1-1988

Chromospherically Active Stars. IV. HD 178450=V478 LYR: an Early-Type BY Draconis Type Binary

Francis C. Fekel
Vanderbilt University

Recommended Citation
Fekel, F.C. "Chromospherically Active Stars. IV. HD 178450=V478 LYR: an Early-Type BY Draconis Type Binary" Astronomical Journal v.95, p.215 (1988)

THE ASTRONOMICAL JOURNAL VOLUME 95, NUMBER 1 JANUARY 1988

CHROMOSPHERICALLY ACTIVE STARS. IV. HD 178450 = V478 LYR: AN EARLY-TYPE BY DRACONIS TYPE BINARY

FRANCIS C. FEKEL[a),b)]
Dyer Observatory, Vanderbilt University, Nashville, Tennessee 37235
Received 11 August 1987

ABSTRACT

The variable star HD 178450 = V478 Lyr is a chromospherically active G8 V single-lined spectroscopic binary with a period of 2.130514 days. This star has strong ultraviolet emission features and a filled-in Hα absorption line which is variable in strength. It is classified as an early-type BY Draconis system and is similar in many respects to the BY Dra star HD 175742 = V775 Her. The unseen secondary of HD 178450 has a mass of about $0.3\mathscr{M}_{\odot}$ and is probably an M2–M3 dwarf. The inclination of the system is $67° \pm 12°$. The lithium abundance of the G8 dwarf results in an age for the system that is somewhat less than that of the Hyades cluster. The system is relatively nearby, with an estimated distance of 26 pc, or a parallax of 0."039.

I. INTRODUCTION

Joy and Wilson (1949) detected Ca II H and K emission in HD 178450 = V478 Lyr ($\alpha = 19^h0^m6$, $\delta = 30°05'$, 1900). Henry's (1981) photometric observations indicated variability with a period of 2.185 days and an amplitude in V of 0.03 mag. Heard (1956) gives a spectral type of G8 V. Radial velocities obtained at David Dunlap Observatory (Heard 1956) and Mount Wilson Observatory (Abt 1973) indicate that the star is a spectroscopic binary. Fekel, Moffett, and Henry (1986) give an orbital period of 2.1305 days (correctly listed in their Table VI but given erroneously as 2.3105 in the notes concerning individual stars) and an average V magnitude of 7.72. In this paper, we present the spectroscopic observations for the orbital-period determination and discuss other properties of this chromospherically active star.

II. OBSERVATIONS AND REDUCTIONS

From 1978 through 1984, 26 high-dispersion ground-based spectroscopic observations were obtained at McDonald Observatory and Kitt Peak National Observatory with a variety of solid-state detectors (Table I). A portion of a CCD observation is shown in Fig. 1. The vast majority of observations included the wavelength range 6390–6455 Å, while the one obtained with the McDonald Observatory 2.1 m telescope also included the Hα line. The observation obtained on Julian date 2445852 was centered at 6690 Å and included the lithium line at 6708 Å. The radial velocity of each of these observations (Table II) was determined relative to that of the G5 IV star μ Her A. A comparison of its velocity with that of β Oph, an International Astronomical Union (IAU) radial-velocity standard, indicates that the assumed velocity of μ Her A, $-15.6\ \mathrm{km\ s^{-1}}$ (Wilson 1953), is within $1\ \mathrm{km\ s^{-1}}$ of the IAU standard system (Pearce 1955). Details of the cross-correlation reduction procedure have been given by Fekel, Bopp, and Lacy (1978).

Two ultraviolet spectroscopic observations were obtained with the short-wavelength-primary (SWP) camera of the *International Ultraviolet Explorer* (*IUE*) satellite. These two observations, SWP 24495 and SWP 24501, were obtained on UT dates 17 and 18 November 1984, respectively, with exposure times of 180 min each. Both observations cover a wavelength region from 1200 to 2000 Å and were obtained through the large aperture, which has a resolution of about 6 Å. The observations were absolutely calibrated with standard computer software routines at the Regional Data Analysis Facility of the Goddard Space Flight Center.

