10-1988

Chromospherically Active Stars. V. HD 91816=LR Hya: A Double-Lined BY Draconis Type Binary

Francis C. Fekel
Vanderbilt University

Kim Gillies
Kitt Peak National Observatory

John L. Africano
Kitt Peak National Observatory

Robert Quigley
Western Washington University

Recommended Citation

Fekel, F.C.; Gillies, K.; Africano, J.; Quigley, R. "Chromospherically Active Stars. V. HD 91816=LR Hya: A Double-Lined BY Draconis Type Binary" Astronomical Journal v.96, p.1426 (1988)

THE ASTRONOMICAL JOURNAL VOLUME 96, NUMBER 4 OCTOBER 1988

CHROMOSPHERICALLY ACTIVE STARS. V. HD 91816 = LR HYA: A DOUBLE-LINED BY DRACONIS TYPE BINARY

FRANCIS C. FEKEL[a]
Dyer Observatory, Vanderbilt University, Nashville, Tennessee 37235

KIM GILLIES AND JOHN AFRICANO
Kitt Peak National Observatory, National Optical Astronomy Observatories,[b] P.O. Box 26732, Tucson, Arizona 85726-6732

ROBERT QUIGLEY[a]
Department of Physics and Astronomy, Western Washington University, Bellingham, Washington 98225

Received 10 May 1988; revised 14 June 1988

ABSTRACT

The star HD 91816 = LR Hya consists of two nearly identical K0 dwarfs. This double-lined binary has an orbital period of 6.866 days and an orbital eccentricity of 0.014 ± 0.003, which is thought to be real. The individual minimum masses are $0.55\mathcal{M}_\odot$ each, implying an inclination of $61° \pm 3°$. The orbital period differs substantially from the previously determined photometric periods of 3.14 and 4.86 days. Either the photometric periods are incorrect or this relatively short-period system is not rotating synchronously. If the latter conclusion is correct, this system imposes important constraints on theories of synchronization of binary systems. The components have little or no lithium, implying that the system has an age equal to or greater than the Hyades cluster. A spectroscopic parallax of $0\overset{''}{.}027$ is in agreement with the trigonometric value of $0\overset{''}{.}029$. Additional photometry should be obtained to determine the correct photometric period. Data on 20 classical BY Draconis binaries do not support the claim of Lucy and Ricco (1979) that double-lined spectroscopic binaries have a mass-ratio distribution that peaks at 0.97.

I. INTRODUCTION

Bidelman (1981), continuing his reports of "early results" from a moderate-dispersion objective-prism survey of the southern sky, listed HD 91816 = LR Hya ($\alpha = 10^{\rm h}\,33^{\rm m}\,33^{\rm s}$, $\delta = -11°39'01''$, 1950) as a dK0 star with slightly fuzzy lines and an apparent magnitude of 7.9. Bopp *et al.* (1984) reported detecting light variations with an amplitude of 0.02 mag in V and a period of 3.1448 days. From ten Kitt Peak observations, their V magnitude is 8.04. One of their two spectroscopic observations showed double lines. Because of its spectral type and light variations, Bopp *et al.* (1984) identified it as a BY Draconis type variable. Fekel, Moffett, and Henry (1986) found an orbital period of 6.865 days and $v \sin i = 6 \pm 2$ km s^{-1} for both components. In this paper, we present the spectroscopic observations for the orbital-period determination and discuss other properties of this chromospherically active system.

II. RADIAL-VELOCITY OBSERVATIONS AND REDUCTIONS

From 1982 to 1988, 32 high-dispersion spectroscopic observations were obtained at Kitt Peak National Observatory with the coudé-feed telescope. Of these spectrograms, 30 were double lined. Table I lists the spectrograph and detector combinations for these observations. All but one of these observations included the wavelength range 6390–6455 Å. A single observation obtained on Julian Date 2445852 was centered at 6690 Å and included the lithium line at 6708 Å.

The vast majority of the radial velocities listed in Table II were determined relative to β Vir or β Gem, both International Astronomical Union velocity standards, which have radial velocities of 3.8 km s^{-1} (Fekel 1981) and 3.3 km s^{-1} (Pearce 1955), respectively. Other reference stars and their assumed velocities are HR 6469 A and μ Her A, with velocities of -1.2 km s^{-1} (Fekel, unpublished) and -15.6 km s^{-1} (Wilson 1953). Details of the cross-correlation reduction program have been given by Fekel, Bopp, and Lacy (1978).

