4-2004

Chromospherically Active Stars. XXII. HD 18955, A Massive K Dwarf Binary

Francis C. Fekel
Tennessee State University

Gregory W. Henry
Tennessee State University

Frank M. Alston
Tennessee State University

Recommended Citation
Fekel, F.C.; Henry, G.W.; Alston, F.M. "Chromospherically Active Stars. XXII. HD 18955, A Massive K Dwarf Binary" The Astronomical Journal, Volume 127, Issue 4, pp. 2303-2309 (2004).

The Astronomical Journal, 127:2303–2309, 2004 April

CHROMOSPHERICALLY ACTIVE STARS. XXII. HD 18955, A MASSIVE K DWARF BINARY

Francis C. Fekel,[1,2] Gregory W. Henry,[2] and Frank M. Alston
Center of Excellence in Information Systems, Tennessee State University, 330 10th Avenue North, Nashville, TN 37203;
fekel@evans.tsuniv.edu, henry@schwab.tsuniv.edu
Received 2003 November 26; accepted 2004 January 2

ABSTRACT

HD 18955 is a double-lined spectroscopic binary with a period of 43.3214 days and a high eccentricity of 0.761. The spectral types of the components are K0 V and K2–K3 V. The secondary is a typical early K dwarf, although its minimum mass is greater than canonical values. However, this larger mass is consistent with other early K dwarf, spectroscopic binary results. The primary is anomalous, being substantially underluminous for its radius and mass, which are equal to or slightly greater than solar values. A lack of lithium argues that the components are not pre–main-sequence stars. The large minimum masses of both components suggest that the system has a high orbital inclination. Our photometric observations around the times of conjunction show no evidence of eclipses, but considering the uncertainties in the ephemerides, there is only a 50% chance that our photometric observations would have detected the primary eclipse and almost no chance that we covered the secondary eclipse. Hence, eclipses remain a real possibility in this system. Photometric variations with an amplitude of 0.02 mag reveal a period of 7.55 days, which is assumed to be the primary star's rotation period. Thus, given the spectral types of the stars, this system is a BY Draconis type variable. With $v \sin i$ values of 5 km s^{-1} for both components, the two stars are rotating more rapidly than typical K dwarf field stars, but the observed rotation period is still substantially longer than the predicted pseudosynchronous rotation period of 4.6 days for the primary.

Key words: binaries: spectroscopic — stars: spots — stars: variables: other

1. INTRODUCTION

HD 18955 ($\alpha = 3^{\rm h}02^{\rm m}32\overset{\rm s}{.}7$, $\delta = -15°16'21''$ [J2000], $V =$ 8.4 mag) came to prominence with its identification as the optical counterpart of an X-ray source observed by the *Einstein* satellite (Stocke et al. 1991). As part of the survey team, Fleming et al. (1989) obtained low- and high-dispersion spectroscopic observations of the star, from which they determined a spectral type of G8 V and measured a projected rotational velocity of 13 km s^{-1}. From radial velocity measurements they concluded that the star is likely single. Observed as part of a lithium abundance survey of late-type, X-ray stars, Favata et al. (1993) reported that HD 18955 is a binary having two similar components. The system was also included in the very extensive survey for candidate Doppler-imaging stars that was conducted by Strassmeier et al. (2000). They showed that the system has moderate-strength Ca II H and K emission and, thus, is chromospherically active. They also found low-level photometric variations with a period of 8.05 days, but as of the most recent naming list (Kazarovets et al. 2003), the star has not been given a variable star designation.

2. SPECTROSCOPIC OBSERVATIONS AND REDUCTIONS

From 1993 September to 2001 September, we obtained 27 spectrograms of HD 18955. All the observations were made with the Kitt Peak National Observatory (KPNO) coudé feed telescope, coudé spectrograph, and a Texas Instruments CCD detector. The vast majority of the KPNO 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. Two are centered at 6695 Å, the lithium line region, and have the same wavelength range and resolution. The spectra have typical signal-to-noise ratios of 150. Figure 1 shows a spectrum of the 6430 Å region when the lines are well separated near nodal passage.

We determined the radial velocities of the spectra with the IRAF cross-correlation program FXCOR (Fitzpatrick 1993) and used β Aquilae as the cross-correlation reference star. A velocity of -40.2 km s^{-1} for β Aql, measured relative to the IAU velocity standard HR 7560, was adopted from our unpublished results. Our spectra of HD 18955 show that its two sets of lines are partially blended over a significant portion of its orbit. In such cases the resulting cross-correlation functions have been fitted simultaneously with two Gaussians. Lines in four of the 27 spectra appear to be single and have been measured as such. All our radial velocities of HD 18955 are given in Table 1.

