular the following consequences: (i) to alter the metallicity of the component a ([M/H] = 0.40), and (ii) to modify the photometric parallax of the system (= 0″016–0″018), which appears to be in quite significant disagreement with the trigonometric parallax. Therefore we consider that the photometry of this system does not support the hypothesis K0 V + (M0 V + M0 V). (3) A hypothesis of the type K0 V + (M V + white dwarf) will give an intermediate result between (1) and (2). The photometric parallax will be less than 0″029 and dependent on the spectral type of the M dwarf.

Infrared photometry could certainly be of some help to detect possible faint red companions. However, apparently no infrared photometry has been done for HD 149162 (Gezari, Schmitz, and Mead 1984).

As a result of the third Kepler law we can estimate the α/π

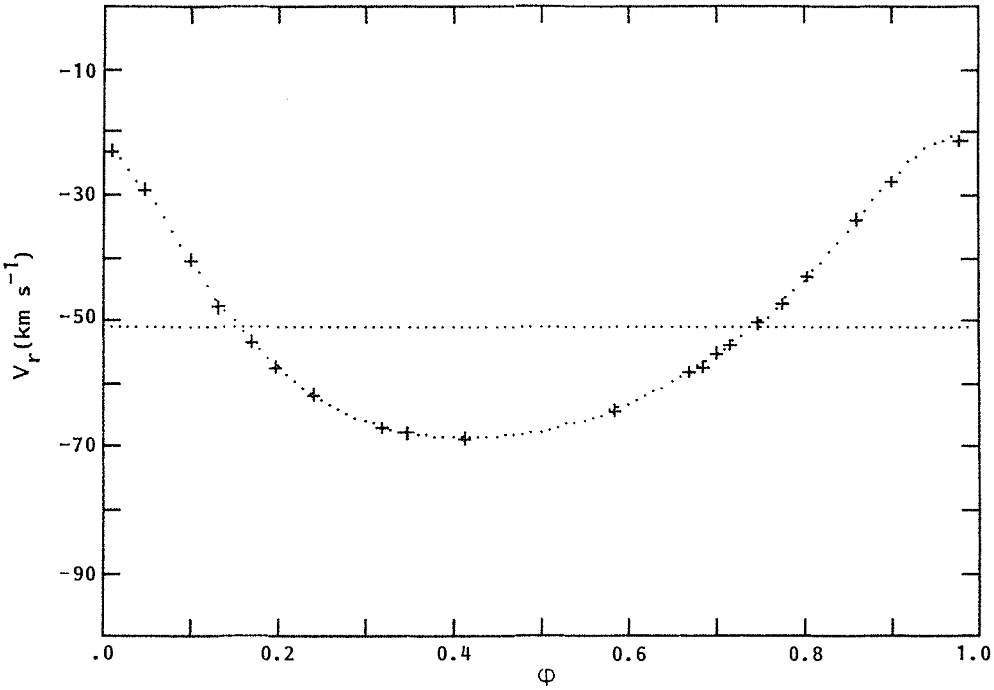

FIG. 1.—CORAVEL radial-velocity measurements and the fitted orbit

TABLE 2

GENEVA PHOTOMETRIC MODELING

STARS $b + c$ (mass each) ($M_\odot$)	STAR a				METALLICITY [M/H]	M_v $a + b + c$ (mag)	ΔV $b + c - a$ (mag)	PHOTOMETRIC PARALLAX
	$T_{\rm eff}$ (K)	$M_{\rm bol}$ (mag)	Mass ($M_\odot$)	M_v (mag)				
0.50.........	5294	5.28	0.86	5.53	0.40	5.10	2.50	$0\farcs018$
0.55.........	5344	5.12	0.89	5.36	0.42	4.91	2.19	$0\farcs016$

ratio of the angular separation between the components to the trigonometric parallax. The extremely high value $\alpha/\pi = 0.9$ possibly suggests a systematic error due to the duplicity in the determination of the parallax of this system. Such a remark should be kept in mind considering the apparent discordance between photometric and trigonometric parallaxes.