III. ORBIT

Bopp *et al.* (1984) suggested that the orbital period might be close to the photometric period, as is usually the case for short-period chromospherically active binaries. In searching for the value of the orbital period, it quickly became apparent that this was not the case. Instead of a period near 3.1 days, a period near 6.8 days was found. Preliminary orbital elements for each component were determined with a slightly modified version of the computer program of Wolfe, Horak, and Storer (1967). The elements of each component were separately refined with a differential-corrections program (Barker, Evans, and Laing 1967). The separate determinations of the period, center-of-mass velocity, and eccentricity agreed within their uncertainties. Thus, a single orbital-element solution was determined from the combined velocities and is given in Table III. These orbital elements supersede the values given by Strassmeier *et al.* (1988a). Velocities from the two observations, obtained when the components were blended, were given zero weight, as were two other velocities, one for each component, which had large residuals. All other velocities were given unit weight, although those obtained with the Fairchild CCD detector may not be quite as accurate because of the lower signal-to-noise ratio of these spectra. Since the formal solution of the

---

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

[b] Operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

TABLE I. Spectrograph/detector combinations.

Detector	Dispersion (Å mm^{-1})	Resolution (Å)	Wavelength range (Å)	Source code
Fairchild CCD	14.8	0.45	165	KF
RCA CCD	4.2	0.30	65	KR
Texas Instruments CCD	7.6	0.23	90	KT1
Texas Instruments CCD	7.0	0.18	84	KT2

spectroscopic orbit gave a value for the eccentricity of 0.0142 ± 0.0028, it is significant according to the precepts of Lucy and Sweeney (1971), and an $e = 0$ solution was *not* adopted. The reality of this very small but nonzero eccentricity is given some support by the values of e and ω determined from the individual component solutions. For the slightly stronger-lined component, which we call component A, $e = 0.016$ and $\omega = 10°$, while for component B, $e = 0.013$ and $\omega = 167°$. Thus, the eccentricities are nearly identical and ω differs by 157°. The observed radial velocities and the computed radial-velocity curve are plotted in Fig. 1.

IV. ACTIVE-CHROMOSPHERE CHARACTERISTICS

Bidelman (1981), who often detects Ca II H and K emission on objective-prism plates, did not detect any emission lines in the spectrum of HD 91816. No observations of the H and K region were made of this star during the survey of Fekel, Moffett, and Henry (1986). There is no previously known detection of such emission. Yet, HD 91816 is listed as a confirmed chromospherically active binary (Strassmeier *et al.* 1988). It was included as a *confirmed* member of this type of star because its short orbital period and photometric variations strongly suggest that it should have Ca II H and K emission lines. Two other such binaries are noted in the catalog. Of these two, BH Vir and HD 143313, Ca II H and K emission has been confirmed for HD 143313 (Bopp 1988).

An observation of the Ca II H and K region with a resolution of 0.3 Å was obtained on JD 2447246 at phase 0.2 with the Kitt Peak coudé-feed telescope, coudé spectrograph, and Texas Instruments CCD detector. Figure 2 shows single H and K emission lines. Presumably, both components have emission lines, but the separation of the lines of the two components, $\Delta V = 34$ km s^{-1}, is not large enough to resolve the individual components.

TABLE II. Radial velocities of HD 91816.