3. PHOTOMETRIC OBSERVATIONS AND REDUCTIONS

We obtained our photometry of HD 18955 with the T3 0.4 m automatic photoelectric telescope (APT) at Fairborn Observatory in the Patagonia Mountains of southern Arizona. This APT uses a temperature-stabilized EMI 9924B bi-alkali photomultiplier tube to acquire data through Johnson B and V filters. The APT is programmed to measure stars in the following sequence, termed a group observation: K, *sky*, C, V, C, V, C, V, C, *sky*, K, where K is a check star, C is the comparison star, and V is the program star. A total of 194 group observations of HD 18955 were obtained with the APT during three observing seasons between 1993 and 2001, with HD 18690 ($V = 7.06$, $B-V = 1.098$) as the comparison star and HD 18511 ($V = 6.51$, $B-V = 1.031$) as the check star.

[1] Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

[2] Senior Research Associate, Department of Physics and Astronomy, Vanderbilt University, Nashville, TN 37235.

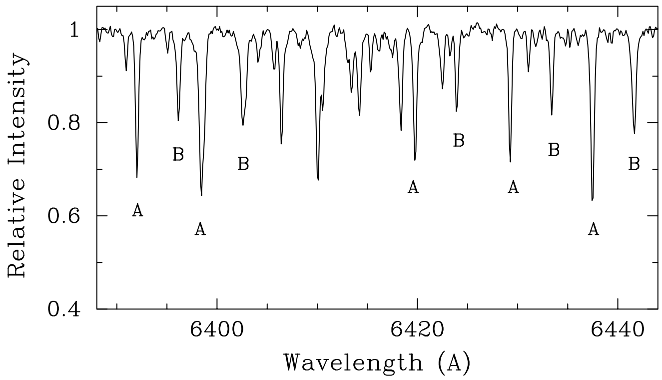

FIG. 1.—Portion of spectrum of HD 18955 in the 6430 Å region. Several lines of components A and B are identified. The observation is at orbital phase 0.007, when the velocity separation of the components is more than 190 km s^{-1} and near its maximum.

To create group means for each group observation, three variable minus comparison ($V-C$) and two check minus comparison ($K-C$) differential magnitudes in each photometric band were computed and averaged. The group means were then corrected for differential extinction with nightly extinction coefficients, transformed to the Johnson system with yearly mean transformation coefficients, and treated as single observations thereafter. The external precision of the group means, based on standard deviations for pairs of constant stars, is typically ∼0.004 mag on good nights with this telescope. Group mean differential magnitudes with internal standard deviations greater than 0.01 mag were discarded. The individual differential magnitudes are given in Table 2. Further details of telescope operations and data reduction procedures can be found in Henry (1995a, 1995b).

4. SPECTROSCOPIC ORBIT

As the observations accumulated, the high eccentricity of the orbit became obvious, making the orbital period of HD 18955 initially difficult to determine. With 23 observations of the primary that were obtained through 1999, we used the least-string method, implemented by T. J. Deeming (Bopp et al. 1970), to search for periods between 1 and 100 days with a step size of 0.01 days. This resulted in a preliminary period of 43.30 days. We then determined initial orbital elements with BISP, a computer program that uses a slightly modified version of the Wilsing-Russell method (Wolfe, Horak, & Storer 1967) and refined those elements with SB1, a differential corrections program from Barker, Evans, & Laing (1967). Rapid velocity changes during periastron passage were predicted by this initial orbit and confirmed on four consecutive nights in 2001.

With all the velocities of the primary component, we made a more extensive period search for aliases. Using the least-string method, we reduced the step size to 0.0001 days and searched periods between 0.1 and 50 days. A step size of 0.001 days was used for a period search between 50 and 100 days, and 0.01 days was used for the 100–500 day range. The fitting parameter of the least-string method (Bopp et al. 1970) clearly preferred periods within a few hundredths of 43.32 days. Phase plots modulo one-half and one-third of the 43.32 day period produced extremely poor radial velocity curves. Thus,

TABLE 1
RADIAL VELOCITIES OF HD 18955

HJD (2,400,000+)	Phase	V_A (km s^{-1})	$(O-C)_A$ (km s^{-1})	V_B (km s^{-1})	$(O-C)_B$ (km s^{-1})
49,249.929.......	0.350	40.8	−0.5	18.7	−0.1
49,250.908.......	0.373	41.5	−0.4	17.9	−0.3
49,301.935.......	0.551	43.9	0.0	17.0	1.0
49,618.925[a].....	0.868	32.0	−2.7	32.0	5.8
49,621.974[b].....	0.938	17.6	0.3	45.5	0.0
50,364.868.......	0.087	17.7	0.1	44.7	−0.5
50,365.887.......	0.110	23.5	−0.1	38.8	0.3
50,366.933.......	0.134	26.0	−1.9	32.2	−1.5
50,400.783[b].....	0.916	24.3	−1.5	35.5	−0.6
50,719.940.......	0.283	39.1	−0.1	22.2	1.1
50,753.890.......	0.067	10.2	0.5	54.1	0.1
50,754.839.......	0.088	18.5	0.4	45.3	0.7
50,757.833[a].....	0.158	31.2	0.3	31.2	0.8
50,758.887[a].....	0.182	31.4	−1.9	31.4	3.7
51,089.907.......	0.823	38.1	−0.6	21.7	−0.1
51,092.896[a].....	0.892	30.3	−0.9	30.3	0.2
51,094.911.......	0.938	17.2	0.0	45.1	−0.5
51,471.897.......	0.640	43.6	−0.1	16.5	0.3
51,472.839.......	0.662	43.3	−0.2	16.6	0.2
51,473.855.......	0.686	43.0	−0.2	17.5	0.8
51,474.867.......	0.709	42.8	0.0	18.3	1.2
51,475.923.......	0.733	41.9	−0.4	18.0	0.3
51,476.882.......	0.756	41.7	0.0	18.8	0.4
52,179.922.......	0.984	−36.3	−0.3	105.2	0.4
52,180.922.......	0.007	−61.0	0.1	132.6	−0.2
52,181.934.......	0.030	−20.9	−0.4	88.3	0.7
52,182.933.......	0.054	1.7	−0.5	62.8	0.4

