3-1998

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Francis C. Fekel
Tennessee State University

Joseph J. Eitter
Iowa State University

José-Renan de Medeiros
Universidade Federal do Rio Grande do Norte

J. Davy Kirkpatrick
California Institute of Technology

Recommended Citation

Fekel, F.C.; Eitter, J.J.; de Medeiros, J.R.; Kirkpatrick, J.D. "Chromospherically Active Stars. XVII. The Double-lined Binary 54 Camelopardalis (AE Lyncis)" The Astronomical Journal, Volume 115, Issue 3, pp. 1153-1159 (1998).

THE ASTRONOMICAL JOURNAL, 115:1153–1159, 1998 March

CHROMOSPHERICALLY ACTIVE STARS. XVII. THE DOUBLE-LINED BINARY 54 CAMELOPARDALIS (AE LYNCIS)

FRANCIS C. FEKEL[1,2]
Center for Automated Space Science and Center of Excellence in Information Systems, Tennessee State University, 330 10th Avenue North, Nashville, TN 37203; and Space Science Laboratory, ES-82, NASA Marshall Space Flight Center, Huntsville, AL 35812; fekel@coe.tsuniv.edu
JOSEPH J. EITTER
Erwin W. Fick Observatory, Iowa State University, Ames, IA 50011; rwl@iastate.edu
JOSÉ-RENAN DE MEDEIROS
Departamento de Física, Universidade Federal do Rio Grande do Norte, CEP 59072-970, Natal, RN, Brazil; renan@dfe-lab.ufrn.br
AND
J. DAVY KIRKPATRICK
Jet Propulsion Laboratory/Infrared Processing and Analysis Center, Mail Stop 100-22, California Institute of Technology, Pasadena, CA 91125; davy@ipac.caltech.edu
Received 1997 October 24; revised 1997 November 20

ABSTRACT

New spectroscopic observations of the double-lined chromospherically active binary 54 Camelopardalis (=AE Lyncis) have been obtained, resulting in improved orbital elements and the determination of the fundamental properties of the system. 54 Cam has a period of 11.06794 days, an eccentricity of 0.125, and a mass ratio of 0.9945. The spectral types are F8 IV–V and G5 IV, positioning the components on opposite sides of the Hertzsprung gap. From a comparison with theoretical evolutionary tracks, the masses are estimated to be 1.60 and 1.59 $M_{\odot}$ for the G and F stars, respectively, while the radii are 3.7 and 3.2 $R_{\odot}$. Only the G star is chromospherically active. 54 Cam is particularly interesting since the F star is the brighter star at blue and red wavelengths, but the G star is slightly more massive and evolved. Both stars appear to be pseudosynchronously rotating, and the orbital and rotational inclinations are aligned. The lithium abundances of the two components are significantly different but consistent with standard theory, supporting the conclusion that both stars are more massive than the lithium-dip stars.

Key words: binaries: spectroscopic — stars: chromospheres

1. INTRODUCTION

54 Camelopardalis [=AE Lyncis = HR 3119 = HD 65626; $\alpha = 08^{h}02^{m}35\overset{s}{.}8$, $\delta = 57°16'25''$ (J2000.0); $V = 6.49$] is a bright, chromospherically active binary whose spectroscopic duplicity has been known for over 75 years (Plaskett et al. 1921) but whose active nature (Wilson & Skumanich 1964) was a more recent discovery. The Flamsteed number and variable star name have different constellation designations because the constellation boundaries were introduced in 1930 by the International Astronomical Union (IAU) (see, e.g., Lovi 1992), long after Flamsteed had assigned his identifications.

The binary nature of 54 Cam was first discovered by Harper (Plaskett et al. 1921). After a hiatus of nearly 16 years, observations were begun in earnest in 1936. Shortly thereafter, Harper (1939a) published orbital elements for 54 Cam and gave a talk (Harper 1939b) on the system at the 1939 meeting of the Astronomical Society of the Pacific. He found the system to have a relatively short period of 11.0764 days, a significant eccentricity of 0.107, and components of nearly equal mass. In addition, Harper (1939a) estimated the fundamental parameters of each component. Contemporaneous with those results, Petrie (1939) determined a blue wavelength magnitude difference of 0.32 mag for the components.

Little additional work was done until Wilson & Skumanich (1964) included 54 Cam in a sample of 142 late F and early G stars observed for possible Ca II H and K emission. They found the fainter component of the binary to have moderate emission and the lines of the components to have modest broadening. Rotational velocities for both components have been determined in several studies, the most recent of which are De Medeiros, do Nascimento, & Mayor (1997) and Fekel (1997a).