HJD 2400000 +	Phase	V_A (km s^{-1})	$(O-C)_A$ (km s^{-1})	V_B (km s^{-1})	$(O-C)_B$ (km s^{-1})	Source	Standard
45075.749	0.995	60.9	1.3	-55.3	2.0	KF	β Gem
45075.768	0.998	58.8	-0.8	-57.4	-0.1	KF	β Gem
45076.746	0.140	40.9[a]	3.3	-33.6	1.7	KF	β Gem
45078.743	0.431	-49.5	1.0	59.2[a]	6.1	KF	β Gem
45356.959	0.954	55.6	-1.4	-56.2	-1.4	KR	β Vir
45358.868	0.232	1.3[a]	-5.6	1.3[a]	5.8	KR	β Gem
45359.948	0.389	-43.5	-0.7	45.1	-0.3	KR	β Gem
45360.897	0.527	-55.4	-0.7	57.0	-0.3	KR	β Vir
45361.832	0.663	-28.4	0.4	31.5	0.1	KR	β Vir
45447.662	0.165	30.3	0.2	-28.2	-0.4	KR	β Gem
45448.678	0.313	-23.4	-1.9	22.0	-2.0	KR	β Gem
45449.765	0.471	-54.4	0.2	57.9	0.6	KR	β Vir
45450.729	0.611	-43.2	-0.6	44.8	-0.4	KR	β Vir
45451.710	0.754	1.2[a]	-0.9	1.2[a]	0.8	KR	β Vir
45717.953	0.533	-53.7	0.6	57.3	0.3	KT1	β Vir
45719.021	0.689	-19.4	1.5	24.8	1.4	KT1	μ Her
45719.978	0.828	28.4	0.5	-24.7	0.9	KT1	β Vir
45720.952	0.970	58.9	0.4	-56.3	-0.0	KT1	β Vir
45721.960	0.117	44.2	0.2	-41.6	0.1	KT1	β Vir
45783.756	0.117	43.5	-0.3	-42.1	-0.6	KT1	HR 6469 A
45811.702	0.188	22.2	-0.3	-20.4	-0.3	KT1	β Vir
45812.770	0.343	-31.2	-0.2	34.2	0.6	KT1	β Vir
45813.705	0.480	-54.6	0.4	58.2	0.5	KT1	β Vir
45814.783	0.637	-36.7	-0.3	38.5	-0.5	KT1	β Vir
45852.683	0.157	32.7	0.1	-31.0	-0.7	KT1	β Vir
45853.690	0.303	-18.5	-0.1	20.2	-0.8	KT1	β Vir
45855.686	0.594	-46.1	0.1	48.9	0.1	KT1	β Vir
46076.958	0.823	26.5	0.3	-23.2	0.6	KT1	β Vir
46534.742	0.500	-55.1	0.4	57.9	-0.3	KT1	β Vir
46866.902	0.880	43.3	0.1	-41.8	-0.9	KT1	β Vir
46867.778	0.007	60.0	0.5	-57.8	-0.5	KT1	β Vir
47248.797	0.503	-55.6	-0.1	58.3	0.2	KT2	β Vir

[a] Velocity given zero weight.

1988AJ.....96.1426F

TABLE III. Orbital elements.

$P = 6.86569 \pm 0.00007$ days (m.e.)
$T = 2446538.18 \pm 0.22$ HJD
$\gamma = 1.2 \pm 0.1$ km s^{-1}
$K_A = 57.5 \pm 0.2$ km s^{-1}
$K_B = 57.7 \pm 0.3$ km s^{-1}
$e = 0.014 \pm 0.003$
$\omega_A = 0^\circ\!.1 \pm 11^\circ\!.4$
$\omega_B = 180^\circ\!.1 \pm 11^\circ\!.4$
$a_A \sin i = 5.43 \pm 0.02 \times 10^6$ km
$a_B \sin i = 5.45 \pm 0.03 \times 10^6$ km
$\mathscr{M}_A \sin^3 i = 0.547 \pm 0.005 \mathscr{M}_\odot$
$\mathscr{M}_B \sin^3 i = 0.545 \pm 0.004 \mathscr{M}_\odot$
$\mathscr{M}_A/\mathscr{M}_B = 1.004 \pm 0.005$
Standard error of an observation of unit weight = 0.8 km s^{-1}

Bopp *et al.* (1984) stated that the Hα absorption features do not appear to be affected by emission. Fekel, Moffett, and Henry (1986) find Hα to be a strong absorption feature. Figure 3 shows the partially resolved Hα profiles of the two components. This spectrum was obtained with the McDonald Observatory 2.1 m telescope, coudé spectrograph, and 1728 element Reticon detector, and has a resolution of 0.55 Å.

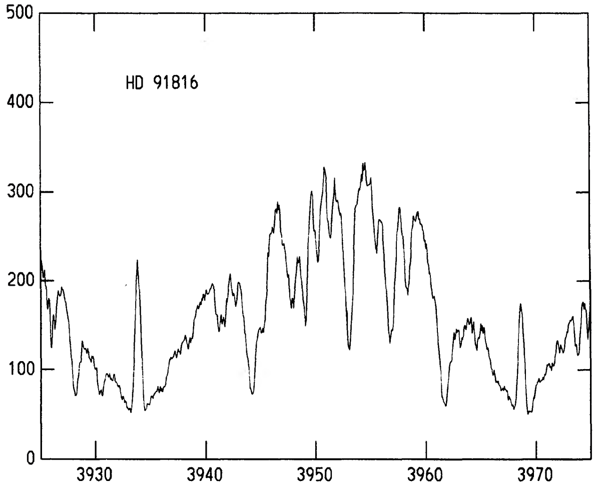

FIG. 2. Ca II H and K regions of HD 91816 showing the H and K lines at an orbital phase that results in single blended lines. The horizontal axis is in Ångstroms and the vertical axis is counts.