[a] Components blended, single velocity measured, and given zero weight.
[b] The 6700 Å region.

TABLE 2
Photometric Observations of HD 18955

HJD (2,400,000+) (1)	Variable *B* (mag) (2)	Variable *V* (mag) (3)	Check *B* (mag) (4)	Check *V* (mag) (5)
49,235.9624........	1.109	1.409	−0.594	−0.555
49,236.8830........	1.092	1.392	−0.617	−0.548
49,237.8750........	1.104	1.389	99.999	99.999
49,240.9718........	1.126	1.410	−0.614	−0.553
49,241.9622........	1.113	1.412	−0.606	−0.538

Note.—Table 2 is presented in its entirety in the electronic edition of the Astronomical Journal. A portion is shown here for guidance regarding its form and content.

we are confident that we have identified the correct orbital period.

With the full compliment of data we determined individual solutions for components A and B with SB1. The variances of the two solutions resulted in weights of 0.4 for the secondary velocities relative to those of the primary. Velocities for the four spectra that showed only a single set of lines were given zero weight. With a modified version of SB1 we then obtained a simultaneous solution of both data sets, resulting in final orbital elements (Table 3). The standard error of an observation of unit weight is 0.3 km s^{-1}, similar to our results for the best orbits in our series on chromospherically active stars (e.g., Fekel 1997a; Fekel, Henry, & Henry 2001b). Orbital phases of the observations and velocity residuals to the eccentric-orbit solution are given in Table 1. Zero phase is a time of periastron passage. Figure 2 compares our velocities with the computed velocity curve.

5. PHOTOMETRIC ANALYSIS

All the Johnson *V* photometric observations are plotted in the top panel of Figure 3. We searched for periodicities in the photometric data using the method of Vaniček (1971), as described in Henry et al. (2001). Each of the three observing seasons was analyzed separately; the results are given in Table 4 and described below.

We first analyzed the check star minus comparison star ($K - C$) data in *B* and *V* over the period range 1–100 days and found no evidence of periodicity. The standard deviations of the $K - C$ observations for all three observing seasons and for both photometric bands are all close to 0.005 mag (Table 4, col. [9]), compared with the nominal precision of 0.004 mag with this telescope. HD 18955 lies at a declination of $-15°$, so the air mass through which we observe the star is somewhat higher than average, which explains the slightly higher than average scatter in our photometry. The seasonal means of the $K - C$ differential magnitudes are given in column (8) of Table 4; the means in both *V* and *B* are constant to 0.0003 mag. Therefore, we have verified that the comparison and check stars are both constant to the limits of our photometric precision.

TABLE 3
Orbital Elements of HD 18955

Parameter	Value
P (days)..	43.32145 ± 0.00047
T (HJD)..	2,451,487.472 ± 0.012
γ (km s^{-1})...	30.666 ± 0.062
K_A (km s^{-1})..	54.50 ± 0.17
K_B (km s^{-1})..	60.64 ± 0.24
e...	0.7612 ± 0.0010
ω_A (deg)..	174.13 ± 0.21
$a_A \sin i$ (km)...	$21.06 \pm 0.08 \times 10^6$
$a_B \sin i$ (km)...	$23.43 \pm 0.10 \times 10^6$
$m_A \sin^3 i$ ($M_\odot$)...	0.9865 ± 0.0094
$m_B \sin^3 i$ ($M_\odot$)...	0.8866 ± 0.0076
Standard error of an observation of unit weight (km s^{-1})..................................	0.3

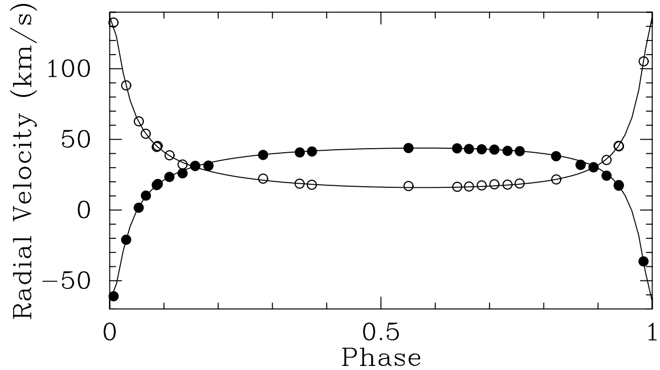

Fig. 2.—Plot of the computed radial velocity curve of HD 18955 compared with the observations. Component A is marked by filled circles, component B by open circles. Zero phase is a time of periastron.