Photometric observations made as a result of the rediscovery of the Ca II H and K emission by Young & Koniges (1977) led to the identification of 54 Cam as an RS CVn binary (Eaton et al. 1981). From three seasons of photometry, Eaton et al. (1981) found a photometric period of 10.163 days, a value significantly different from its orbital period of 11.08 days. Hall (1986) later identified this difference as the result of pseudosynchronous rotation (Hut 1981). Mekkaden, Raveendran, & Mohin (1982) made several additional observations, while Strassmeier et al. (1989) obtained more extensive photometry during three seasons. Both groups confirmed that the photometric period is significantly different from the orbital period and found the light variations to have a typical amplitude of a few hundredths of a magnitude.

Strassmeier & Fekel (1990) classified the components as F9 IV and G5 IV and concluded that the Ca II H and K emission came only from the star with the later spectral type. A spectrum in Fernández-Figueroa et al. (1994) indi-

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

[2] National Research Council Senior Research Associate.

TABLE 1

RADIAL VELOCITIES OF 54 CAMELOPARDALIS

HJD − 2,400,000	Observatory[a]	Phase	V_F (km s^{-1})	$(O-C)_F$ (km s^{-1})	V_G (km s^{-1})	$(O-C)_G$ (km s^{-1})
43,826.694	HPO	0.652	79.9	1.1	...	...
43,826.703	HPO	0.653	79.5	0.7	...	...
43,826.714	HPO	0.654	...	...	−24.0	−0.6
43,826.719	HPO	0.654	...	...	−24.2	−0.9
43,918.437	HPO	0.941	−12.4	0.2	...	...
43,918.442	HPO	0.941	...	...	70.7[b]	3.1
43,923.442	HPO	0.393	51.5	−0.1	...	...
43,925.445	HPO	0.574	...	...	3.2	−0.3
46,389.001	KPNO	0.159	−23.3	0.7	79.1	0.4
46,390.027	KPNO	0.252	6.5	0.0	48.8	0.4
46,393.041	KPNO	0.524	76.2	−0.4	−22.5	−1.2
46,516.592	Fick	0.687	73.1	−1.7	...	...
46,530.753	KPNO	0.966	−21.8	0.2	78.2	1.4
46,531.791	KPNO	0.060	−39.0	0.1	93.6	−0.2
46,532.777	KPNO	0.149	−27.5	−0.9	80.4	−0.9
46,533.752	KPNO	0.237	1.3	−0.2	54.0	0.6
46,836.729	Fick	0.612	...	...	−23.6	1.9
46,868.726	KPNO	0.503	73.2[c]	−0.7	−20.0[c]	−1.3
46,869.726	KPNO	0.593	80.4	−0.5	−25.8	−0.2
47,152.007	KPNO	0.097	−36.5	0.4	91.6	0.1
47,162.791	Fick	0.072	−37.5	1.4	...	...
47,244.732	KPNO	0.475	69.6	−0.1	−14.1	0.3
47,245.713	KPNO	0.564	79.8	−0.1	−24.2	0.4
47,247.807	KPNO	0.753	60.6	−0.4	−5.4	0.4
47,248.778	KPNO	0.841	27.8[b]	−2.6	27.8[b]	3.2
47,308.646	KPNO	0.250	5.6	−0.2	49.7	0.6
47,312.626	KPNO	0.609	81.0	0.1	−25.2	0.4
47,456.029	KPNO	0.566	79.5	−0.5	−24.5	0.2
47,457.017	KPNO	0.655	78.1	−0.4	−22.9	0.3
47,555.936	KPNO	0.593	81.7	0.8	−25.8	−0.2
47,556.931	KPNO	0.683	75.5	0.1	−20.2	−0.1
47,623.738	KPNO	0.719	69.1	−0.1	−13.3	0.6
47,627.758	KPNO	0.082	−39.3	−0.9	92.6	−0.4
47,811.037	KPNO	0.641	78.9	−0.7	−24.6	−0.3
47,812.035	KPNO	0.732	65.9	−0.5	−11.3	−0.2
47,813.028	KPNO	0.821	38.4	0.2	16.6	−0.2
47,816.027	KPNO	0.092	−37.8	−0.3	91.9	−0.2
47,916.945	KPNO	0.210	−7.6	0.3	62.4	−0.3
48,002.671	KPNO	0.956	−17.6	0.7	73.9	0.9
48,005.729	KPNO	0.232	0.1	0.5	55.9	0.6
48,347.596	KPNO	0.120	−34.1	−0.9	86.6	−1.3
48,769.637	KPNO	0.252	6.7	0.1	48.1	−0.2
48,913.047	KPNO	0.209	−7.8	0.4	64.4	1.3
49,620.028	KPNO	0.086	−37.9	0.2	91.8	−0.9
49,835.614	KPNO	0.564	79.8	−0.1	−24.0	0.6
50,143.684	Fick	0.399	53.2	0.2	−0.5	−2.6
50,143.696	Fick	0.400	54.9	1.6	3.4	1.5
50,145.664	Fick	0.578	79.2	−1.3	...	...
50,145.676	Fick	0.579	79.9	−0.7	−27.7	−2.4
50,151.661	Fick	0.119	−32.9	0.5	88.2	0.1
50,155.652	Fick	0.480	70.9	0.4	−13.3	1.9
50,176.569	Fick	0.370	47.5	2.3	9.2	−0.7
50,179.588	Fick	0.643	80.3	0.8	−20.3[b]	3.9
50,182.588	Fick	0.914	−0.3	0.9	54.9	−1.2
50,200.662	KPNO	0.547	78.6	−0.1	−23.2	0.2
50,201.686	KPNO	0.639	80.0	0.3	−23.5	0.9
50,202.622	KPNO	0.724	68.5[c]	0.4	−13.4[c]	−0.5
50,362.001	KPNO	0.124	−32.3	0.2	86.8	−0.4
50,405.022	KPNO	0.011	−34.4	−0.3	88.4	−0.3
50,575.671	KPNO	0.429	61.2	0.8	−5.2	0.0