V. DISCUSSION

From Bopp *et al.* (1984), the average V magnitude and colors of HD 91816 are $V = 8.04$, $U - B = 0.50$, and $B - V = 0.85$. Such colors correspond to a K0 V classification according to the color–spectral-type relation of Johnson (1966) and are in agreement with the dK0 type of Bidelman (1981). Thus, the spectral type of K3–4 V for both components given in Fekel, Moffett, and Henry (1986) and listed by Strassmeier *et al.* (1988) is incorrect. This K3–4 V classification actually belongs to the comparison star used by Bopp *et al.* (1984).

From Popper (1980), the mean mass of three K0 V stars is $0.82\mathscr{M}_\odot$. If a range of 0.75–0.9 $\mathscr{M}_\odot$ is considered, then the orbital inclination is 61° ± 3° and is rather tightly constrained.

Bopp *et al.* (1984) found small brightness variations for which they determined a period of 3.1448 days. They assumed, as is normally done for chromospherically active stars, that this photometric period represented the rotation period of the star. Assuming a typical radius for a K0 V star, the predicted equatorial rotational velocity is 13.7 km s^{-1}. However, Fekel, Moffett, and Henry (1986) determined that $v \sin i = 6 \pm 2$ km s^{-1}. Thus, the expected spin inclination is 26° ± 10°. It is generally assumed that the orbital and spin axes of the stars in a binary system are parallel. Even if the uncertainty on the spin inclination is increased due to the uncertainty of the actual size of the K0 V star, this inclination is still substantially different from the value of 61° ± 3° for the orbital inclination. Thus, either the two inclinations are not parallel, the photometric period is not the rotation period of the star, or the photometric period is incorrect. Some chromospherically active stars appear to have two spot groups on their surface. If these two groups were about 180° apart, the rotation period would be double that of the photometric period, or 6.29 days.

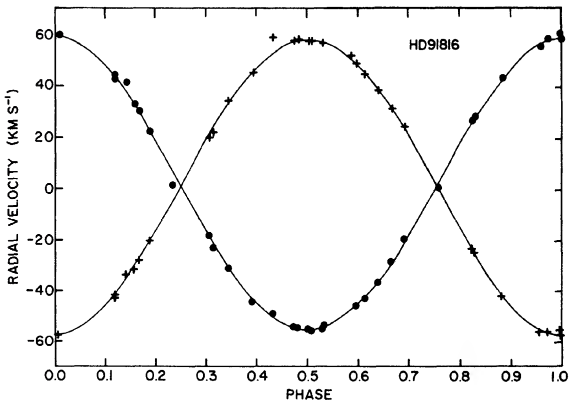

FIG. 1. Observations and computed radial-velocity curves of HD 91816. The ●'s represent velocities of the star with stronger lines, while the + 's are for the star with weaker lines.

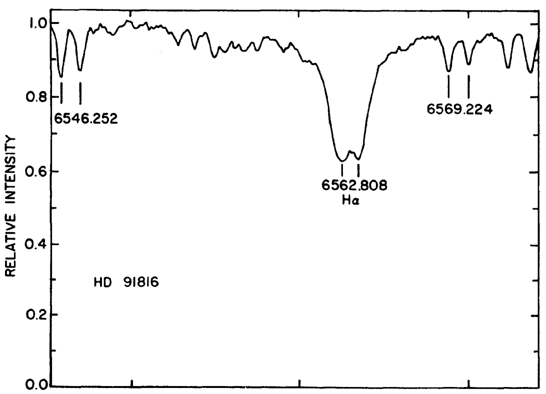

FIG. 3. Partially blended profile of the Hα line of HD 91816.

As noted by Fekel, Moffett, and Henry (1986), this would make the photometric period about 8% shorter than the spectroscopic period. Photometric periods typically differ from spectroscopic periods by several percent, but an 8% difference is relatively large.

Strassmeier *et al.* (1988b) have carried out a recent analysis of new photometric data obtained over the 1984–1985 observing season. They find a very different photometric period of 4.86 ± 0.03 days, with no evidence for a period at 3.145 days or near the orbital period of 6.87 days. However, once again, the possible amplitude is quite small relative to the uncertainty of the individual observations and the periodicity is not particularly obvious to the eye.