c) CORAVEL Cross-Correlation Dip Surface W

The surface of the cross-correlation dip is a measure of the mean blocking in the 1500 absorption lines used in the mask. For the dwarfs such a surface is a function of temperature and metallicity, $W(T_{\rm eff}, [{\rm M/H}])$ (cf. Mayor 1980). The observed values $W = 5.09$ and $B_2 - V_1 = 0.541$ for HD 149162 correspond to a slight metal deficiency with respect to the Sun, as for hypothesis (1) above. If we take an analogous composition to hypothesis (2) (K0 V + M0 V + M0 V), the color of the component a is modified toward the blue ($B_2 - V_1 = 0.50$) and the observed correlation dip surface must be increased by about 10% in order to obtain its intrinsic value. Here, once again, this new set of values of $B_2 - V_1$ and W agrees with the photometric estimation of $[{\rm M/H}] = 0.40$, as for hypothesis (2) above. Therefore, taking the correlation dip surface into account does not remove the ambiguity concerning the composition of this system.

d) IUE Low-Dispersion Spectrogram

Figure 2 reproduces the plot of these data. Mg II *h* and *k* and some other features of the spectrum have been briefly described (Johnson 1983*a*), where HD 149162 is called Woolley 9566. Comparison with the plot of the K0 V star HD 185144 in the *IUE* spectral atlas (Wu *et al.* 1983), where the Mg II doublet is in normal absorption, shows that, despite greater noise in HD 149162, the feature is relatively filled with emission in HD 149162. The exposure (*IUE* image LWR 10836, large aperture, 100 min) on JD 2,444,767 was at phase 0.72 of the orbit. The spectrum is just noise below 2250 Å, descending to about F_λ (2300 Å) $\gtrsim 6.7 \times 10^{-15}$ ergs cm^{-2} s^{-1} Å^{-1}. This upper limit now provides a constraint on the effective temperature of a white-dwarf component. A white dwarf can be found on Koester's (1978) mass-radius relation with $M = 1.25$ $M_\odot$, $R = 5.75 \times 10^{-3}$ $R_\odot$, and $\log g = 9$. Wickramasinghe's (1972) DA model with $\log g = 9$, $T_{\rm eff} = 10^4$ K, predicts emer-

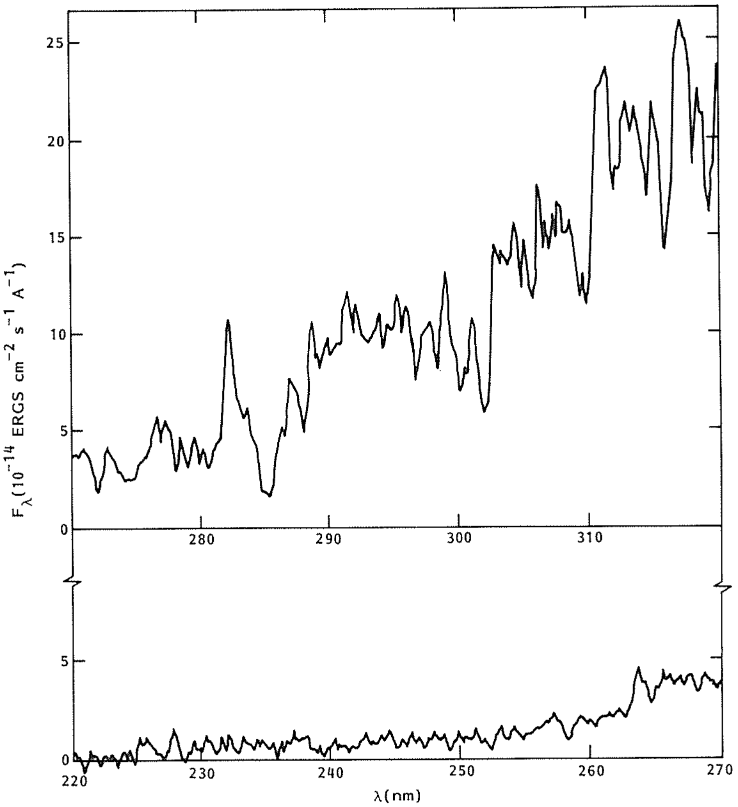

FIG. 2.—*IUE* spectrogram of HD 149162 (two sections) exposed on 1981 June 12 (JD 2,444,767) at $\phi = 0.72$

gent flux density density $F_{\lambda,\,\mathrm{mod}}$ (2293.2 Å) $= 4.6 \times 10^{-15}$ ergs cm^{-2} s^{-1} Å^{-1} for $R = 5.75 \times 10^{-3}\ R_\odot$ at the distance of 23 pc corresponding to the absolute trigonometric parallax of HD 149162. This white dwarf can be accepted within the observed *IUE* flux density because the signal to noise ratio of the *IUE* spectrogram at 2293 Å is not good enough to claim any perturbation of the K0 V spectrum by the additional flux density of the model white dwarf. The model flux densities diminish toward longer wavelengths and increase to only 5.36×10^{-15} ergs cm^{-2} s^{-1} Å^{-1} at 2050 Å, so it is clear that they will not perturb any part of the observed K0 V spectrum.

