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Study of δ Scuti variables

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UBV photoelectric observations have been made on 14 known or suspected δ Scuti stars with $m_v < 6.5$. Observing techniques were designed to detect brightness variations on the order of $0^m.015$ and periods of from one to four hours. Of the four suspected variables studied, one, HR 3889, was found definitely variable. It is of interest because of its fairly large Δm_1 index and because its close companion is a spectroscopic binary. New P–C–L and P–L relations are presented, and a case is made for a possible separation of variables on the basis of mass, period, and log g.

SINCE 1964 almost 60 variables have been given the δ Sct classification, mainly by surveys listed by Baglin *et al.* (1973). That paper also defines the characteristics of δ Sct stars as a class.

Breger's investigation (1969b, 1970) for variability of over 300 field stars situated in the lower Hertzsprung gap reveals the proportion of variables to constant stars to be quite small, on the order of 20%. Inside the instability strip, the number of variables seems to follow an exponential increase with decreasing amplitude; therefore, any "constant" star in the instability strip may actually be variable if: (a) its amplitude is too small to be detected instrumentally; (b) it has too long a period and too small an amplitude to be detected during the period of observation; (c) it experiences a beat phenomenon resulting in little or no variation during the observation interval; and (d) it has once varied and has now stopped (Breger 1969c). It is possible that HR 5435 (Magalashivili and Kumsishivili 1965), HR 8130 (Pande 1960), and HR 5489 (Percy 1970), which were reported variable and then found constant, are examples of this last possibility. They are probably on the verge of stability and can regain it, even if only temporarily.

TABLE I. Observational results.

HR	Longest observing interval (Days)	C_1[a]	C_2[b]	Comparison star S_V	Mean Scatter[c] S_{B-V}	S_{U-B}
68	0.11833	HR 63	HR 154A	7	6	7
114	0.07993	HR 63	HR 154A	4	4	3
1706	0.05486	HR 1689	HR 1776 HR 1843	6	6	4
2107	0.07431	HR 2108	HR 2109	8	8	6
2837	0.0736	HR 2857	HR 2821	5	2	1
3889	0.1785	HR 3900	HR 3873	4	5	4
4684	0.0583	HR 4694	HR 4668	2	5	10
5329	0.2069	HR 5345	HR 5302	5	5	5
5435	0.1251	HR 5447	HR 5429	8	3	3
5788/9	0.1770	HR 5758	HR 5802	8	9	1
6290	0.0827	HR 6287	HR 6293	4	4	6
6391	0.1465	HR 6410	HR 6324	4	14	12
7222	0.1917	HR 7235	HR 7176	5	3	7

[a] Primary comparison.
[b] Secondary.
[c] Mean scatter in $0^m.001$ over all nights.

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I. SELECTION OF INDIVIDUAL VARIABLES

Variables and suspected variables were selected with the following purposes in mind: (a) to test the limits of the instability strip; (b) to observe metallic-like stars in order to investigate the existence of a high-metal group of δ Sct stars; (c) to investigate known spectroscopic and close binaries to see if their pulsation periods remain constant; (d) to determine if the periods of stars which exhibit beat phenomena remain constant; (e) to reinvestigate variables with few observations; and (f) to reobserve peculiar stars.

II. OBSERVATIONS

A. Equipment

Approximately 90% of the observations were made with the MacDonald Observatory 36-in. reflecting telescope. The remainder were made with the Kitt Peak #1 36-in. and #4 16-in. reflectors.

In all cases, the photomultiplier used was a refrigerated RCA 1P21, and the filters were standard *UBV* (Johnson 1955). At Kitt Peak, a Weitbrecht (1957) charge–integrating system was utilized with the results being punched on paper tape.

At McDonald, the signal from the 1P21, was amplified by a Keithly Electrometer which was in turn connected to a Vidar voltage-to-frequency converter. The output of the Vidar was measured by means of a digital counter (the count rate was never allowed to approach the limit of the counter).

B. Reductions

Correction for extinction and transformation to the *UBV* system was accomplished with a revised version of the University of Texas' *UBVRI* program. Average extinction values for McDonald compare favorably with those obtained by Angione (1968) and de Vaucouleurs (1965). Extinction and color coefficients were determined on each individual night. An explanation of the period-finding program is found in Bopp *et al.* (1970).

3. Observing Procedures and Selection of Survey Stars

The differential photometric method was chosen since it affords a gain in accuracy over other techniques. For each program star, two nearby stars were designated as comparisons (Table I). An effort was made to choose a comparison star within two degrees of the program star; however, because the program stars are quite bright ($m_v < 6^m.5$), it was sometimes necessary to allow a larger separation.

Comparison, extinction, and color transformation stars were selected wherever possible from lists by Johnson and Morgan (1953), Johnson (1955), and Iriarte *et al.* (1965). If feasible, comparisons for known variables are the same as those of previous observers in order to tie the present writer's magnitudes to those previously found. Standard *UBV* observing techniques were used to observe program and comparison stars.

Photometric errors on the order of $0^m.002$–$0^m.004$ in the observation of a star with an amplitude of only $0^m.020$–$0^m.040$ can sometimes make the time of maximum light appear to come early or late, although it does not hide the variation. This problem was encountered in HR 114, 5329, and 6290. Errors in the time of observed maximum light are generally on the order of $\pm 0^d.003$.