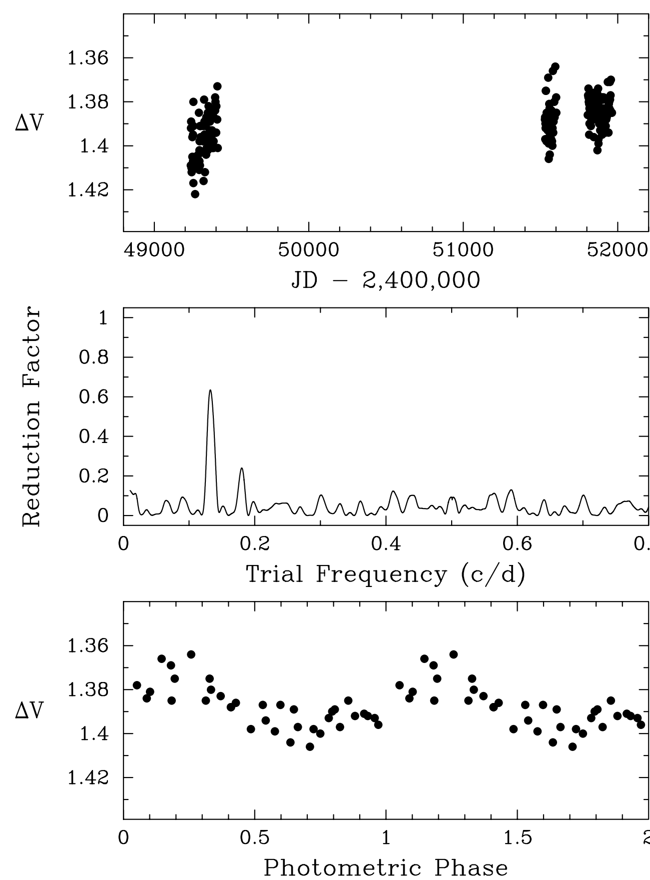

Fig. 3.—*Top*: Complete set of Johnson *V* photometric observations acquired in three separate observing seasons plotted against Julian Date. *Middle*: Power spectrum of the data in the second season, which showed the most coherent brightness variations. The best frequency is 0.132 day^{-1}, corresponding to a period of 7.55 ± 0.07 days. *Bottom*: Photometric observations from the second observing season plotted modulo the 7.55 day period, revealing a rotational amplitude of 0.022 mag.

TABLE 4
Results from Photometric Analysis of HD 18955

Season (1)	Photometric Band (2)	Date Range (HJD − 2,400,000) (3)	N_{obs} (4)	$\langle V-C \rangle$ (mag) (5)	σ_{V-C} (mag) (6)	Photometric Period (days) (7)	$\langle K-C \rangle$ (mag) (8)	σ_{K-C} (mag) (9)
1..................	*V*	49,235–49,410	73	1.3965	0.0105	7.08 ± 0.04	−0.5456	0.0054
1..................	*B*	49,235–49,410	75	1.1037	0.0102	7.11 ± 0.05	−0.6062	0.0057
2..................	*V*	51,528–51,602	36	1.3879	0.0099	7.55 ± 0.07	−0.5461	0.0050
2..................	*B*	51,528–51,602	34	1.0992	0.0106	7.68 ± 0.13	−0.6056	0.0062
3..................	*V*	51,805–51,961	69	1.3839	0.0069	3.81 ± 0.02	−0.5463	0.0053
3..................	*B*	51,805–51,961	74	1.0951	0.0103	3.81 ± 0.02	−0.6061	0.0046

The standard deviations of the $V-C$ observations are given in column (6) of Table 4 and are all close to 0.01 mag, suggesting low-level photometric variability in HD 18955. Although HD 18955 is 1.4 mag fainter in V than the comparison star, the resulting increase in photon noise over that in the comparison star is only about 0.001 mag. Since we have shown that the comparison star is constant to 0.005 mag from night to night, the 0.01 variability in the $V-C$ observations is good evidence of variability in HD 18955. The seasonal means in column (5) also show that HD 18955 varies by about 0.01 mag on longer timescales as well. The results of our period search of the $V-C$ observations are given in column (7). The power spectrum of the second-season V observations, which produce the strongest periodicity, is shown in the middle panel of Figure 3 and yields a period of 7.55 ± 0.07 days. We take this to be our best determination of the star's rotation period, made apparent by modulation in the visibility of photospheric starspots, as shown for several dozen other chromospherically active stars in Henry, Fekel, & Hall (1995). The second-season observations are phased with the 7.55 day period and the arbitrary epoch of 2,450,000 and plotted in the bottom panel of Figure 3. A sine-curve fit to the phase curve gives a peak-to-peak amplitude of 0.022 ± 0.003 mag. The first-season observations give a similar period, though not strictly identical within the uncertainties. The first-season phase curve is not as coherent as the second season's, indicating short-term changes in the starspot distribution that probably affected the period determination. The third season yields a photometric period of 3.81 days, one-half of the second-season period, though considerable scatter also exists in its low-amplitude phase curve. Most likely, small spot groups of comparable size existed on opposite hemispheres of HD 18955 at this epoch, yielding a photometric period equal to one-half the stellar rotation period, as seen on occasion, for example, in UV Fornacis (Fekel et al. 2001a). Our most robust period, 7.55 days, is similar to the value of 8.05 days, determined by Strassmeier et al. (2000) from data obtained one season earlier. Their individual magnitudes, when plotted modulo the 8.05 day period, show substantial scatter (Strassmeier et al. 2000), suggesting that the spot distribution was evolving during their brief observing season of about 40 days. With the K dwarf spectral types of the components, this system is a BY Draconis type variable.