III. ORBIT

Listed in Table II along with the new high-dispersion observations are the old observations from Mount Wilson Observatory (Abt 1973) and David Dunlap Observatory (Heard 1956). These observations were used to improve the determination of the orbital period but were given no weight in the final orbital solution for the other elements. Preliminary orbital elements were determined with a slightly modified version of the computer program of Wolfe, Horak, and Storer (1967), which uses the Wilsing–Russell method. Final orbital elements for this single-lined spectroscopic binary were computed with a differential corrections program (Barker, Evans, and Laing 1967). Table III lists the orbital elements for a solution with the period fixed at the value determined with the inclusion of the old velocities. The formal solution of the spectroscopic orbit gave a value for the eccentricity of 0.001 ± 0.007, so in accordance with the precepts of Lucy and Sweeney (1971), an $e = 0$ solution has been adopted. The DDO velocity of Julian date 2432347 had a very large residual in all solutions. Lyons (1985) confirmed that the date listed by Heard (1956) should be one day earlier, and the correct date is given in Table I of the present paper. The observed radial velocities and the computed radial-velocity curve are plotted in Fig. 2. The phases of the observations in Table II and Fig. 2 are computed from the time of maximum positive radial velocity in the circular orbit T_0 in Table III.

IV. ACTIVE-CHROMOSPHERE CHARACTERISTICS

The BY Draconis variables were defined by Bopp and Fekel (1977) as stars with dK and dM spectral types that have strong emission lines of Ca II and often hydrogen emission

[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)] Guest Observer with the *International Ultraviolet Explorer* satellite.

TABLE I. Telescope–detector combinations.

Telescope	Detector	Dispersion (Å mm^{-1})	Resolution (Å)	Wavelength range (Å)	Source code
McDonald 2.7 m	Reticon	4.4	0.24–0.36	110	MR 1
McDonald 2.1 m	Reticon	9.5	0.56	235	MR 2
Kitt Peak coudé feed	Fairchild CCD	14.8	0.45	165	KF
Kitt Peak coudé feed	RCA CCD	4.2	0.30	65	KR
Kitt Peak coudé feed	Texas Instruments CCD	4.2	0.21	50	TI 1
Kitt Peak coudé feed	Texas Instruments CCD	7.6	0.23	90	TI 2

present in their spectra. Finally, they have low-amplitude light variability with periods of a few days.

Photometric light variability was detected by Henry (1981) with a period of 2.185 days and a V amplitude of 0.03 mag. Boyd *et al.* (1988) discuss additional photometry.

The Ca II H and K emission in this G8 dwarf was first noted by Joy and Wilson (1949). Fekel, Moffett, and Henry (1986) confirmed its presence and found it to be moderate in strength, class C on Hearnshaw's (1979) qualitative emission scale.

In over 90% of the known BY Dra stars, hydrogen, particularly Hα, is detected as an emission feature. In a few of the earliest-type BY Dra variables, the Hα line is seen as an absorption feature (Bopp *et al.* 1981). Figure 15 of Fekel, Moffett, and Henry (1986) shows that the Hα line of HD 178450 is a relatively weak absorption feature which is partially filled in by emission. The equivalent width is 1.3 Å compared to 2.4 Å for μ Her A, an inactive G5 IV star. Observations of Hα obtained on five consecutive nights from 23 to 27 August 1983 show only modest equivalent-width changes of several tenths of an Angstrom during this time period.

HD 178450 is quite similar to HD 175742 (classified as dK1 by Joy and Wilson 1949), which was recently identified as a BY Dra variable by Bopp *et al.* (1981). They found that the Hα feature of HD 175742 was normally filled by emission to the continuum level. Their extensive monitoring resulted in the detection of emission intensity of about 10% above the continuum on several occasions.

Of the 17 BY Dra variables known when the definition for

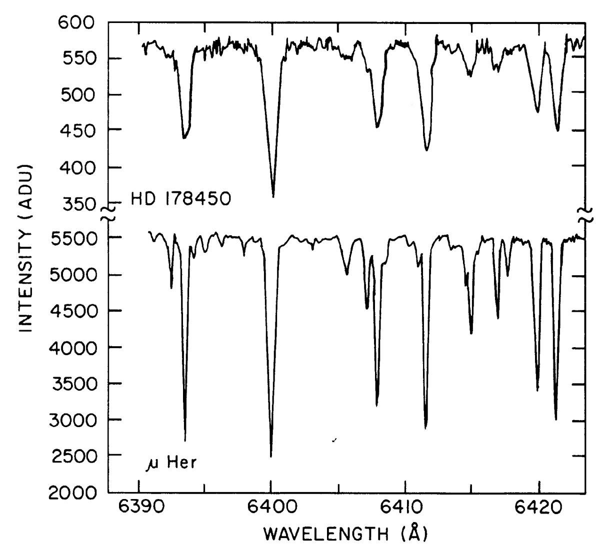

FIG. 1. Portion of a CCD observation of HD 178450 compared with that of μ Her A.