In most cases, the program stars in the survey were observed on at least three nights. The results of the first night were confirmed, and the probability of detecting variables with amplitudes at time below the threshold of detectability was increased.

III. OBSERVATIONAL RESULTS

A. Observational Summary

In Table I, the scatter due to observational error for the comparison stars can be considered as the same as the corresponding error for the variables since they are close in magnitude and color as well as airmass. The values of the scatter were calculated as

$$S = (1/N) \sum_{i=1}^{N} |y_i - \bar{y}|, \tag{1}$$

where N is the number of measurements, S is the scatter, y_i is the i-th measurement, and $\bar{y}$ is the mean magnitude of the comparison star over all nights of observation. A decision on the variability of a star was based in some degree on the numerical criteria for goodness of fit built into the period finding program (Bopp *et al.* 1970). The scatter for the individual nights was also considered in the decision. In general, unless the observed variation in a suspected variable was more than 2.5 times the scatter in the comparison star, the suspected variable was considered constant. Table II gives the results for the comparison stars.

TABLE II. New *UBV* photometry of the comparison stars.

HR	V	$B-V$	$U-B$	No. of nights
63	4.607	+0.051	+0.055	4
1689	4.817	+0.201	+0.090	6
2108	5.024	+0.180	+0.166	4
2857	5.003	+0.113	+0.118	2
3881	5.069	+0.606	+0.137	3
3900	5.317	+0.224	+0.055	3
4694	6.138	+0.306	+0.066	7
5110	4.979	+0.398	+0.053	3
5345	6.577	+0.096	+0.078	4
5447	4.460	+0.366	−0.084	4
6287	5.399	+0.963	+0.699	5
6410	3.121	+0.089	+0.067	6
7235	2.986	+0.019	+0.018	8
7565	4.940	−0.167	−0.688	3

B. Individual Variables

The observational data for individual stars are available on request.

HR 68. This star, suggested as a possible variable by Frolov (1970), is just beyond the hot β border of the instability strip defined by Breger (1972). Observations on three nights in October 1970 failed to show any significant variation; however, on two nights the observed variations in V did appear to be slightly over

TABLE III. Epoch of maxima.

	Observed	(Observed–calculated)
HR 114	JD 2440 870.7989+0.0696(375)E	
	934.5860	0.000
	934.6516	−0.004
HR 3265	JD 2440 221.4510[a]+0.0755(4753)E	
	663.6308	0.000
	667.540	0.003
	667.680	−0.005
HR 3889	JD 2440 654.6465+0.0818(4505)E	
	658.5812	0.005
	669.5423	0.000
	669.6291	0.005
HR 4684	JD 2440 697.6287+0.0551(5028)E	
	719.5726	−0.006
	721.6100	0.009
HR 5329	JD 2440 657.8291+0.0668(20)E	
	722.7043	−0.010
	722.7752	−0.006
	724.6592	0.005
	753.6871	0.002
HR 6290	JD 2440 363.8160[b]+0.1150(5449)E	
	670.8858	−0.004
	770.7548	0.000
HR 7222	JD 2440 720.7916+0.1090(1407)	
	722.8675	−0.005
	769.7458	0.007

[a] Stobie (1972).
[b] Breger (1972a).

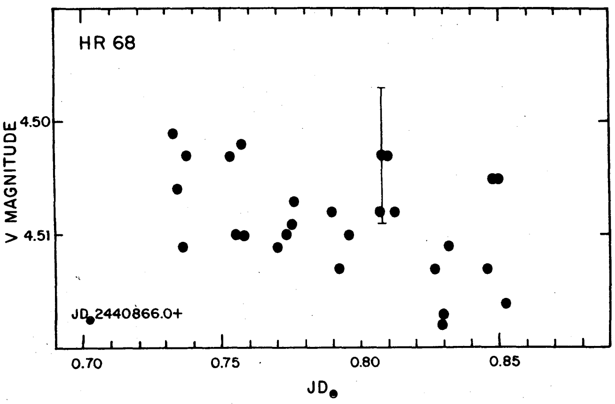

FIG. 1. V mag vs JD⊙ for HR 68 on JD 2440866. No significant variation was observed.

that which was expected from the scatter. It is still possible that this star exhibits variations of $0^{\rm m}000$–$0^{\rm m}015$. By analogy with HR 1223 and other variables near the hot border of the instability strip, the possibility of marked beats in this star could hamper observations.

HR 114 (*28 And*). Nishimura and Watanabe (1969) observed a period of $0^{\rm d}071$. Breger (1969a), over a smaller data sample, concluded that the period was $0^{\rm d}069$. Both investigations show a $\Delta V = 0^{\rm m}040$ and $\Delta B = 0^{\rm m}048$ with very little evidence of beat phenomena. This star was first classified as an Am star but has since been found to have the spectrum of a normal late A star.