[a] (HPO) Haute-Provence Observatory; (KPNO) Kitt Peak National Observatory; (Fick) Erwin W. Fick Observatory.

[b] Velocity given zero weight.

[c] Lithium region.

cates that the Hα line depths of the two components are also quite different.

54 Cam has been included in samples of active stars observed at various other wavelengths. Spangler, Owen, & Hulse (1977) detected it as a radio source in their survey of close binaries. Walter (1981) observed it with the *Einstein* X-ray observatory as part of a program to examine the coronae of rapidly rotating stars. Basri, Laurent, & Walter (1985) obtained and analyzed *IUE* spectra of its chromospheric and transition-region emission lines. Although

TABLE 2

ORBITAL ELEMENTS OF 54 CAMELOPARDALIS

Parameter	Value
P (days)	11.067938 ± 0.000018
T (HJD)	2,447,582.578 ± 0.019
γ (km s^{-1})	27.509 ± 0.058
K_F (km s^{-1})	60.026 ± 0.091
K_G (km s^{-1})	59.697 ± 0.128
e	0.1253 ± 0.0014
ω_F (deg)	151.28 ± 0.63
ω_G (deg)	331.28 ± 0.63
$a_F \sin i$ (10^5 km)	90.64 ± 0.14
$a_G \sin i$ (10^5 km)	90.14 ± 0.19
M_F/M_G	0.9945 ± 0.0026
$M_F \sin^3 i$ ($M_\odot$)	0.9605 ± 0.0041
$M_G \sin^3 i$ ($M_\odot$)	0.9657 ± 0.0034
Standard error of an observation of unit weight (km s^{-1})	0.46

detected with *ROSAT* as a source of soft X-rays (Dempsey et al. 1993), it was not identified as an extreme-ultraviolet source with the *ROSAT* Wide Field Camera (Pye et al. 1995).

The identification of the components in some earlier papers is problematic, because the work of Harper (1939a) and Petrie (1939) indicated that the components were quite similar in mass and luminosity. Our results indicate that the slightly more massive and more evolved star is actually the *fainter* component at both blue and red wavelengths—a rather unusual situation. Thus, to avoid confusion in discussing the primary and secondary, we will refer to the components according to the spectral classes of Strassmeier & Fekel (1990), calling them the F and G stars.

Here we analyze our recent sets of radial velocities to obtain significantly improved orbital elements. Those elements, and additional spectroscopic and photometric information, are used to discuss the fundamental properties of this active binary system. The current results supersede previously published preliminary results such as those given in the catalogs of Strassmeier et al. (1988, 1993).

2. OBSERVATIONS AND REDUCTIONS

Forty high-dispersion spectroscopic observations, all but one obtained at phases at which line doubling was resolved, were made from 1985 to 1997 with the KPNO coudé feed telescope, coudé spectrograph, and Texas Instruments CCD detector. Nearly all the observations 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 observations at 6707 Å have the same wavelength range and resolution.

The KPNO velocities (Table 1) were determined relative to 10 Tau or β Vir, two IAU radial velocity standard stars (Pearce 1957) whose velocities were assumed from the work of Scarfe, Batten, & Fletcher (1990). Details of the velocity reduction procedure have been given by Fekel, Bopp, & Lacy (1978).

From 1986 to 1996, 11 observations of the F star and nine of the G star (Table 1) were obtained at the Erwin W. Fick Observatory with a radial velocity spectrometer. The telescope-spectrometer system and velocity reduction procedures have been described by Beavers & Eitter (1986).