Wickramasinghe's (1972) models with higher T_{eff} cannot be accepted as above. Models with $\log g = 8$ imply $M = 0.63$ $M_\odot$, $R = 1.3 \times 10^{-3}\ R_\odot$ on the mass-radius relation, and the corresponding 10^4 K model (Wickramasinghe 1972) predicts $F_{\lambda,\,\mathrm{mod}}$ (2293.2 Å) $= 2.3 \times 10^{-14}$ ergs cm^{-2} s^{-1} Å^{-1}. A pair of such white dwarfs (to make total $M > 1\ M_\odot$) gives 10 times more than the flux of the single model white dwarf described in the preceding paragraph. Therefore, white dwarfs with $\log g = 8$ might remain undetected in the present *IUE* spectrogram only if they are cooler than $T_{\mathrm{eff}} = 10^4$ K. A 1 $M_\odot$ white dwarf cools to 10^4 K in 2×10^9 yr (Lamb and Van Horn 1975).

e) X-Rays

HD 149162 has the 0.25–4 keV (IPC band) luminosity $L_x = 1.1 \times 10^{29}$ ergs s^{-1}, highest of a small sample of observed K0 dwarfs with a range of the sample as low as 3.1×10^{27} ergs s^{-1} (Johnson 1983*b*). Thus the system joins the class of highest order-of-magnitude X-ray luminosity among all observed K–M dwarfs within 25 pc of the Sun. X-ray luminosity in these stars is normally attributed to their coronae, and the range of L_x among them to some parameter that perhaps depends on rotation rate, and that rate on age. But HD 149162 is ostensibly an old-disk star with the rather low $v \sin i = 3.4 \pm 0.5$ km s^{-1} (Johnson and Mayor 1984) as measured with the CORAVEL technique (cf., Baranne, Mayor, and Poncet 1979; Benz and Mayor 1984). Since the dispersion of L_x among similar stars is not completely understood, HD 149162 is not definitely anomalous, but we believe that another source of X-rays besides the K-dwarf corona is possible. One of us (Johnson 1983*a*) has suggested that the optically invisible companion may contribute to L_x and to the apparent Mg II *h* and *k* emission. The Sirius B mass (1.03 $M_\odot$) and L_x (6×10^{28} ergs s^{-1}), but not the T_{eff} (28,000 K), would permit it to be the invisible component of HD 149162. One white dwarf, HZ 43 with $L_x = 4 \times 10^{31}$ ergs s^{-1}, is too luminous in X-rays as well as too hot to come within the parameters of HD 149162. Conversely, white dwarfs with $T_{\mathrm{eff}} \leq 10^4$ K would not contribute significantly to the value of L_x in the system. Most white dwarfs do not have the required mass or the X-ray luminosity to be a significant candidate as a sole secondary of HD 149162, but a white dwarf–red dwarf pair is photometrically possible and otherwise adaptable, since M dwarfs may produce the observed L_x.

f) High-Dispersion Hα *Profile*

All of the observed M dwarfs with $L_x \geq 10^{29}$ ergs s^{-1} show Hα emission (Johnson 1983*c*), so we have looked for Hα evidence of such a star in the HD 149162 system. At our request C. A. Pilachowski has obtained Kitt Peak coudé-feed CCD system records of the region around Hα, with Th-Ar comparison spectra. The spectra were obtained with an 800×800 pixel, 3-phase Texas Instruments CCD. This device, known as "TI3" in Kitt Peak instrument manuals, has 15 μm square pixels. The CCD was mounted on spectrograph camera number 5 with the spectrum dispersed parallel to the columns. Grating D (1200 grooves mm^{-1} blazed in first order at 8000 Å) was used. With on-chip summation, two pixels perpendicular to the dispersion were binned together for an effective pixel size of 30×15 μm. The spectrum was about three such pixels wide. The plots that we reproduce are an average of those three columns, but each column individually shows the emission feature on the red wing of Hα that is described below. In Dr. Pilachowski's experience with this detector, features as broad as the red-wing Hα emission are real. Sharp (i.e., single-pixel) emission features are most likely attributable to cosmic-ray or radiation events, and they would appear in only one column of the raw spectrum. Calibration defects are less than 1% of the continuum. The spectrum is located on a clean region of the CCD. A reciprocal dispersion of 7.5 Å mm^{-1} gives a resolution of 2 pixels equal to $\frac{1}{4}$ Ångstrom, and a signal to noise ratio ≈ 40 in 1 hr exposures.