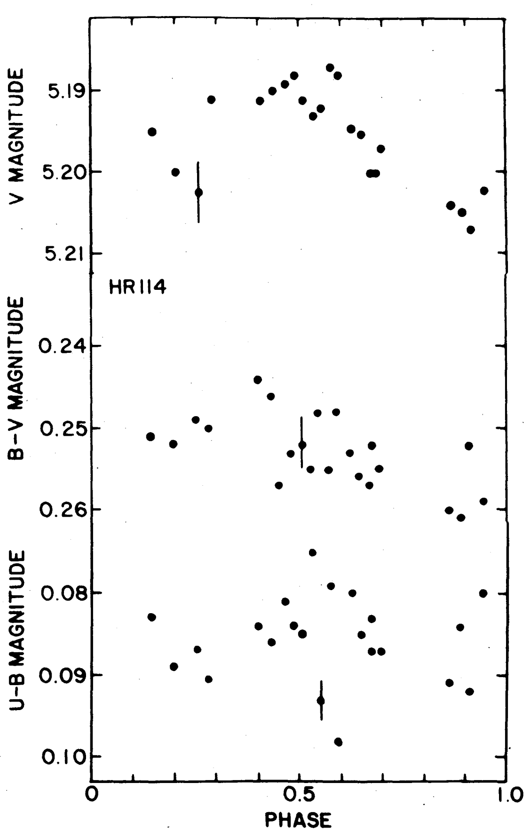

FIG. 2 (a). V mag vs phase for HR 114 (28 And) on JD 2440870. (b) $B-V$ vs phase. (c) $U-B$ vs phase.

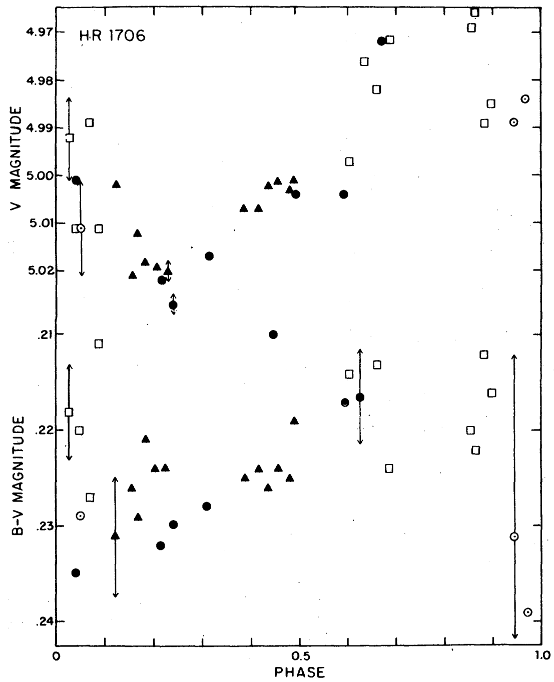

FIG. 3. (a) V mag vs phase for HR 1706. Dates are JD 2440649 (closed circle), 2440659 (dotted circle), 2440866 (open square), and 2440872 (filled triangle) (b) $B-V$ vs phase. Symbols refer to the same dates.

The period of $0^{\rm d}0696$ and amplitude of $0^{\rm m}020$ observed during the present study are in good accord with the previous results. The observed amplitude is smaller than that previously reported, but long-term changes in amplitude cannot be ruled out. The $(B-V)$ color shows a trend to be bluest at maximum V mag, but no cyclical variation was observed in $U-B$.

While the light curve for 28 And is quite bumpy, it is thought to be systematically variable rather than merely irregular. When the dates of maximum light from previous work were combined with maxima obtained during the present survey, the formula given in Table III proved quite satisfactory.

HR 1706 (*14 Aur*). Harper (1916, 1938) discovered this star to be a spectroscopic binary with a period of $3^{\rm d}78873$. It is the brighter component of a wide binary system with a $7^{\rm m}99$ companion. Danziger and Dickens (1967) discovered it to be a δ Sct with an estimated period of $0^{\rm d}122$. Chevalier *et al.* (1968) and Hudson *et al.* (1971) suggested that a nonradial mode of pulsation along the axis connecting the centers of the two stars might be responsible for the observed variations in amplitude. Their suggestion was substantiated by radial velocity as well as photometric data. Chevalier finds that her data best fit a period of $0^{\rm d}0938$.

The period of $0^d.0867$ found in the present study is in good accord with that value found in Hudson *et al.* (1971); however, it was never possible to observe the star over an entire cycle. It was not possible to construct a formula such that the times of maxima could be located with any accuracy; the period found by Hudson *et al.* (1971) did not accurately locate our observed maxima either. It is thought that this discrepancy is probably caused by the beat phenomenon which is also probably responsible for the wide range of periods.

HR 2107 (*1 Mon*). Danziger and Dickens (1967) first reported this star variable with a period of $0^d.137$, a $\Delta V=0^m.30$, minimum $B-V$ occurring about 0.04P before minimum V, and evidence of a strong secondary period. Combining his photometric data with that of Jones and Lagerweij (1966) and with radial velocity data of his own, Jones (1971) found a period of $0^d.135384$. Valtier (1971) reports a period of $0^d.139$ observed on one night of excellent photometric quality.

Only a few scattered observations of this star were taken during this survey. The data fit the period of $0^d.13494$ found by Millis (1973) quite well (Fig. 4). The $\Delta V=0^m.20$ is also consistent with his findings.