TABLE II. Radial velocities of HD 178450.

HJD 2400000 +	Phase	V (km s^{-1})	O − C (km s^{-1})	Source
24344.981	0.033	24.6	7.9	MTW
26523.931	0.768	− 17.8	− 1.8	MTW
26935.769	0.072	16.1	2.4	MTW
32342.940	0.037	11.4	− 5.1	MTW
32346.796	0.847	3.2	1.8	DDO
33094.843	0.958	12.5	− 3.7	DDO
33098.758	0.796	− 2.9	6.6	DDO
34173.849	0.412	− 52.4	− 0.2	DDO
34513.856	0.001	8.9	− 8.6	DDO
43740.663	0.790	− 10.8	0.0	MR 1
43743.626	0.181	− 5.2	− 0.9	MR 1
44474.621	0.288	− 30.2	− 1.1	MR 1
44480.695	0.139	4.2	0.2	MR 2
45075.928	0.524	− 55.9	1.5	KF
45076.998	0.026	17.6	0.6	KF
45077.955	0.475	− 58.8	− 1.4	KF
45079.952	0.412	− 52.6	− 0.3	KF
45447.945	0.137	5.0	0.7	KR
45448.976	0.621	− 48.8	− 1.4	KR
45449.980	0.093	9.8	− 1.5	KR
45450.919	0.533	− 57.1	− 0.1	KR
45451.929	0.007	16.6	− 0.9	KR
45525.826	0.692	− 33.2	0.3	KT 1
45594.682	0.011	18.1	0.7	KT 2
45595.688	0.484	− 57.7	− 0.1	KT 2
45596.752	0.983	17.4	0.1	KT 2
45598.717	0.905	11.6	0.6	KT 2
45811.952	0.992	16.8	− 0.6	KT 2
45812.958	0.464	− 56.2	0.7	KT 2
45813.940	0.925	13.5	0.2	KT 2
45814.974	0.410	− 51.4	0.6	KT 2
45851.947	0.764	− 16.2	0.7	KT 2
45852.875	0.200	− 7.8	0.6	KT 2
45855.896	0.618	− 47.7	0.3	KT 2
45941.796	0.936	14.4	− 0.1	KT 2

Notes to TABLE II

MTW = Mount Wilson Observatory.
DDO = David Dunlap Observatory.

TABLE III. Orbital elements.

$P = 2.130514 \pm 0.000007$ (m.e.)
$T_0 = 2445939.801$ HJD
$\gamma = -20.2 \pm 0.2$ km s^{-1}
$K_1 = 37.7 \pm 0.2$ km s^{-1}
$e = 0.0$ (assumed)
$a_1 \sin i = 1.104 \pm 0.006 \times 10^6$ km
$f(m) = 0.0118 \pm 0.0002\ \mathcal{M}$
Standard error of an observation of unit weight $= 0.7$ km s^{-1}.

this type of variable star was suggested by Bopp and Fekel (1977), only three were K dwarfs and all the rest were M dwarfs; hence, the limiting spectral types in the definition. With the discovery of many additional chromospherically active stars, the range of properties of chromospherically active stars has increased. Fekel, Moffett, and Henry (1986) expanded the definition of BY Dra variables to include main-sequence F and G stars and called these stars, including HD 178450, early-type BY Dra variables. Since these stars are in the same evolutionary state, it is more appropriate to classify them together than to put the F and G dwarfs with the evolved RS CVn systems. Other early-type BY Dra systems include σ^2 CrB, HD 8358, HD 22403, HD 165590, and HD 166181. As has been noted by Collier (1982), most of the short-period RS CVn systems should be classified as early-type BY Dra systems.

One of the two SWP ultraviolet spectra, SWP 24495, is shown in Fig. 3. Ultraviolet-emission features typical of chromospherically active stars are noted. Table IV gives the emission-feature identifications and the measured observed fluxes. Although both observations had the same exposure time, the background level of SWP 24501 was much higher, producing a more noisy spectrum. Thus, whether the differences in flux between the two observations represent real changes is uncertain. Only the fluxes of SWP 24495 have been converted into surface fluxes, following the procedure of Linsky *et al.* (1979). Since the $V-R$ color of active stars appears to have a color excess relative to inactive ones (Fekel, Moffett, and Henry 1986), we used the surface-brightness–$(B-V)$ color relation of Barnes, Evans, and Moffett (1978) and observed values of $V=7.67$ and $B-V=0.74$ (Fekel, Moffett, and Henry 1986). Surface fluxes for HD 175742 were computed from the observed fluxes listed by Simon and Fekel (1987) and the observed values of $V=8.04$ and $B-V=0.91$ (Fekel, Moffett, and Henry 1986). As can be seen in Table IV, most of the line surface fluxes of the two stars are quite similar.