The results, represented in Figure 3, show stellar absorptions of Fe I, Ti I, and one of Ca I, as well as telluric absorptions; the deep Hα absorption is normal for a K0 V star (cf. Zarro and Rodgers 1983). Central residual intensity R_c is slightly larger in HD 149162 than in the standard, but this may merely indicate different instrumental light scattering.

A significant emission feature is superposed on the red wing of Hα on 1985 March 22, and it is displaced $\Delta\lambda = 1.6$ Å $= +73$ km s^{-1} with respect to the absorption core. Displaced emission is not evident in the nearly symmetrical absorption feature on 1985 June 8, and the spectral subtraction shows the residual emission of March 22 again. The subtraction also shows that R_c appears larger on June 8 so that Hα absorption is not completely cancelled, and the metallic lines tend to appear less deep on June 8. The base width of the March 22 emission is ~ 2.4 Å in the subtraction tracing. This width is a little greater than the base widths of chromospheric Hα emission observed in dMe flare-star spectra (Worden and Peterson 1976), but it is somewhat narrower than the Hα observed in the low state of the cataclysmic binaries MV Lyr (Robinson *et al.* 1981) and TT Ari (Shafter *et al.* 1985) and attributed to M dwarf chromospheres in those systems.

It is not reasonable to attribute the Hα emission in HD 149162 to the K0 V star, so we assume that it must belong to the otherwise invisible secondary. Moreover, it must belong to only one component of a close pair wherein the other component does not show definite Hα emission. The CORAVEL orbit for the K0 V primary and the mass function suggest that at the phase 0.83 the center of mass of the hypothetical close-pair secondary should have a radial-velocity shift of about -23 km s^{-1} $= 0.5$ Å with respect to the Hα absorption of the primary. The Hα emitter is therefore in orbit at a velocity of at least 96 km s^{-1} with respect to the center of mass of the close pair. We conclude that the non–Hα emitter of the close pair may be either a white dwarf or a red dwarf, but if the latter it appears to be atypical for lack of Hα emission under the circumstances of most systems of such close pairs. Some of the detached dMe and white dwarf binaries in Lanning (1982) and Sion, Wesemael, and Guinan (1984) (e.g., Case 1), may resemble the close binary that we propose here, although their white-dwarf components have too high T_{eff} to match the secondary of HD 149162.

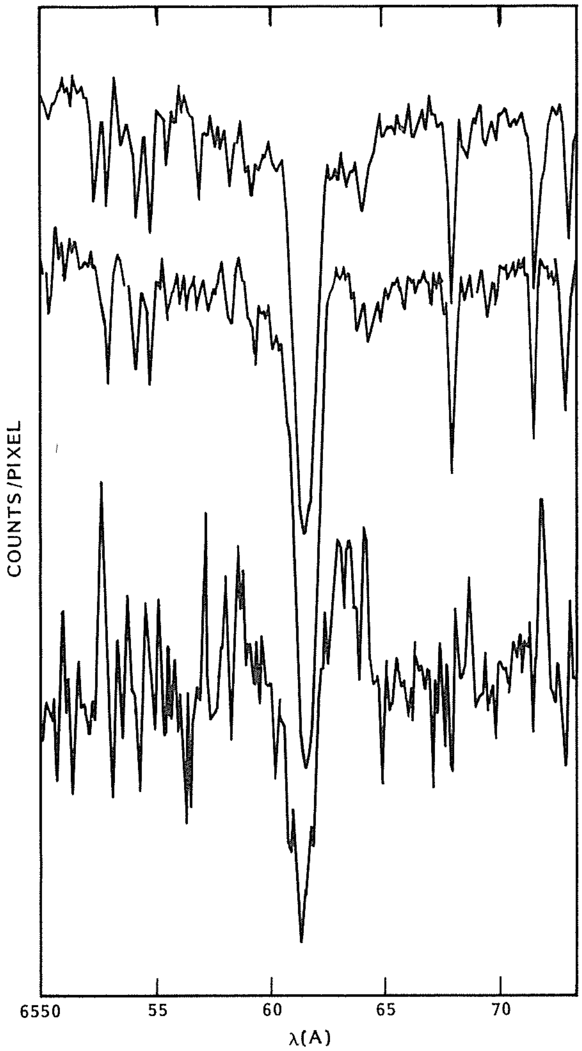

FIG. 3.—Kitt Peak coude-feed CCD records around Hα in the spectrum of HD 149162. From top to bottom: 1985 June 8 (JD 2,446,225), 1985 March 22 (JD 2,446,147), and a subtraction of the record of June 8 from the record of March 22 with a magnified vertical scale. Note emission on red wing of Hα in the March 22 record and in subtraction. Residual peaks in the subtraction result chiefly from telluric H_2O (vibration band number 311) which was stronger on June 8.