HR 2837. This A6 star is situated well within the instability strip. It is reported to be a spectroscopic binary in the Yale Catalogue of Bright Stars (Hoffleit

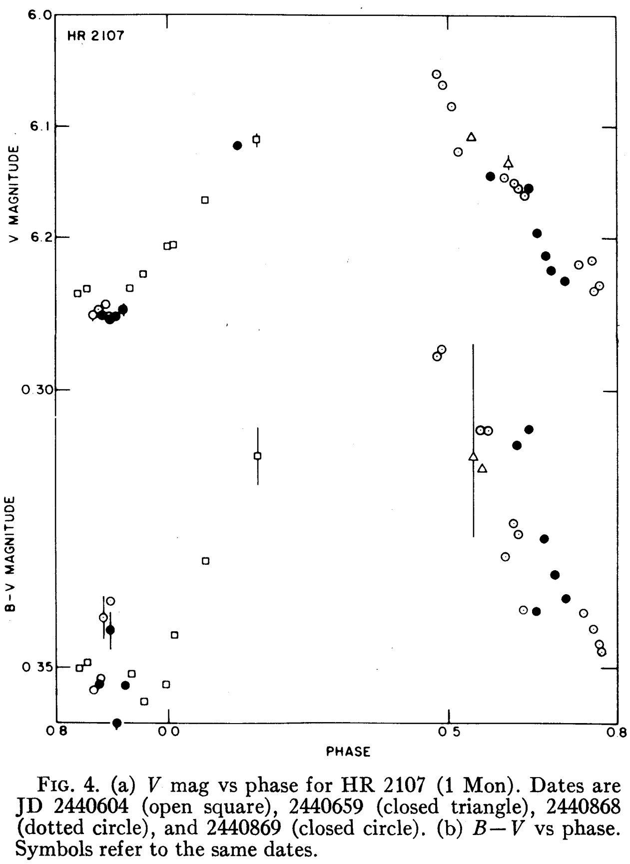

FIG. 4. (a) V mag vs phase for HR 2107 (1 Mon). Dates are JD 2440604 (open square), 2440659 (closed triangle), 2440868 (dotted circle), and 2440869 (closed circle). (b) $B-V$ vs phase. Symbols refer to the same dates.

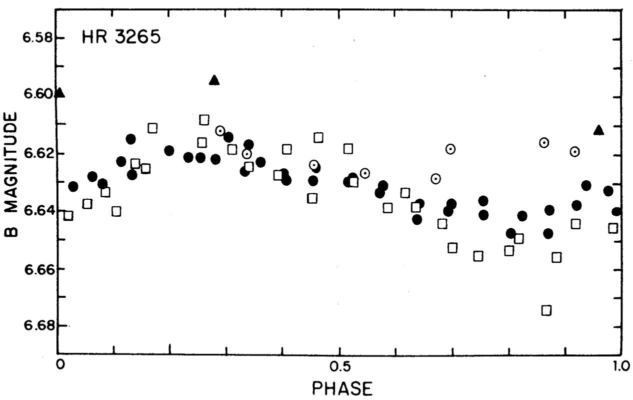

FIG. 5. B mag vs phase for HR 3265. Dates are JD 2440221 (closed circle), 2440223 (open square), 2440663 (closed triangle), and 2440667 (dotted circle). Observations on JD 2440221 and 2440223 were made by R. S. Stobie on the 13-in. Cape Astrographic refractor.

1965), but no orbit could be found. It was not possible to determine an accurate period. Since the comparison star, HR 2857, had to be measured on a less sensitive gain, it is quite possible that the scatter in the program star was somewhat more than the scatter in the comparison. There is only a slight suggestion of a period near $0^d.07$.

HR 3265. Danziger and Dickens (1967) first investigated this star and found a period of $0^d.12$–$0^d.14$ with a $\Delta V=0^m.039$. Penfold (1969) found no significant variation, but Cousins *et al.* (1969) found a period of $0^d.079$–$0^d.082$. R. S. Stobie kindly furnished 65 observations in the B filter taken on the 13-in. astrographic refractor

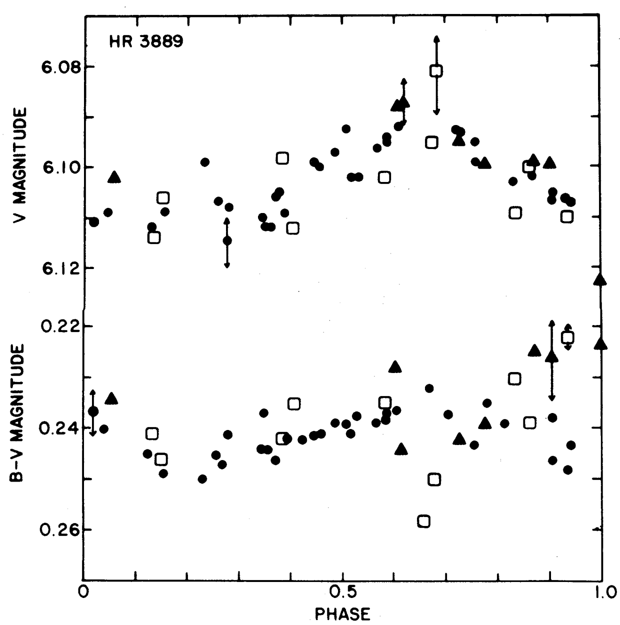

FIG. 6. (a) V mag vs phase for HR 3889 (20 Leo). Dates for JD 2440654 (filled triangle), 2440658 (open square), and 2440669 (filled circle). (b) $B-V$ vs phase. Symbols refer to the same dates.