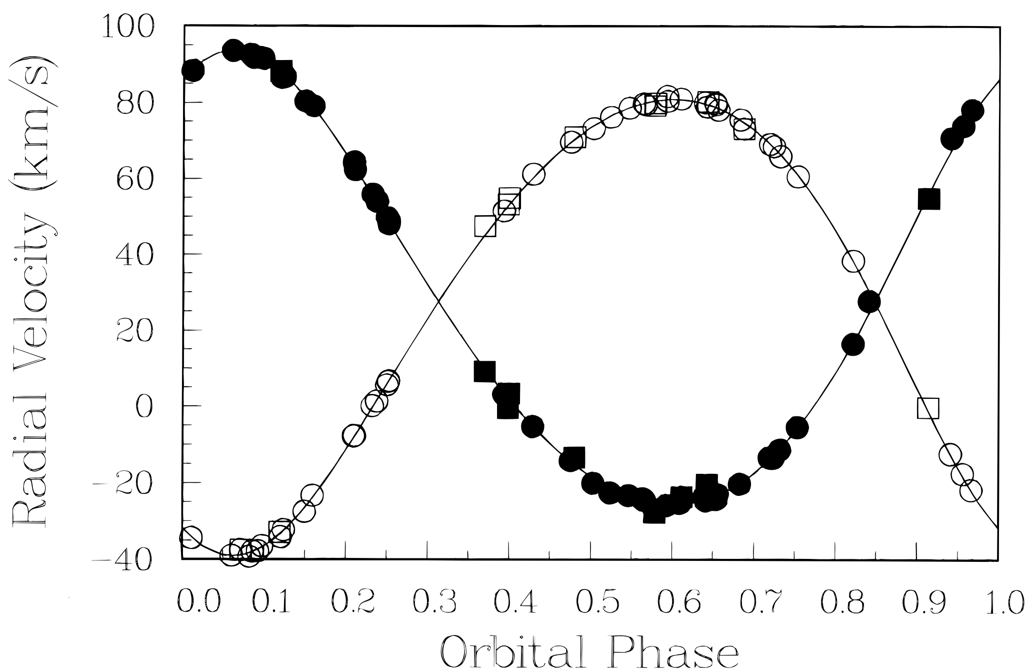

FIG. 1.—Plot of the computed radial velocity curves of 54 Cam compared with the observations. For the G star, filled circles represent KPNO and CORAVEL velocities, and filled squares represent Fick velocities. For the F star, open circles represent KPNO and CORAVEL velocities, and filled squares represent Fick velocities. Phase is computed from periastron passage.

Eight observations, four of each component, were obtained during the 1978–1979 observing season with the CORAVEL radial velocity spectrometer (Baranne, Mayor, & Poncet 1979) and Swiss 1 m telescope at the Haute-Provence Observatory. Radial velocities (Table 1) were determined with the methods discussed by Duquennoy (1987) for the measurement of unblended and blended cross-correlation dips. The CORAVEL velocities of 54 Cam have uncertainties of about 0.6 km s^{-1} (Duquennoy, Mayor, & Halbwachs 1991).

The spectrograms described by Harper (1939a) were obtained at the DAO. We identify the F star as Harper's main component and the G star as Harper's secondary component, except for the two spectrograms of 1920 that show double lines and for which his component identifications should be switched.

3. ORBIT

A period search of all the F star data identified a period of 11.06796 days, somewhat different from Harper's (1939a) value of 11.0764 days. This is because Harper (1939a) incorrectly identified the components for his two observations of 1920, obtained 16 years before the beginning of the rest of his observations. With the revised period assumed as a starting value, orbital elements were computed separately for both the old DAO velocities of Harper (1939a) and the KPNO velocities. For each component of the two data sets, preliminary orbital elements were determined with a slightly modified version of the Wilsing-Russell method (Wolfe, Horak, & Storer 1967). The four separate orbital solutions were improved with a differential-corrections computer program by Barker, Evans, & Laing (1967). The variances and center-of-mass velocities of the solutions were compared to determine the relative weights of the four sets of velocities and velocity zero-point shifts. The weights assigned to the KPNO velocities were 1.0 and 0.5 for the F and G stars, respectively. For the DAO observations, weights of 0.01 were assigned to both components, although many velocities had such large residuals that they were assigned zero weight. In addition, all blended observations were given zero weight, and 3.0 km s^{-1} was added to each DAO velocity.

Orbital solutions of the Fick velocities were also obtained. From a comparison of their variances with the KPNO velocities, the Fick velocities were given weights of 0.1 and 0.05, respectively, for the F and G star velocities. No zero-point adjustment was made to the velocities.

The CORAVEL velocities lengthen the time span of the recent observations to nearly 20 years, but they are not numerous enough to warrant an independent solution. Velocities of the two components were included with the same weights as the KPNO velocities and with no zero-point adjustment.