The large minimum masses of HD 18955 (Table 3) suggest that the components may eclipse, and the orientation of the major orbital axis indicates that both primary and secondary eclipses have similar detection probabilities. From our orbit the eclipse ephemerides are

$$T_{pri} = \text{HJD } 2,451,486.19(\pm 0.01) + 43.3214(\pm 0.0005)E, \quad (1)$$

$$T_{sec} = \text{HJD } 2,451,489.14(\pm 0.01) + 43.3214(\pm 0.0005)E. \quad (2)$$

Our photometric observations show no evidence of either eclipse. However, the coverage around the predicted times of conjunction is fairly sparse. To estimate the probability that our photometric observations should have detected the eclipses if they occur, we recomputed the orbital phases of our observations in 10,000 trials, allowing the times of conjunction and the orbital period to range over their uncertainty intervals. Our observations missed the computed primary eclipse windows in ~50% of the trials and missed the secondary eclipse windows in nearly all of the trials. Thus, eclipses remain a very real possibility. Unfortunately, the relatively long orbital period and southern declination of the system provide few eclipse-search opportunities per season for an observatory in the northern hemisphere.

6. THE $v \sin i$, SPECTRAL TYPES, AND MAGNITUDE DIFFERENCE

Using the procedure of Fekel (1997b), we determined projected rotational velocities for the two components of HD 18955 from four KPNO red-wavelength spectra. For each spectrum the FWHM of two to four moderate or weak lines was measured, and the results were averaged for each component. The instrumental broadening was removed, and the calibration polynomial of Fekel (1997b) was used to convert the resulting broadening in angstroms into a total line broadening in kilometers per second. We assumed a macroturbulence of 2 km s^{-1}, appropriate for a K dwarf (Marcy & Basri 1989). The resulting $v \sin i$ values are 5.3 and 5.1 km s^{-1} for components A and B, respectively, with an estimated error of 1 km s^{-1}. Given that the secondary's lines are weaker than the primary's and therefore more affected by blends, our values are in reasonable agreement with those of Strassmeier et al. (2000), who determined 5.2 km s^{-1} for component A and 8.8 km s^{-1} for component B. The values of 20 and 13 km s^{-1} for A and B, respectively, by Favata et al. (1995) are clearly upper limits.

We determined the spectral types of the components of HD 18955 with the spectrum addition technique used by Strassmeier & Fekel (1990). They identified several luminosity-sensitive and temperature-sensitive line ratios in the 6430–6465 Å region and used them, along with the general appearance of the spectrum, as spectral type criteria. Because of the spectral classifications of K0 V (Houk & Smith-Moore 1988, p. 31) and G8 V (Fleming et al. 1989) for the combined spectrum, the spectra of late G and early K dwarf reference stars from the lists of Keenan & McNeil (1989) and Fekel (1997b) were obtained at KPNO with the same telescope, spectrograph, and detector as our spectra of HD 18955. Comparison spectra were created with a computer program developed by Huenemoerder & Barden (1984) and Barden (1985). Various combinations of reference-star spectra were rotationally broadened, shifted in radial velocity, appropriately weighted, and added together in an attempt to reproduce best the spectrum of HD 18955 in the 6430 Å region. Very good fits to the whole spectrum were found with reference star combinations of K0 V plus K2 V and K0 V plus K3 V. We also measured the three best line ratios, which indicate spectral types ranging from G8 V to K0 V for A and from K1 V to K2 V for B. On average, each component is about one spectral subclass earlier than the results found from the spectrum addition. Since there are lines from two stars in the spectrum, a measured line of one star might be blended with a nearby line from the other, adding uncertainty to the line ratio measurements. Thus, we give greater weight to the spectrum addition results and classify component A as K0 V and component B as K2–K3 V. Averaged abundance values (Taylor 2003) for the reference stars indicate that the [Fe/H] value of HD 18955 is equal to or perhaps greater than the sun's.