III. EVOLUTIONARY ASPECTS

Perhaps the most interesting probable configuration of the HD 149162 triple that has been discussed includes a white dwarf, and this would imply that the close dMe companion once orbited the white-dwarf progenitor before the latter became a red giant, then spiraled in during envelopment by the evolved red giant, and now it is in a precataclysmic stage (cf. Paczyński 1976, 1983). It is unlikely to be actually a cataclysmic binary because L_x is at the lower limit of the observed range for them, namely 10^{29}–10^{32} ergs s^{-1} (Becker 1981). The accretion disk of a cataclysmic binary might also be too bright optically in HD 149162. The distance scale that establishes the range of L_x or optical brightness for cataclysmic binaries is crude, nevertheless, and a theoretical lower limit of their L_x has not been given.

A remarkable aspect of the evolution is that the maximum radius of the white-dwarf progenitor envelope should have exceeded 200 $R_\odot$ (cf. Webbink 1979) and therefore may have enveloped the K0 dwarf as well as the proposed M dwarf component. In such a situation the orbit circularization time due to tidal interaction and/or mass transfer is extremely short (Mayor and Mermilliod 1984; Burki and Mayor 1983). The observed orbital eccentricity 0.28 excludes such an evolution. If the K0 dwarf has never been enveloped by a red giant atmosphere, it may serve as a close constraint on the size of the envelope that would have been produced by the white-dwarf progenitor, i.e., to be less than $(a_1 + a_2)$ cosec $i =$ 185 cosec $iR_\odot$.

Finally, the presence of a neutron star is a possible alternative in terms of mass and L_x if a sufficient wind arises from the K0 dwarf. According to Davidson and Ostriker (1973), $L_x = 10^{29}$ ergs s^{-1} may be produced from gravitational infall onto the surface of a 1 $M_\odot$ neutron star by an accretion rate $\dot{M}_{\rm accr} = 10^{-17}$ $M_\odot$ yr^{-1}. Following their analysis we find that the required mass-loss rate of the K0 dwarf is $\dot{M}_{\rm wind} = 1.2 \times 10^{-12}$ $M_\odot$ yr^{-1} on the following assumptions: the ratio of the neutron-star mass to the K0 dwarf mass is 1.25, the ratio of the mean separation in orbit to the K0 dwarf stellar radius is 220, and the K0 dwarf velocity of escape equals the wind velocity at the radius of the orbit. The result depends on the squares of these ratios. The computed $\dot{M}_{\rm wind}$ is ~40 times greater than the solar-wind mass-loss rate, but nothing is known about $\dot{M}_{\rm wind}$ for any other K0 dwarf. Aside from the unknown variabilities of $\dot{M}_{\rm wind}$ and unknown wind velocity as a function of distance from the star, a test of the neutron-star hypothesis would be variable L_x induced by variable orbit radius. The ratio of maximum to minimum L_x is $(1 + e)^2(1 - e)^{-2} = 3.2$ in the orbital period of HD 149162. In shorter periods the total of about 10^2 counts in the IPC observation of HD 149162 does not allow a satisfactory test of neutron-star pulse phenomena. An FFT analysis of periods from 5×10^{-2} s to 6.66 s gives the exponential distribution of the power that is expected for random data.

IV. CONCLUSIONS

The SB1 system HD 149162 is composed of a nearly normal K0 dwarf and a secondary with a mass of at least 1 $M_\odot$. This mass is probably split into a dMe star and a white dwarf or another dM(e) star in a close binary. Further observations of Hα and Ca II H and K or Mg II *h* and *k* emissions may tell much more about the system.

We thank Dr. C. A. Pilachowski for providing and describing the coudé-feed observations, Dr. F. Rufener for Geneva photometry, Dr. M. Grenon for analysis of the latter, and Dr. F. D. Seward for the FFT pulse analysis of the X-ray data by request under the *HEAO 2* Guest Investigator Program. We also thank Dr. N. Houk and Dr. W. van Altena for responding to our requests for data before publication. H. M. J.'s part of this work has been done under the Lockheed Independent Research Program, and M. M.'s part has been supported by funds of the Swiss National Foundation.

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