A double-lined solution of all the data was computed and compared with a solution that included only our new data. Although the DAO velocities extend the time baseline, they have such large residuals and low weights that they provide only a modest improvement in the period of the all-data solution and do not improve the other elements at all. This result is not surprising, given the moderate resolution of the DAO spectrograms and the difficulties of velocity measurement described by Harper (1939a). In fact, it is a tribute to Harper's observing equipment and data analysis technique that his orbital elements agree so well with the current determination. Although the DAO velocities have not been used in the final solution, they are consistent with it.

With the period fixed from the all-data solution, the other orbital elements for the primary and secondary components were determined in a simultaneous solution of just the KPNO, Fick, and CORAVEL velocities. The lone blended KPNO velocity and two velocities of the G star, one each from CORAVEL and Fick Observatory, have been given zero weight. The final orbital elements are listed in Table 2, and our observed velocities are compared with the computed velocity curves in Figure 1.

4. CHROMOSPHERIC ACTIVITY CHARACTERISTICS

The nearly equal minimum masses determined by Harper (1939a) and the small magnitude difference of Petrie (1939) suggest very similar spectral types. However, Wilson & Skumanich (1964) and Wilson (1966) noted that the Ca II H and K emission came only from one component, the fainter one at blue wavelengths. Young & Koniges (1977) focused additional attention on this apparent peculiarity. Strassmeier & Fekel (1990) classified the two components as F9 IV and G5 IV. From a new orbital ephemeris, Strassmeier & Fekel (1990) concluded that the Ca II H and K emission lines arise from the G star, while the blue absorption spectrum appears to be dominated by the F star. Another activity indicator, the Hα line, was observed by Fernández-Figueroa et al. (1994) and Eker, Hall, & Anderson (1995), who presented spectra showing that the Hα lines of the two components have somewhat different intensities. A comparison of the observational dates of Eker et al. (1995) and Montes et al. (1995) with our orbital elements indicates that, as expected, it is the G star whose Hα line is significantly filled by emission.

Tan & Liu (1987) found that both stars are rapidly rotating, while Strassmeier & Fekel (1990) concluded that the projected rotational velocity of the G star is somewhat greater than that of the F star. Additional $v \sin i$ determinations have been made by Randich, Giampapa, & Pallavicini (1994), De Medeiros et al. (1997), and Fekel (1997a). Comparison of the $v \sin i$ values is complicated because neither Tan & Liu (1987) nor Randich et al. (1994) were able to identify to which component each value belonged. The best values to date are those of Fekel (1997a) and De Medeiros et al. (1997), which were determined from our KPNO and CORAVEL observations, respectively. For the F star, the two $v \sin i$ values are identical (12.9 km s^{-1}), while for the G star the values equal 17.0 (Fekel 1997a) and 15.8 km s^{-1}, or an average of 16.4 km s^{-1}. The uncertainty of these determinations is 1 km s^{-1} or less.

5. SPECTRAL TYPES, LUMINOSITY RATIO, AND MAGNITUDE DIFFERENCE

Using a spectrum addition technique, Strassmeier & Fekel (1990) determined spectral types of F9 IV and G5 IV for the primary and secondary components, respectively. We have reexamined the spectral types of the two stars using the same technique, our KPNO red-wavelength spectra, and a more extensive grid of reference stars (Fekel 1997a). Spectra of stars from the list of Keenan & McNeil (1989) were obtained with the same equipment as our spectra of 54 Cam. 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 best reproduce the spectrum of 54 Cam in the 6430 Å region.

The starting point for our new determination was the spectral types of Strassmeier & Fekel (1990). Having a limited grid of stars, they considered abundance variations among their standards to be a second-order effect that was ignored. Their best fit to the spectrum of 54 Cam was with a combination of HR 3862 plus μ Her A. HR 3862 is slightly metal-poor, [Fe/H] $= -0.11 \pm 0.10$, while μ Her A is metal-rich, [Fe/H] $= 0.24 \pm 0.09$. We find an improved fit (Fig. 2) to the red-wavelength spectrum of 54 Cam with a weighted combination of 5 Ser (F8 IV–V; Johnson & Morgan 1953), having [Fe/H] $= -0.08 \pm 0.06$, plus ω Sgr (G5 IV; Keenan & McNeil 1989), having [Fe/H] $= 0.08 \pm 0.07$. All the abundances and their errors are from the analysis catalog of Taylor (1994). The resulting continuum intensity ratio is F/G = 0.639 with an estimated uncertainty of 0.05. To determine the luminosity ratio, the intrinsic line strength ratio must be taken into account since the intrinsic line strength of the G star is greater than that of the F star. A direct comparison in the 6430 Å region of the Fe I line equivalent widths of 5 Ser relative to ω Sgr results in a ratio of 0.810. However, the metallicity difference of the two best reference stars makes the continuum intensity ratio too large. From an examination of similar reference stars with a variety of metallicities, we estimate that the correction for the metallicity difference compensates for the intrinsic line-strength ratio correction and so have assumed that the uncorrected continuum intensity ratio is equal to the luminosity ratio. This results in a magnitude difference of 0.49 mag. The 6430 Å region is about 0.6 between the central wavelengths of the V and R bandpasses. Guided by the colors of stars of the appropriate spectral types, we find $\Delta V = 0.54 \pm 0.1$ mag and $\Delta B = 0.74 \pm 0.1$ mag. Assuming $V = 6.49$ (Eggen 1978), the apparent visual magnitudes for the components are $V_F = 7.01 \pm 0.1$ mag and $V_G = 7.55 \pm 0.1$ mag.