The resulting continuum intensity ratio $I_B/I_A = 0.54$. To determine the luminosity ratio, the intrinsic line-strength ratio must be taken into account, since the actual line strength of the cooler secondary is greater than that of the hotter primary. In the 6430 Å region the average of the Fe I line strengths in the reference stars, a mean of the K2 V and K3 V stars relative to those in the K0 V star, results in a line-strength ratio $B/A = 1.12$. This produces a luminosity ratio in the 6430 Å region of 0.48, corresponding to a magnitude difference of 0.80 mag. This central wavelength is about 60% of the way between the effective wavelengths of the Johnson V and R bandpasses. Thus, from the mean colors of early K dwarfs (Johnson 1966) we adopt $\Delta V = 0.9$ mag and estimate an uncertainty of 0.1 mag from the various best-fit combinations.

7. FUNDAMENTAL PARAMETERS

The large minimum masses of 0.99 and 0.89 $M_\odot$ for the K0 V star and K2–K3 V star, respectively, are only increased by 1% if the orbital inclination is 85°. However, decreasing the inclination to 80° increases the masses by nearly 5%, resulting in 1.03 $M_\odot$ for component A and 0.93 $M_\odot$ for component B. The masses for an inclination of 85° are listed in Table 5.

We searched the literature and examined our APT data for the brightest visual magnitude and corresponding $B-V$ of HD 18955. From Figure 3, HD 18955 is brightest in season 2 with a peak differential V magnitude of about 1.37. To convert this to an apparent V magnitude, we adopted $V = 7.06$ mag (ESA 1997) for our comparison star, HD 18690. This resulted in a maximum V magnitude of 8.43 for HD 18955. In a similar manner we obtained $B-V = 0.82$. Using the same procedure on the data of Strassmeier et al. (2000) results in $V = 8.43$ mag, while the *Hipparcos* result is $V = 8.45$ mag (ESA 1997). O'Neal, Saar, & Neff (1996) showed that on some heavily spotted stars the observed maximum V magnitude underestimates the brightness of the unspotted star by 0.3–0.4 mag. However, the modest chromospheric emission flux (Strassmeier et al. 2000) and low-amplitude light variations of HD 18955 suggest that it is not heavily spotted. Thus, we have adopted $V = 8.43$ as the unspotted magnitude for the system.

The *Hipparcos* parallax (ESA 1997) corresponds to a distance of 49 ± 3 pc, and so we assume no interstellar reddening. As a result, the parallax, adopted V magnitude, and the magnitude difference of the components were combined to obtain absolute magnitudes $M_V = 5.39 \pm 0.18$ mag and $M_V = 6.29 \pm 0.18$ mag for A and B, respectively. Adopting bolometric corrections of −0.22 for A and −0.32 for B (Flower 1996) and an assumed $M_{\rm bol} = 4.71$ mag for the Sun results in $L_{\rm A} = 0.65 \pm 0.03\ L_\odot$ and $L_{\rm B} = 0.31 \pm 0.03\ L_\odot$. From the $(B-V)$-$T_{\rm eff}$ relation of Flower (1996), we used effective temperatures of 5231 and 4963 K for A and B, respectively. The luminosity and temperature combine to produce a radius $R_A = 0.99 \pm 0.04\ R_\odot$ and $R_B = 0.76 \pm 0.05\ R_\odot$. This information is summarized in Table 5.

TABLE 5

Fundamental Properties of HD 18955

Parameter	Value	Ref.
V (mag)	8.43	1
$B-V$ (mag)	0.82	1
π	0''.02056 ± 0''.00136	2
Spectral type of A	K0 V	1
Spectral type of B	K2–K3 V	1
$v_A \sin i$ (km s^{-1})	5.3 ± 1.0	1
$v_B \sin i$ (km s^{-1})	5.1 ± 1.0	1
M_V(A) (mag)	5.39 ± 0.18	1
M_V(B) (mag)	6.29 ± 0.18	1
L_A ($L_\odot$)	0.65 ± 0.03	1
L_B ($L_\odot$)	0.31 ± 0.03	1
R_A ($R_\odot$)	0.99 ± 0.04	1
R_B ($R_\odot$)	0.76 ± 0.05	1
M_A (i = 85°) ($M_\odot$)	1.0	1
M_B (i = 85°) ($M_\odot$)	0.9	1

References.—(1) This paper; (2) ESA 1997.

8. DISCUSSION

Since HD 18955 is a double-lined binary consisting of two K dwarfs that are rotating significantly more rapidly than typical single K dwarfs (see below), it is likely that both components are chromospherically active. The Ca II H and K region spectrum of Strassmeier et al. (2000) clearly shows emission features, but the spectrum was obtained at an orbital phase of 0.453, and so the components have a predicted velocity separation of only 26 km s^{-1}. While the Ca II emission lines of HD 18955 appear broader than those of the single K dwarf HD 82883, suggesting that both components are indeed chromospherically active, it is not possible to resolve the lines into separate components to determine their relative contributions. With a V magnitude difference of 0.9, the light of the primary dominates that of the secondary, and so the photometric variations are probably from the primary.