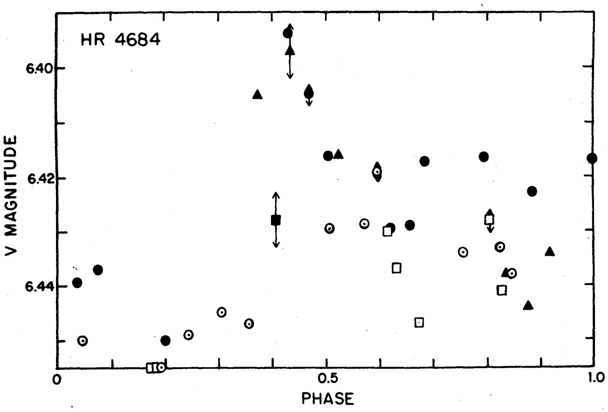

FIG. 7. V vs phase for HR 4684. Dates are JD 2440654 (open square), 2440657 (filled square), 2440697 (dotted circle), 2440719 (filled triangle), and 2440721 (filled circle). No significant variation was observed in $B-V$ or $U-B$.

at the Cape. When the Cape data were combined with 11 observations in the present survey, we found a good fit at 0ᵈ.0755. There is evidence for the existence of beats since ΔV is 0ᵐ.02 on JD 2440221, 0ᵐ.03 on JD 2440223, and 0ᵐ.018 on JD 2440667. The star shows a high Strömgren metallicity index, Δm_1, for a δ Sct variable.

Stobie (1972) has revised his original period to 0ᵈ.08±0.01. Our period is well within these limits.

HR 3889 (*20 Leo*). This star was included in the survey by Danziger and Dickens (1967), but the results were inconclusive. 20 Leo is the primary in this multiple (0.4 arcsec separation) system. The other component is a spectroscopic binary with a period of 4.024 days (Bopp 1974). From radial velocity data, Bopp believes that the primary is the variable. The elements of Bopp's orbit for the spectroscopic binary are included in a forthcoming publication.

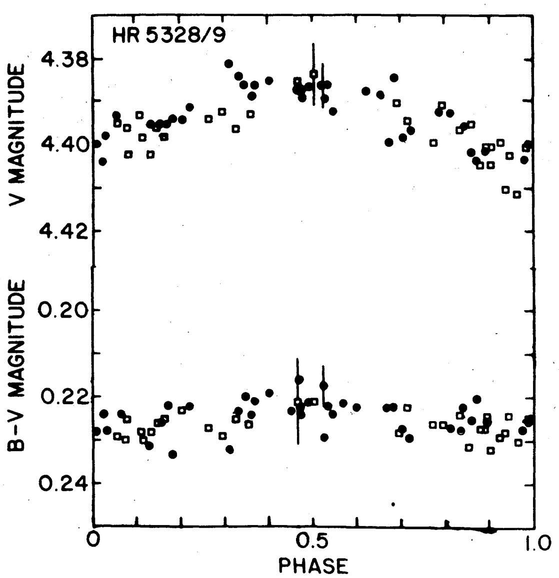

FIG. 8. (a) V mag vs phase for HR 5328/9. Dates are JD 2440722 (filled circle), and 2440724 (open square). (b) $B-V$ mag vs phase. Symbols refer to the same dates.

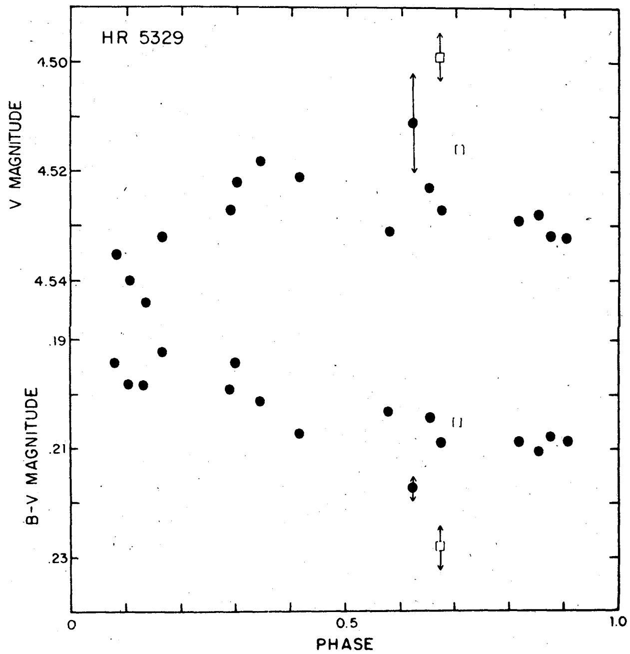

FIG. 9. (a) V mag vs phase for HR 5329. Dates are JD 2440657 (open square), and 2440753 (filled circle). (b) $B-V$ mag vs phase. Symbols refer to the same dates.

The formula in Table III fits the period of 0ᵈ.0818 well. Little evidence was found for beats. The observed light variation was 0ᵐ.042 in V and 0ᵐ.033 in $B-V$. Note that since this star cannot be separated photometrically from its companions, it's amplitude is quite a bit larger than that observed. 20 Leo should be further examined for the kind of variation of amplitude with orbital phase exhibited by HR 1706. The Strömgren Δm_1 index is quite high for a δ Sct variable.

HR 4684. This was the first δ Sct variable to be discovered in a galactic cluster (Coma). It was found to have a period of 0ᵈ.055 and $\Delta V=0.04$ by Breger and Sanwal (1968).