6. LITHIUM ABUNDANCES

Lithium abundances have previously been determined by Liu et al. (1993) and Randich et al. (1994). Liu et al. (1993) found that the lithium line equivalent widths of the two components are quite different. Our measured equivalent widths are 103 and 43 mÅ for the F and G stars, respectively. Correcting for line dilution due to the two continua results in equivalent widths of 167 and 110 mÅ.

The lithium abundances of the two stars are very dependent on the assumed effective temperatures. Recently, Flower (1996) provided updated $(B-V)$-$T_{\rm eff}$ scales. Guided by the $B-V$ colors of our reference stars and Flower's scales, we assume effective temperatures of 6100 ± 100 and 5400 ± 100 K for the F and G stars, respectively. According

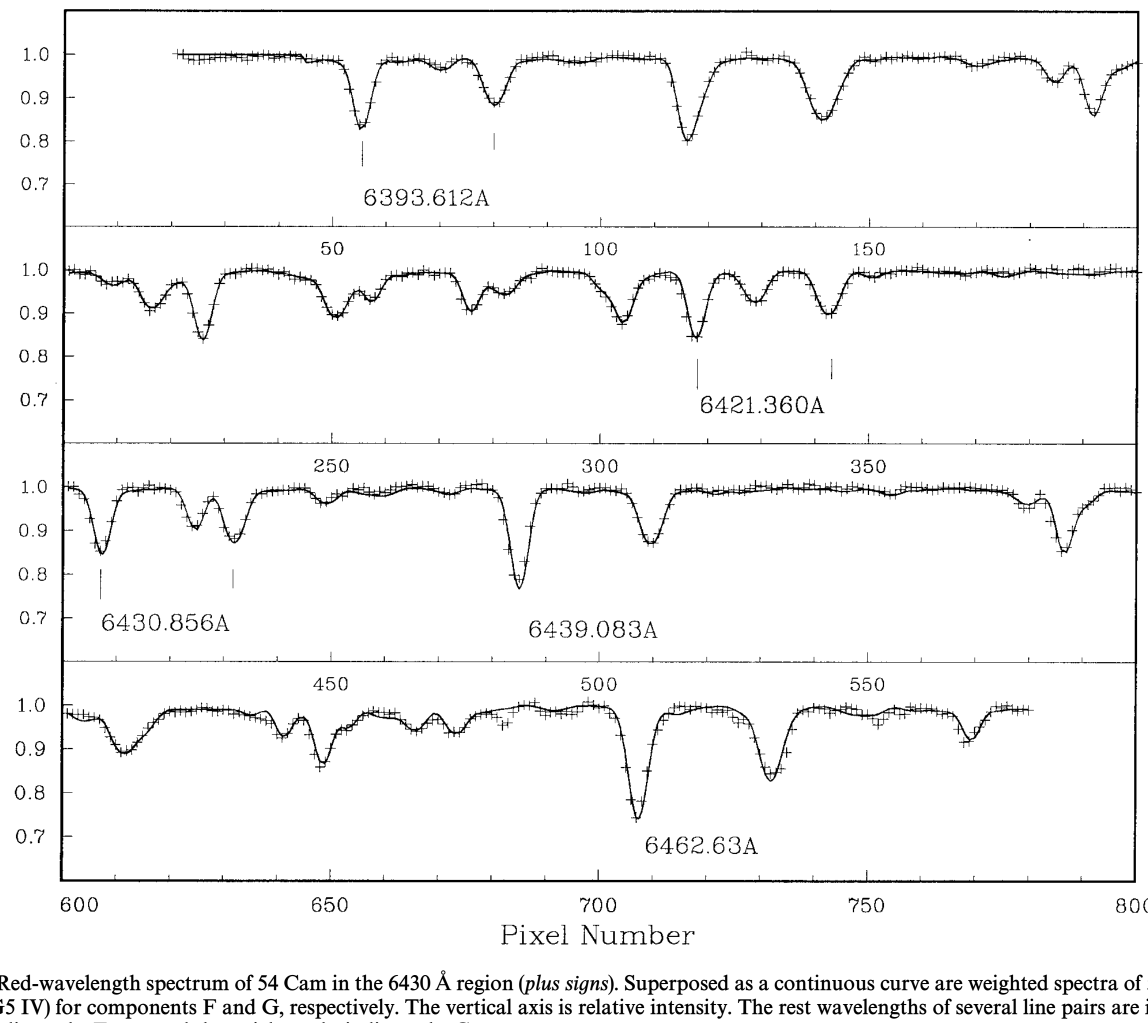

FIG. 2.—Red-wavelength spectrum of 54 Cam in the 6430 Å region (*plus signs*). Superposed as a continuous curve are weighted spectra of 5 Ser (F8 IV–V) and ω Sgr (G5 IV) for components F and G, respectively. The vertical axis is relative intensity. The rest wavelengths of several line pairs are identified. Long tick marks indicate the F star, and short tick marks indicate the G star.

to Table 2 of Soderblom et al. (1993), those temperatures and the corrected equivalent widths result in log ϵ(Li) = 3.4 for the F star and log ϵ(Li) = 2.3 for the G star, with an estimated uncertainty of 0.3 for both values.

7. DISCUSSION

The 54 Cam system is very interesting from an evolutionary point of view. Despite virtually identical minimum masses, the mass difference between the two components is great enough so that some properties of the stars are significantly different. Indeed, the F and G stars are on opposite sides of the Hertzsprung gap, the slightly more massive star having taken the "plunge" and evolved rapidly almost to the base of the giant branch. Thus, the G star currently has a convection zone that is significantly deeper than that of the F star.

The apparent visual magnitudes (Table 3) and the *Hipparcos* parallax of 0"00984 ± 0"00073 (ESA 1997) result in $M_v = 1.94 \pm 0.19$ and 2.52 ± 0.19 for the F and G stars, respectively. Assuming the $B-V$ colors, 0.54 and 0.75, of our reference stars for the F and G stars, respectively, and Flower's (1996) calibration, we computed $L_F = 13.30 \pm 2.33\, L_\odot$ and $L_G = 9.08 \pm 1.59\, L_\odot$ (Table 3).