If the 4.86 day period is real and is interpreted as the rotation period of the star, the resulting rotational velocity of the star is 8.8 km s^{-1}. This is within the uncertainty of the spectroscopic value of $V = 7 \pm 2$ km s^{-1}, assuming $\sin i = 61°$.

Bopp *et al.* (1984) note that the period determined from the Cloudcroft and McDonald Observatory observations is supported by their independent set of photometry obtained at Kitt Peak National Observatory. However, neither dataset has a very large number of observations, only 17 and 10, respectively. Our analysis of their data with a period-finding algorithm suggests a number of possible periods for each dataset. We suggest that the small number of observations, combined with the low amplitude of the variability and possible intrinsic variations due to the growth and decay of the spots, may have resulted in a nonunique and spurious period determination.

Synchronization timescales are substantially shorter than circularization timescales (Zahn 1977; Tassoul 1988). Our value of $v \sin i$ is consistent with synchronized orbital and rotation periods. From the tidal-friction theory of Zahn (1977), the synchronization time for HD 91816 is 2×10^7 yr, substantially less than the minimum age of the system determined from its maximum lithium abundance.

The circularization time from the tidal-friction theory of Zahn (1977) is 3×10^{10} yr. However, Tassoul (1988) has recently claimed that a purely hydrodynamic mechanism is more efficient in producing both synchronization and circularization in late-type binaries. From his Eq. (4), the circularization time is 2.4×10^8 yr for HD 91816. This is in rough agreement, given the uncertainties and assumptions in the theory, with the minimum age of this system.

It appears that the system should be expected to be synchronized and possibly circularized. The lack of photometric evidence for synchronization poses a puzzle that might be solved by more accurate photometry. However, if either of the suggested photometric periods is correct, indicating substantial nonsynchronous rotation, this system would impose important constraints on theories of synchronization of late-type binaries.

The spectrum obtained of the lithium region on JD 2445852 at phase 0.157 shows no obvious lithium line of either component. An upper limit of 5 mÅ for the equivalent width of each component was determined. Assuming an effective temperature of 5200 K (Popper 1980) and the curve-of-growth results for lithium of Pallavicini, Cerruti-Sola, and Duncan (1987), the abundance of lithium is log $n(\mathrm{Li}) \leqslant 0.5$. Pleiades stars of similar temperatures have log $n(\mathrm{Li}) \geqslant 2.0$ (Duncan and Jones 1983), while similar Hyades stars have log $n(\mathrm{Li}) \leqslant 0.48$ (Cayrel *et al.* 1984). Thus, based on the lithium results, HD 91816 must be at least as old as the Hyades cluster, which has a nuclear age of 7×10^8 yr (Patenaude 1978). This age is consistent with its *UVW* space motions, which are + 39, − 20, and − 14 km s^{-1}, respectively (Strassmeier *et al.* 1988a), which indicate, according to the definition of Eggen (1969), that HD 91816 is not younger than the Hyades cluster.

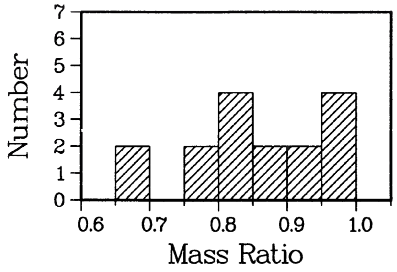

FIG. 4. Distribution of mass ratios for the BY Draconis double-lined binaries listed in Strassmeier *et al.* (1988).

From the measurement of five pairs of lines in each of two spectrograms, the magnitude difference $\Delta R = 0.08 \pm 0.03$ mag and is assumed to be the same in the V band. The V magnitudes of the components are 8.75 and 8.83 for components A and B, respectively. Assuming an absolute magnitude of 5.9 (Corbally and Garrison 1984) for component A results in a distance of 37 pc or a parallax of 0ʺ027. This is in excellent agreement with the trigonometric parallax of 0ʺ029 ± 0ʺ012 (p.e.) (Jenkins 1952).

Lucy and Ricco (1979) claimed that double-lined spectroscopic binaries have a mass-ratio distribution that peaks at a mass ratio $q = 0.97$ and that this peak is a clue to the formation mechanism for short-period binaries. One subset of their binary star sample was the BY Draconis variables, for which they found a similar peak. They argued that this value of q was not due to selection effects but was real.