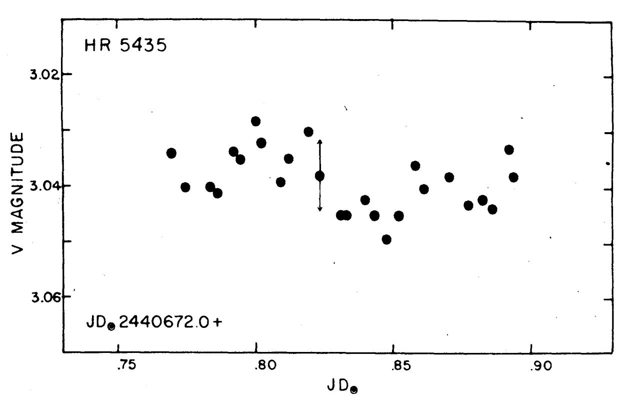

FIG. 10. V vs JD⊙ for HR 5435 on JD 2440720. No significant variation was observed in any filter.

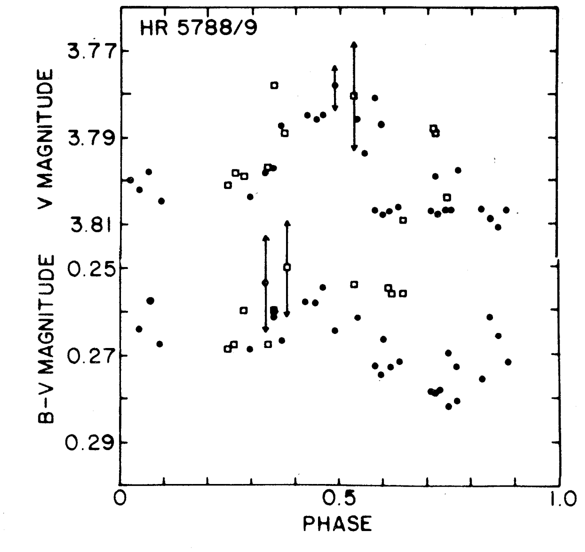

FIG. 11. (a) V vs phase for HR 5788/9. Dates are JD 2440697 (filled circle), and 2440718 (open square). (b) $B-V$ vs phase. Symbols refer to the same dates.

The maximum ΔV we found on any one night is $0^m_.056$, on the same order as Breger's. The variation in amplitude indicates the possibility of beats. There is need for longer observing sessions on individual nights, but this was not possible during this survey.

When the present data were combined with that of Breger and Sanwal (1968), the period was determined to be $0^d_.0551$.

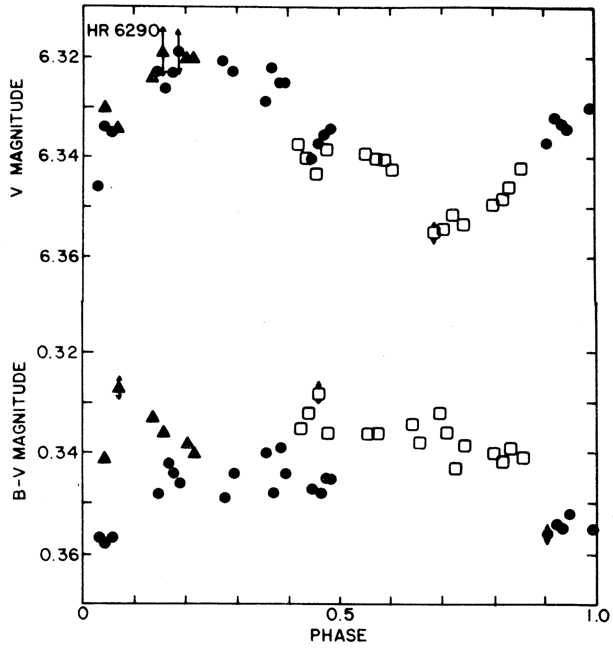

FIG. 12. (a) V mag vs phase for HR 6290. Dates are JD 2440670 (filled triangle), 2440724 (open square), and 2440770 (filled circle). (b) $B-V$ vs phase for HR 6290. Symbols refer to the same dates.

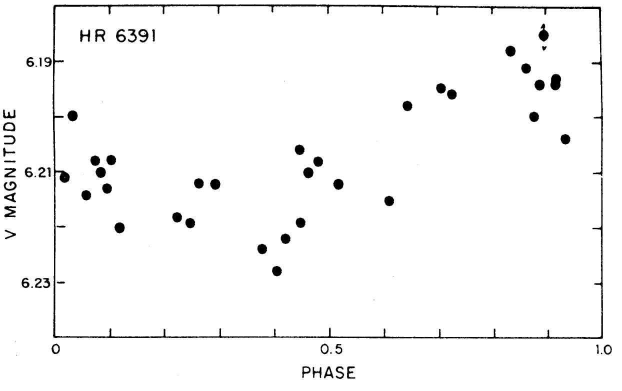

FIG. 13. V vs phase for HR 6391 on JD 2440749. No variation was observed in $B-V$ or $U-B$.

HR 5329 (*κ Boo A*). κ Boo A is the bright component of visual binary with a separation of 13 arcsec. It was first reported to be a δ Sct variable with a period of $0^d_.069$ (Millis 1967). Desikachary *et al.* (1971) found a period of $0^d_.07306$ with an alias of the main period at $0^d_.067$. They detected the presence of beats in the variation with a period near 16 days.