A comparison of the luminosities and temperatures of the components with solar-abundance evolutionary tracks of Schaller et al. (1992) results in a mass of 1.6 $M_\odot$ (Fig. 3), giving the system an age of 2.3 Gyr. Tracing the stars back to their position on the zero-age main sequence (ZAMS) produces a spectral type of about A8 and an effective temperature of approximately 7550 K.

The photometric period of 10.163 days (Eaton et al. 1981) is assumed to be the rotational period of the active G star. This period and our mean $v \sin i$ result in a minimum radius of 3.3 $R_\odot$, consistent with its subgiant classification. The rotational period of the F star is unknown, but with the assumption that it is also pseudosynchronously rotating, we obtain a minimum radius of 2.6 $R_\odot$. The mass of 1.6 $M_\odot$ for the components results in an orbital inclination of 58°. If the rotation axes are aligned with the orbital axis (Stawikowski & Glebocki 1994), the radii are 3.1 ± 0.3 and $3.9 \pm 0.3\, R_\odot$ for the F and G stars, respectively. From the computed luminosities and assumed effective temperatures the radii are 3.3 ± 0.3 and $3.5 \pm 0.3\, R_\odot$ for the F and G stars, respectively. Thus, weighted averages (Table 3) are 3.2 ± 0.2 and $3.7 \pm 0.2\, R_\odot$. The good agreement of those results supports the assumptions that the orbital and rotational inclinations are equal and that the F star is pseudosynchronously rotating. If, from its position relative to the evolutionary tracks in Figure 3, the mass of the G star is assumed to be 1.60 $M_\odot$, from the mass ratio the mass of the F star is 1.59 $M_\odot$. We estimate errors of $\leq 0.1\, M_\odot$ for the masses. Some of the above derived parameters are quite close to the values estimated by Harper (1939a).

TABLE 3

DERIVED PROPERTIES OF 54 CAMELOPARDALIS

Parameter	Value
$M_{v,F}$ (mag)	1.94 ± 0.19
$M_{v,G}$ (mag)	2.52 ± 0.19
L_F ($L_\odot$)	13.30 ± 2.33
L_G ($L_\odot$)	9.08 ± 1.59
$T_{\rm eff,F}$ (K)	6100 ± 100
$T_{\rm eff,G}$ (K)	5400 ± 100
R_F ($R_\odot$)	3.2 ± 0.2
R_G ($R_\odot$)	3.7 ± 0.2
M_F ($M_\odot$)	1.59 ± 0.1
M_G ($M_\odot$)	1.60 ± 0.1