With $M_V = 6.3$ mag and $R_B = 0.76\ R_\odot$, the absolute magnitude and radius of component B, a K2–K3 V star, are consistent with canonical values of a K2 dwarf (Gray 1992). On the other hand, its minimum mass of 0.89 $M_\odot$ is substantially greater than the canonical value of 0.76 $M_\odot$ (Gray 1992). But as summarized by Fekel et al. (1994), and further supported by work on HD 95559 (Fekel & Henry 2000), the canonical masses for early K dwarfs are too small. In this spectral type range Griffin et al. (1985) suggested increasing the masses given in the earlier tabulation of Allen (1973) by 15%, an amount consistent with our current results.

While the properties of component B confirm expectations, those of component A do not. The radius and minimum mass of A, $R_{\rm A} = 1.0\ R_\odot$ and $m_{\rm A} \sin^3 i = 1.0\ M_\odot$, are solar, but its spectral type is K0 V. The expectation from its spectral type is $M_V = 6.0$ mag (Gray 1992) as opposed to its actual absolute magnitude, $M_V = 5.4$, suggesting that the star is slightly evolved. When compared with solar abundance evolutionary tracks (Charbonnel et al. 1999), this component is near the end of its main-sequence evolution but significantly underluminous for its mass.

Could component A be a pre–main-sequence star rather than a slightly evolved main-sequence object? If it were the former, its Li I line at 6707 Å should have a large equivalent width. For example, late G and early K dwarf Pleiades stars, a benchmark cluster for zero-age main-sequence stars, have equivalent widths of 80–180 mÅ (Ford, Jeffries, & Smalley 2002). However, Favata et al. (1993) measured an equivalent width of just 8 mÅ for the 6707 Å lines of components A and B. Our two spectra of this region likewise show no evidence of a strong lithium line.

Is the spectral type of the primary substantially in error? Perhaps the system is really a metal-rich early G dwarf. Our experience with the 6430 Å region indicates that a metal-rich G dwarf mimics a star of higher luminosity class rather than a star of substantially later spectral class. One of the critical line ratios does indicate an earlier type for the primary, but only G8 and not the early G star suggested by the mass and radius. The *Hipparcos* $B-V$ (ESA 1997) and the Strömgren $b-y$ (Olsen 1993) values are consistent with a G9 or K0 spectral class for the combined system. Although the secondary affects the colors to some extent, it does not change them nearly enough to make the primary an early G star.

Mathieu et al. (2003) have found two subluminous, subgiant binaries that they argue are members of the old open cluster M67. In the case of S1113 the properties of the secondary are consistent with a 0.9 $M_{\odot}$ star, while the subgiant primary is 1 mag below the cluster subgiant branch. With a secondary consistent with expectations and a subluminous primary, the system is reminiscent of HD 18955. In an attempt to solve their conundrum Mathieu et al. (2003) examined several scenarios but were unable to satisfactorily account for all the properties of the binaries. In the end they speculated that close stellar encounters, perhaps involving binaries, might produce alternative evolutionary tracks from mass-exchange episodes, mergers, or stellar exchanges. In the case of HD 18955 we do not have the luxury of a dense cluster neighborhood.

The two main theories of orbital circularization and rotational synchronization (e.g., Zahn, 1977; Tassoul & Tassoul 1992) disagree significantly on absolute timescales but do agree that synchronization should occur first. Hut (1981) has shown that in an eccentric orbit a star's rotational angular velocity will tend to synchronize with that of the orbital motion at periastron, a condition called pseudosynchronous rotation. With equation (42) of Hut (1981) we calculated a pseudosynchronous period of 4.64 days, compared with 7.55 days for the photometric rotation period. Adopting the radii determined in § 7, the pseudosynchronous period results in rotational velocities of 11 and 8 km s^{-1} for A and B, respectively. The 14 K0–K3 V stars listed in Table 1 of Fekel (1997b) have a mean $v \sin i$ value of 1.5 ± 0.3 km s^{-1}. Thus, components A and B of HD 18955, having $v \sin i$ values of 5 km s^{-1}, are spun up compared with typical early K dwarfs, but they have not yet attained pseudosynchronous rotation.

Of the 205 systems listed in the second edition of the Catalog of Chromospherically Active Binary Stars (Strassmeier et al. 1993), 68 are dwarf systems, binaries in which both components are dwarfs or, if the system's spectrum is single-lined, presumed dwarfs. Twelve of those systems have orbital periods $\geq$10 days. One binary, HR 7578 = V4200 Sgr, is rather reminiscent of HD 18955. It consists of a pair of K2–K3 dwarfs that have an orbit with a period of 46.82 days and an eccentricity of 0.69 (Fekel & Beavers 1983). The calculated pseudosynchronous period is 7.5 days. From their best season of photometric data, Hooten & Hall (1990) determined a period of 16.5 days. Thus, like HD 18955, HR 7578 has a longer period, roughly by a factor of 2, than its pseudosynchronous value.

L. Boyd's dedicated efforts at Fairborn Observatory have been invaluable. We thank S. Henry for computing the probabilities that our photometric observations might have detected eclipses. The automated astronomy program at Tennessee State University is supported in part by NASA grant NCC 5-511 and NSF grant HRD 97-06268.