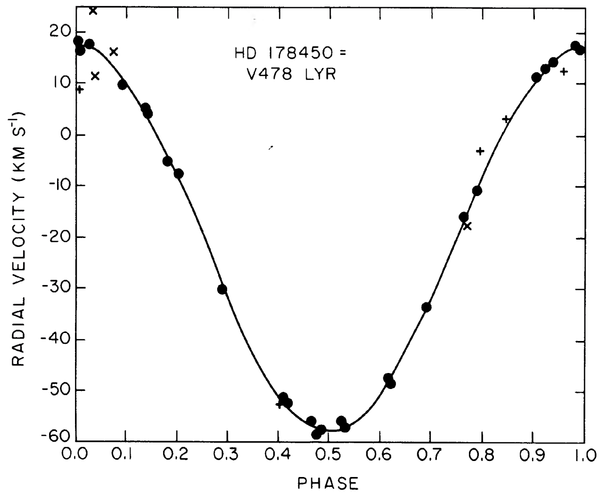

FIG. 2. Observations and computed radial-velocity curve of HD 178450. Phase is computed from T_0, the time of maximum positive velocity.

Simon and Fekel (1987) included HD 178450 in their examination of the dependence of ultraviolet chromospheric emission upon rotation among late-type stars. Their Fig. 3 shows that the normalized C IV flux and the line surface flux of HD 178450 are appropriate for its rotation period when compared with other active-chromosphere stars.

V. DISCUSSION

The spectral classification of HD 178450 is reported as G8 V by Heard (1956). From one night of observation, Eg-

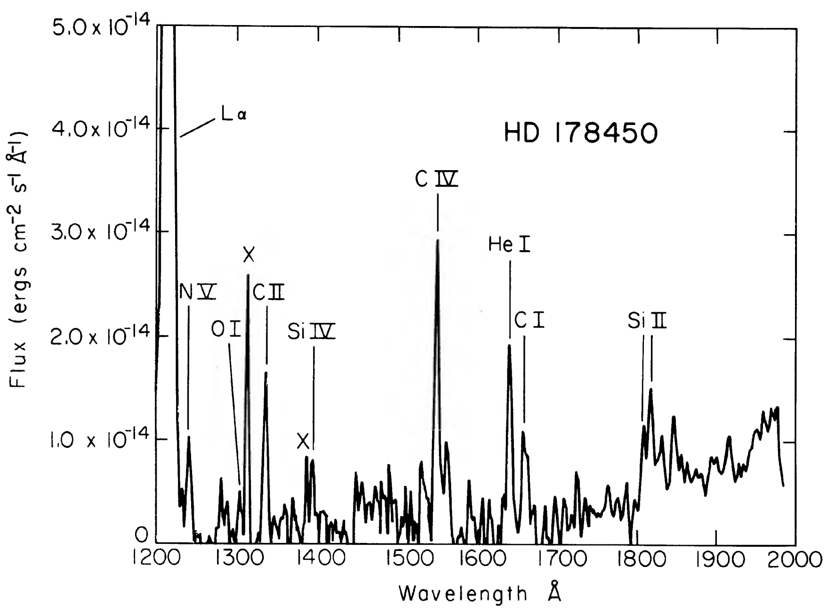

FIG. 3. *IUE* low-resolution short-wavelength observation, SWP 24495, of HD 178450 with the emission lines identified. Lyα is of geocoronal origin. The features marked by x's are not real features but result from particle hits.

TABLE IV. Ultraviolet emission-line fluxes (erg cm^{-2} s^{-1}).