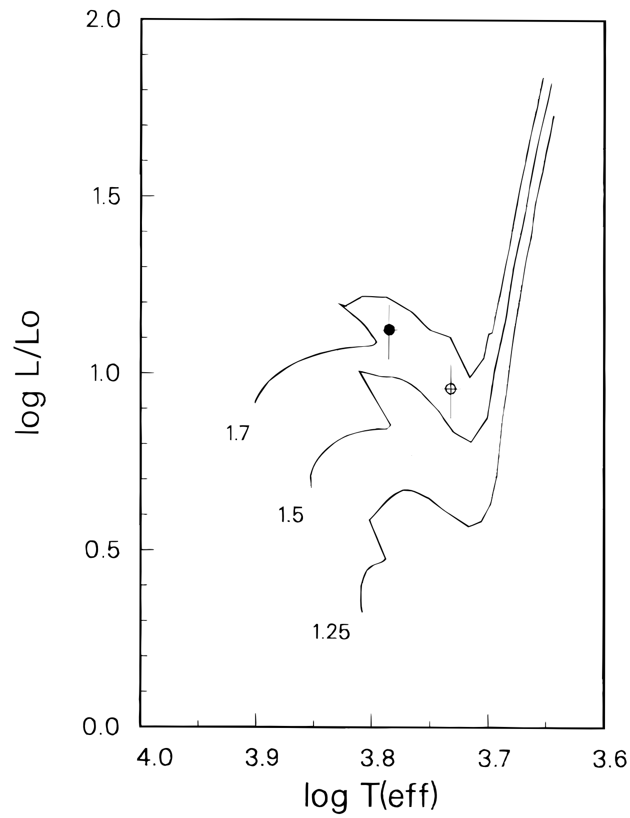

FIG. 3.—Components of 54 Cam compared with several different-mass solar-abundance evolutionary tracks of Schaller et al. (1992).

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. Hall (1986) found that the component of 54 Cam having the photometric light variations is rotating pseudosynchronously. With our improved elements the predicted pseudosynchronous rotational period is 10.12 days, compared with an observed photometric period of 10.16 days for the G star. Thus, the G star is indeed pseudosynchronously rotating despite its rapid evolution across the Hertzsprung gap.

That 54 Cam has a significant eccentricity of 0.125 is not particularly surprising for a chromospherically active binary with a period greater than 10 days. In the catalog of Strassmeier et al. (1993), Fekel (1996) found 30 systems with orbital periods between 10 and 20 days, 43% of which have eccentricities greater than 0.05. The orbital period and eccentricity of 54 Cam are similar to two other recently studied systems, HD 8357 (=AR Psc; Fekel 1996) and 42 Cap (Fekel 1997b).

Population I stars begin their lives on the main sequence with a lithium abundance of log ϵ(Li) ~ 3.2 (Balachandran 1990). This initial abundance is reduced when lithium reaches regions with temperatures hot enough for nuclear reactions. Standard theoretical models (Iben 1967) indicate that by the time a low-mass star reaches the base of the red giant branch, destruction and dilution of surface lithium have reduced its abundance by a factor of roughly 10. The lithium abundances of the two components of 54 Cam are consistent with such a model.

It is also of interest to compare the lithium abundances of 54 Cam with those of F dwarfs and G subgiants found in clusters of known ages. Boesgaard & Tripicco (1986) discovered that F stars in the Hyades with effective temperatures near 6600 K have lithium abundances that are a factor of 30 or more below those of hotter and cooler F stars. Such lithium-dip stars have been found in clusters as old as 2 Gyr (Hobbs & Pilachowski 1986). However, as seen in M67, by the age of 4–5 Gyr the lithium-dip stars have evolved off the main sequence (Balachandran 1995). The lithium abundance of the F star of 54 Cam is that of a ZAMS star, while the abundance of the G star appears to be consistent with standard theory. Those results indicate that both components were originally hotter and more massive than the lithium-dip stars. The lithium abundance of the G star is nearly identical to that of 42 Cap A, a less massive G subgiant that Fekel (1997b) has recently discussed.

Although made more difficult by its double-lined nature and broadened spectral lines, spectrum synthesis of the spectrum of 54 Cam should be a future priority in order to determine the effective temperatures and gravities of the components, to confirm the solar abundances, and to improve the lithium abundance determinations. The observational results for this system, consisting of two subgiants on opposite sides of the Hertzsprung gap, will have even greater value once optical interferometers, such as the one being built on Mount Wilson, begin regular operation and accurate masses can be determined. With such improved parameters, this system would then provide an important confrontation with theoretical evolutionary tracks.

This research has been supported in part by NASA grants NAG 8-1014 and NCCW-0085, plus National Science Foundation (NSF) grant HRD 95-50561 to Tennessee State University. J. J. E. is grateful to Willet I. Beavers, who initiated the Fick radial velocity project and directed it until 1987, and to Philip N. Appleton for his continued support of the project. The Fick project has been supported by NSF grants AST 82-05956, AST 86-04324, and AST 88-19696.

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