The question of a mass-ratio peak at $q = 0.97$ is re-examined with the data listed in Strassmeier *et al.* (1988a). Bopp and Fekel (1977) proposed that the BY Draconis variables are K and M dwarf stars having low-amplitude light variations with periods of a few days and showing Ca II H and K emission in their spectra. Fekel, Moffett, and Henry (1986) expanded the definition to include F and G dwarfs as well and called them early-type BY Dra stars. To be consistent with the analysis of Lucy and Ricco (1979), we will consider only the K and M dwarfs of the original definition. Our sample consists of the 19 systems with orbital elements that are identified as BY Dra stars in Table I of Strassmeier *et al.* (1988a), plus the dMe double-lined binary Gl 268 (Tomkin and Pettersen 1986). Thus, the number of systems that we will consider is slightly more than twice the number considered by Lucy and Ricco (1979). In addition, several of the systems have improved orbital elements. Mass ratios are taken from Table V of Strassmeier *et al.* (1988a) or the original references. Figure 4 is a histogram of the number of double-lined systems with mass ratios grouped in intervals of 0.05. Of the nine systems considered by Lucy and Ricco (1979), four were shown as having mass ratios between 0.95 and 1.0. Our Fig. 4 shows quite a different story. Six of the 15 double-lined systems have mass ratios between 0.91 and 1.0, but six also have mass ratios between 0.81 and 0.90. Not plotted are five single-lined systems with mass ratios $\leqslant 0.6$. Thus, the present more extensive data do not support a sharp peak of the mass ratio at 0.97.

We thank G. Henry for his observation of Hα, and D. Willmarth for his invaluable help over the years with the coudé-feed spectograph and CCD detectors. We thank the referee for suggesting that a new look at the distribution of the mass ratios of BY Dra binaries might be of interest.

REFERENCES

Barker, E. S., Evans, D. S., and Laing, J. D. (1967). R. Obs. Bull. No. 130.

Bidelman, W. P. (1981). Astron. J. **86**, 553.

Bopp, B. W. (1988). Private communication.

Bopp, B. W., Africano, J. L., Goodrich, B. D., Henry, G. W., Hall, D. S., and Barksdale, W. S. (1984). Inf. Bull. Var. Stars No. 2604.

Cayrel, R., Cayrel de Strobel, G., Campbell, B., and Dappen, W. (1984). Astrophys. J. **283**, 205.

Corbally, C. J., and Garrison, R. F. (1984). In *The MK Process and Stellar Classification*, edited by R. F. Garrison (University of Toronto, Toronto), p. 277.

Duncan, D. K., and Jones, B. F. (1983). Astrophys. J. **271**, 663.

Eggen, O. J. (1969). Publ. Astron. Soc. Pac. **81**, 553.

Fekel, F. C. (1981). Astrophys. J. **248**, 670.

Fekel, F., Bopp, B. W., and Lacy, C. H. (1978). Astron. J. **83**, 1455.

Fekel, F. C., Moffett, T. J., and Henry, G. W. (1986). Astrophys. J. Suppl. **60**, 551.

Jenkins, L. F. (1952). *General Catalog of Trigonometric Stellar Parallaxes* (Yale Observatory, New Haven).

Johnson, H. L. (1966). Annu. Rev. Astron. Astrophys. **4**, 193.

Lucy, L. B., and Ricco, E. (1979). Astron. J. **84**, 401.

Lucy, L. B., and Sweeney, M. A. (1971). Astron. J. **76**, 544.

Pallavicini, R., Cerruti-Sola, M., and Duncan, D. K. (1987). Astron. Astrophys. **174**, 116.

Patenaude, M. (1978). Astron. Astrophys. **66**, 225.

Pearce, J. A. (1955). Trans. IAU **9**, 441.

Popper, D. M. (1980). Annu. Rev. Astron. Astrophys. **18**, 115.

Strassmeier, K. G., Hall, D. S., Boyd, L., and Genet, R. M. (1988b). Astrophys. J. Suppl. (in press).

Strassmeier, K. G., Hall, D. S., Zeilik, M., Nelson, E., Eker, Z., and Fekel, F. C. (1988a). Astron. Astrophys. Suppl. **72**, 291.

Tassoul, J. L. (1988). Astrophys. J. Lett. **324**, L71.

Tomkin, J., and Pettersen, B. R. (1986). Astron. J. **92**, 1424.

Wilson, R. E. (1953). *General Catalog of Stellar Radial Velocities* (Carnegie Institution, Washington, DC).

Wolfe, R. H., Horak, H. G., and Storer, N. W. (1967). In *Modern Astrophysics*, edited by M. Hack (Gauthiers-Villars, Paris), p. 251.

Zahn, J. P. (1977). Astron. Astrophys. **57**, 383.