REFERENCES

Allen, C. W. 1973, Astrophysical Quantities (3rd ed.; London: Athlone)
Barden, S. C. 1985, ApJ, 295, 162
Barker, E. S., Evans, D. S., & Laing, J. D. 1967, R. Obs. Bull., 130
Bopp, B. W., Evans, D. S., Laing, J. D., & Deeming, T. J. 1970, MNRAS, 147, 355
Charbonnel, C., Däppen, W., Schaerer, D., Bernasconi, P. A., Maeder, A., Meynet, G., & Mowlavi, N. 1999, A&AS, 135, 405
ESA. 1997, The Hipparcos and Tycho Catalogues (ESA SP-1200) (Noorwijk: ESA)
Favata, F., Barbera, M., Micela, G., & Sciortino, S. 1993, A&A, 277, 428
———. 1995, A&A, 295, 147
Fekel, F. C. 1997a, AJ, 114, 2747
———. 1997b, PASP, 109, 514
Fekel, F. C., & Beavers, W. I. 1983, ApJ, 267, 682
Fekel, F. C., Dadonas, V., Sperauskas, J., Vaccaro, T. J., & Patterson, R. 1994, AJ, 108, 1936
Fekel, F. C., & Henry, G. W. 2000, AJ, 120, 3265
Fekel, F. C., Henry, G. W., Brooks, K., & Hall, D. S. 2001a, AJ, 122, 991
Fekel, F. C., Henry, G. W., & Henry, S. M. 2001b, AJ, 122, 3447
Fitzpatrick, M. J. 1993, in ASP Conf. Ser. 52, Astronomical Data Analysis Software and Systems II, ed. R. J. Hanisch, R. J. V. Brissenden, & J. Barnes (San Francisco: ASP), 472
Fleming, T. A., Gioia, I. M., & Maccacaro, T. 1989, ApJ, 340, 1011
Flower, P. J. 1996, ApJ, 469, 355
Ford, A., Jeffries, R. D., & Smalley, B. 2002, A&A, 391, 253
Gray, D. F. 1992, The Observation and Analysis of Stellar Photospheres (Cambridge: Cambridge Univ. Press)
Griffin, R. F., Gunn, J. E., Zimmerman, B. A., & Griffin, R. E. M. 1985, AJ, 90, 609
Henry, G. W. 1995a, in ASP Conf. Ser. 79, Robotic Telescopes, ed. G. W. Henry & J. A. Eaton (San Francisco: ASP), 37
———. 1995b, in ASP Conf. Ser. 79, Robotic Telescopes, ed. G. W. Henry & J. A. Eaton (San Francisco: ASP), 44
Henry, G. W., Fekel, F. C., & Hall, D. S. 1995, AJ, 110, 2926
Henry, G. W., Fekel, F. C., Kaye, A. B., & Kaul, A. 2001, AJ, 122, 3383
Hooten, J. T., & Hall, D. S. 1990, ApJS, 74, 225
Houk, N., & Smith-Moore, M. 1988, Michigan Catalogue of Two-dimensional Spectral Types for the HD Stars, Vol. 4 (Ann Arbor: Univ. Michigan)
Huenemoerder, D. P., & Barden, S. C. 1984, BAAS, 16, 510
Hut, P. 1981, A&A, 99, 126
Johnson, H. L. 1966, ARA&A, 4, 193
Kazarovets, E. V., Kireeva, N. N., Samus, N. N., & Durlevich, O. V. 2003, Inf. Bull. Variable Stars, No. 5422
Keenan, P. C., & McNeil, R. C. 1989, ApJS, 71, 245
Marcy, G. W., & Basri, G. 1989, ApJ, 345, 480
Mathieu, R. D., van den Berg, M., Torres, G., Latham, D., Verbunt, F., & Stassun, K. 2003, AJ, 125, 246
Olsen, E. H. 1993, A&AS, 102, 89
O'Neal, D., Saar, S., & Neff, J. E. 1996, ApJ, 463, 766
Stocke, J. T., Morris, S. L., Gioia, I. M., Maccacaro, T., Schild, R., Wolter, A., Fleming, T. A., & Henry, J. P. 1991, ApJS, 76, 813
Strassmeier, K. G., & Fekel, F. C. 1990, A&A, 230, 389
Strassmeier, K. G., Hall, D. S., Fekel, F. C., & Scheck, M. 1993, A&AS, 100, 173

Strassmeier, K. G., Washuettl, A., Granzer, T., Scheck, M., & Weber, M. 2000, A&AS, 142, 275
Tassoul, J.-L., & Tassoul, M. 1992, ApJ, 395, 259
Taylor, B. J. 2003, A&A, 398, 731
Vaniček, P. 1971, Ap&SS, 12, 10
Wolfe, R. H., Horak, H. G., & Storer, N. W. 1967, in Modern Astrophysics, ed. M. Hack (New York: Gordon & Breach), 251
Zahn, J.-P. 1977, A&A, 57, 383