Observations on JD 2440722 and 2440724 were restricted to both components of the binary because poor seeing made it impossible to successfully separate them. This is the only instance known to this author where both components were observed in the same diaphragm. It was possible to observe HR 5329 alone on JD 2440753. The variation in amplitude ($0^m_.023$–$0^m_.033$) indicates the possibility of beats. The period of 0.0668 is in good agreement with Valtier's (1972) recalculated period for this star.

The size of some of the residuals (Table III) indicates the possibility of (a) long-term changes in the period, (b) interference from a 16-day beat period, or (c) both of the above. Additional problems are encountered when one tries to place the time of maxima in some cases. The

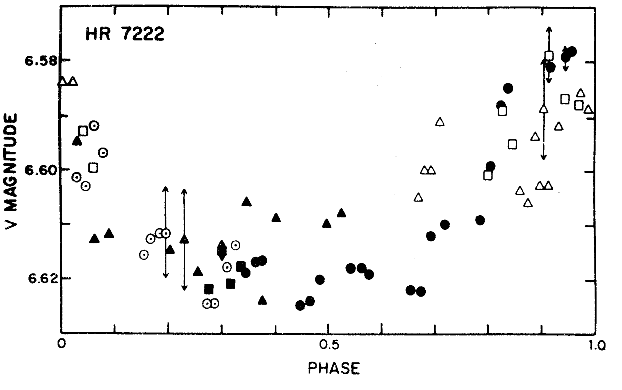

FIG. 14. Phase diagram for V mag observed for HR 7222. Dates are JD 2440719 (filled triangle), 2440720 (open square), 2440722 (filled circle), 2440724 (filled square), 2440761 (dotted circle), and 2440769 (open triangle).

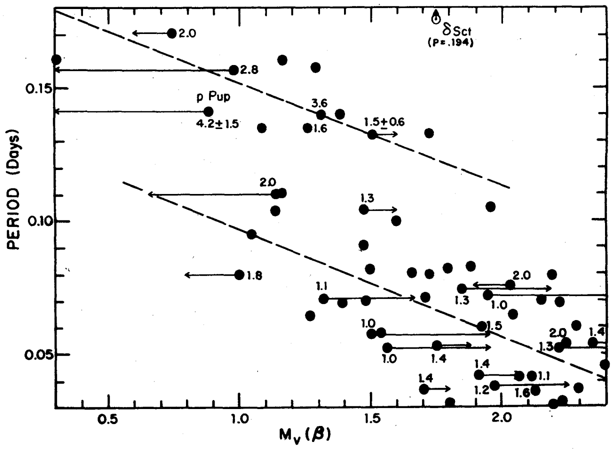

FIG. 15. Period–luminosity diagram for the Delta Scuti stars. The small numbers near the stars represent the masses in solar masses calculated from $M_v(I)$. The arrows show the direction and distance the points would be moved if $M_v(I)$ were plotted instead of $M_v(\beta)$. The solid lines represent mean relations for two proposed groups of δ Sct stars. $M_v(I)$ are magnitudes determined by methods other than *uvbyβ* photometry.

period found by Desikachary *et al.* (1971) does not fit the present data. We feel that they performed their calculations on too limited a data sample and that the alias to the main period they detected is in actuality the main period. The fact that HR 5328/9 and 5329 both show the same light curve and both conform to the same formula for maximum indicates that only the brighter component of the binary (HR 5329–κ Boo A) is variable.

HR 5435 (γ *Boo*). Irregular variation in the brightness of this Johnson–Morgan standard has been observed by many authors (see Seeds and Yanchak 1972). Magalashivili and Kumsishivili (1965) were able to derive a period of 0ᵈ290. The observations of Sareyan *et al.* (1971) are consistent with this period; however, Millis (1967) and Baglin *et al.* (1968) report no observable variation. Le Contel *et al.* (1970) observed marked changes in the K-line from night to night. This has led Baglin *et al.* (1968) to speculate on a possible relation between γ Boo and the Ap stars.

The star's rapid rotation (135 km sec^{-1}) could result in its temporarily regaining stability or in the damping of pulsation to an undetectable level. The agreement between the observations of Magalashivili and Kumsishivili (1965) and Sareyan *et al.* (1971) do make the star seem to be stable in its variation for long period. Sareyan thinks there may be a 7000-day beat period.

γ Boo was observed on only one night on which conditions were reasonable. No significant variation was found; however, variations on the order of 0ᵐ020 could have been hidden in the scatter.

HR 5788/9 (δ *Ser*). This binary system consists of a 4ᵐ23 F0IV star and a 5ᵐ16 dF0 star separated by 3.9 arcsec. Though both stars were measured together, the subgiant is probably the variable by analogy with other δ Sct stars.

A period somewhat over three hours was reported by Millis (1967). This is consistent with the findings of this survey. On JD 2440697, the star appeared nearly constant for the first 75 minutes then a $\Delta V = 0^m03$ was observed without a corresponding change in the comparison star. This strongly suggests a beat, but much more data is needed to support this. A fair fit was found to a period of 0ᵈ149. The star showed a tendency to be bluest when brightest. Because of the irregular shape of the light curve, it was very difficult to locate the exact time of maximum; therefore, it was not possible to combine the data in the present survey with previous data for the purpose of predicting maxima.

HR 6290. At the time this survey was begun, this star was only suspected to be variable (Breger 1969b). It has been classified as an F2II by Harlan (1969), but *uvbyβ* photometry is consistent with a luminosity classification of III or IV. It should also be investigated for a dependence of amplitude on orbital phase. This star is a spectroscopic binary with a period of 11ᵈ878 (Worley 1963) and a large Δm_1 index.