Ion	Wavelength (Å)	Observed flux $\times 10^{-14}$ SWP 24495	SWP 24501	Surface flux $\times 10^{-4}$ HD 178450	HD 175742
N V	1240	6.3	9.8	12.2	12.9
O I	1305	2.5	6.4	4.9	15.8
C II	1335	8.1	10.3	15.7	13.9
Si IV	1400	4.6	14.9	8.9	—
C IV	1550	19.0	25.0	36.9	32.3
He II	1640	14.5	11.1	28.2	15.5
C I	1657	11.4	4.7	22.1	33.9
Si II	1808, 1817	10.0	13.7	19.4	15.7

gen (1964) obtained $V=7.63$, $B-V=0.73$, and $U-B=0.21$. Fekel, Moffett, and Henry (1986) obtained an average V magnitude and colors of $V=7.72$, $B-V=0.74$, $V-R=0.65$, and $R-I=0.43$ from three observations, with the V magnitude ranging from 7.67 to 7.74 mag. This $B-V$ color corresponds to a spectral type of G8 V according to the color–spectral-type relation of Johnson (1966).

Since the system is not double lined, it is more difficult to determine properties of the system such as the inclination and the nature of the secondary. Yet some limits can be determined if reasonable assumptions are made. The mass of the G8 V star is assumed to be $0.93\mathcal{M}_\odot$, the average of the mass of two eclipsing binary components (Popper *et al.* 1986). Fekel (1985) found no evidence of lines of the secondary in the red region of the spectrum. Since lines of the secondary have been detected in other late-type binaries for mass ratios as small as $\mathcal{M}_2/\mathcal{M}_1=0.6$ (e.g., Fekel and Tomkin 1983), it is assumed that the mass ratio of HD 178450 is less than this value. Combining the mass function (Table III) with the assumed value of the mass of the primary results in the values of the inclination and mass of the secondary listed in Table V. These values range from a mass of $0.25\mathcal{M}_\odot$ for $i=90°$ to a mass of $0.56\mathcal{M}_\odot$ for $i=32°$. Thus, the range of these two parameters is only modestly constrained. The value of the projected rotational velocity provides a much tighter constraint. Fekel, Moffett, and Henry (1986) determined $v \sin i = 21 \pm 2$ km s^{-1}. This value, combined with the rotational period of 2.13 days (assuming synchronous rotation), gives a minimum radius $R_1 \sin i = 0.88 \pm 0.08 R_\odot$. Popper *et al.* (1986) determined the radii of two G8 dwarf eclipsing binaries to be 1.0 and 0.96

TABLE V. Range of possible mass $\mathcal{M}_2$ and inclination ($\mathcal{M}_1 = 0.93\mathcal{M}_\odot$).

$\mathcal{M}_2$ ($\mathcal{M}_\odot$)	$\mathcal{M}_2/\mathcal{M}_1$	i (°)
0.25	0.27	90
0.30	0.32	61
0.35	0.38	50
0.40	0.43	44
0.50	0.54	35
0.55	0.59	32

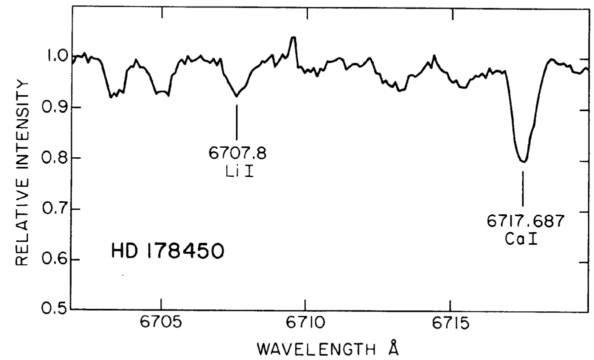

FIG. 4. Portion of a CCD observation of HD 178450 showing the lithium line.

$R_\odot$. Combining the average observed value of the radius with the value of $R_1 \sin i$ and its uncertainties results in an inclination of 64° and a range of 55°–78°. Thus, the inclination is constrained to be greater than 55°, ruling out secondary masses greater than $0.33\mathcal{M}_\odot$. Since there is no photometric evidence for eclipses, $R_1 + R_2 < a \cos i$, where R_1 and R_2 are the radii of the primary and secondary, respectively, and a is the semimajor axis of the relative orbit. For the mass range 0.33–0.25 $\mathcal{M}_\odot$, the maximum value of the inclination is $\leqslant 80°$. Thus we estimate $i = 67° \pm 12°$ and $\mathcal{M}_2 \approx 0.3\mathcal{M}_\odot$, which corresponds to a spectral type of M2–M3 V (Popper 1980). Since the ultraviolet spectrum shows no evidence of a hot continuum, it is not possible that the secondary is a hot white dwarf.

The spectrum obtained of the lithium region (Fig. 4) showed a modest-strength lithium line having an equivalent width of 47 mÅ. Assuming an effective temperature of 5500 K (Popper 1980) and the curve-of-growth results for lithium of Pallavicini, Cerruti-Sola, and Duncan (1987), the abundance of lithium is $\log n(\mathrm{Li}) = 1.9$. At the same temperature, the derived lithium abundance of Hyades stars is about 1.5 (Cayrel *et al.* 1984), while the lithium abundance for Pleiades stars is about 3.0 (Duncan and Jones 1983). Thus HD 178450 has an age that is slightly less than that of the Hyades cluster, which has a nuclear age of 7×10^8 yr (Patenaude 1978). This young age is consistent with its $U\ V\ W$ space motions, which are -25, -9, and -8 km s^{-1}, respectively (Strassmeier *et al.* 1988).

Apparently, no trigonometric parallax has been determined for this bright nearby G8 dwarf. Assuming an absolute magnitude of 5.6 (Corbally and Garrison 1984) and a V magnitude of 7.67 (Fekel, Moffett, and Henry 1986) results in a distance of 26 pc or a parallax of 0."039. Thus, HD 178450 is an excellent candidate for parallax determination.

We wish to thank Dr. Y. Kondo and the staff of the *IUE* observatory for their help in the acquisition and reduction of the ultraviolet spectra. This research has been supported in part by NASA grant 5-397 to F. Fekel.

REFERENCES

Abt, H. A. (1973). Astrophys. J. Suppl. **26**, 365.
Barker, E. S., Evans, D. S., and Laing, J. D. (1967). R. Obs. Bull. No. 130.
Barnes, T. G. Evans, D. S., and Moffett, T. J. (1978). Mon. Not. R. Astron. Soc. **183**, 285.
Bopp, B. W., and Fekel, F. (1977). Astron. J. **82**, 490
Bopp, B. W., Noah, P. V., Klimke, A., and Africano, J. (1981). Astrophys. J. **249**, 210.
Boyd, L., Genet, R., Hall, D., Seufert, E., and Henry, G. (1988). In preparation.
Cayrel, R., Cayrel de Strobel, G., Campbell, B., and Dappen, W. (1984). Astrophys. J. **283**, 205.
Collier, A. C. (1982). Ph. D. thesis, University of Canterbury, New Zealand.
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**, 773.
Eggen, O. J. (1964). Astron. J. **69**, 570.
Eggen, O. J. (1978). Inf. Bull. Var. Stars No. 1426.
Fekel, F., Bopp, B. W. and Lacy, C. H. (1978). Astron. J. **83**, 1455.
Fekel, F. C. (1985). In *Stellar Radial Velocities*, IAU Colloquium No. 89, edited by A. G. D. Philip and D. Latham (Davis, Schenectady), p. 389.
Fekel, F. C., Moffett, T. J., and Henry, G. W. (1986). Astrophys. J. Suppl. **60**, 551.
Fekel, F. C., and Tomkin, J. (1983). Publ. Astron. Soc. Pac. **95**, 1000.
Heard, J. F. (1956). Publ. David Dunlap Obs. **2**, 107.
Hearnshaw, J. B. (1979). In *Changing Trends in Variable Star Research*. IAU Colloquium No. 46, edited by F. M. Bateson, J. Smak, and I. H. Urch (University of Waikato, Hamilton, New Zealand), p. 371.
Henry, G. W. (1981). Inf. Bull. Var. Stars No. 1928.
Johnson, H. L. (1966). Annu. Rev. Astron. Astrophys. **4**, 193.
Joy, A. H., and Wilson, R. E. (1949). Astrophys. J. **109**, 319.
Linsky, J. L., Worden, S. P., McClintock, W., and Robertson, R. M. (1979). Astrophys. J. Suppl. **41**, 47.
Lucy, L. B., and Sweeney, M. A. (1971). Astron. J. **76**, 544.
Lyons, R. (1985). Private communication.
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.
Popper, D. M., Lacy, C. H., Frueh, M. L., and Turner, A. E. (1986). Astron. J. **91**, 383.
Simon, T., and Fekel, F. C. (1987). Astrophys. J. **316**, 434.
Strassmeier, K. G., Hall, D. S., Zeilik, M., Nelson, E., Eker, Z., and Fekel, F. C. (1988). Astron. Astrophys. Suppl. (in press).
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.