The data in the present survey are consistent with a period of 0.1150. ΔV over all nights was 0ᵐ044. When the dates of maxima in this survey were combined with those of Breger (see Baglin *et al.* 1973), who studied this star independently, we predicted dates of maxima as given in Table III.

HR 6391 (*63 Her*). When originally studied by Breger (1969a), this star was found to have a period of 0ᵈ077 and a mean amplitude of 0ᵐ025. This is in agreement with the recent spectral classifications of A9IVn and A8V. The present data indicate a period of 0ᵈ0797.

Maxima from this survey and from Breger (1969a) were combined to form the formula seen in Table III.

HR 7222. Breger (1969a) originally observed this star to have a period of 0ᵈ096 and an amplitude of 0ᵐ04.

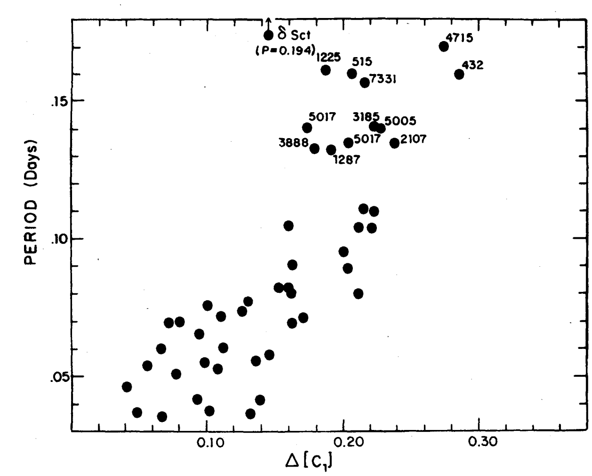

FIG. 16. Relation between period and distance of the main sequence.

The present data indicate the presence of a period of 0ᵈ109. The mean variation in this study, 0ᵐ025, contrasted against the 0ᵐ040 of Breger indicates the possibility of beats.

The epoch of maxima derived by combining this data with Breger's (1969a) can be found in Table III.

3. The P–C–L and P–L Relations

Figure 15 shows a period-$M_v(\beta)$ plot for all δ Sct stars with *uvbyβ* photometry. Using 47 stars we solved for a period–color–luminosity relation using least squares,

$$M_v = -2.21(\pm 0.23)\log P + 5.44(\pm 1.40)(b-y)_0, \\ -1.68(\pm 0.39) \pm 0.26. \quad (1)$$

Errors quoted are standard deviations. The error in the P–C–L relation is very near the value of 0.25 which Breger (1974) quotes as the fit per star in the $M_v(\beta)$ calibration. Using Breger's (1969b) relation, the standard deviation becomes ± 0.28.

Because of the small spread in $(b-y)_0$ for δ Sct stars, the formation of a P–L relation is possible. From a least squares solution on the same group of stars we obtain

$$M_v = -1.88(\pm 0.24)\log P - 0.46(\pm 0.27) \pm 0.32. \quad (2)$$

The slope with log P of -2.21 in Eq. (1) agrees well with the theoretical value of -2.5 used by Breger (1969b). The coefficient in Eq. (2) is somewhat less in agreement; however, the error of ± 0.24 makes it appear more reasonable.

Both Breger (1969b) and Leung (1970) compute separate relations excluding all the stars with large values of Δm_1. We found that the removal of δ Sct, $\Delta[m_1] + 0.1\Delta[c_1] = +0.036$, had the same effect as removal of all the higher metal stars. We formed the relations with all the stars of high-metal content included but excluded δ Sct for the following reasons:

(1) δ Sct is peculiar among the Delta Scuti variables, it has an amplitude and period larger and longer by far than any other δ Sct variable of well-known period and amplitude.
(2) It's $\Delta[m_1] + 0.1\Delta[c_1]$ index is one of the largest of the variables.
(3) Millis (1967) has remarked that the shape of the light curve and multiple periods of δ Sct are much more like the Dwarf Cepheid VZ Cnc than like any other δ Sct variable.
(4) δ Sct's absolute magnitude based on trigonometric parallax is very uncertain.
(5) It's period is more than twice as long as any other variable of the same β and $\Delta[c_1]$.
(6) Chevalier (1971) has listed δ Sct as possibly pulsating in a mixed mode.

In nearly every respect δ Sct is the exception rather than the rule. The P–C–L relation indicates that a star of equal period and color would have an absolute magnitude of +0ᵐ9. This is within the 1ᵐ2±0.5 based on trigonometric parallax but almost 0.9 brighter than $M_v(\beta)$. Since δ Sct is a slow rotator, we cannot appeal to rotation effects to remove the discrepancy. Even after consideration of the errors both in the P–C–L relation and in the *uvbyβ* calibration, $M_v(\beta) - M_v$(P–C–L) < -0.6. Figure 15 shows, just as does Fig. 16, that δ Sct has nearly twice the period of any star of equal luminosity. δ Sct's $\Delta[c_1] = 0.143$ places it near the main-sequence band, but its period indicates a $\Delta[c_1] > 0.200$. This is what might be expected if δ Sct is pulsating in a mixture of modes or in a higher harmonic than the fundamental. Thus, it could be a star of fundamentally longer period masquerading as a short-period variable.

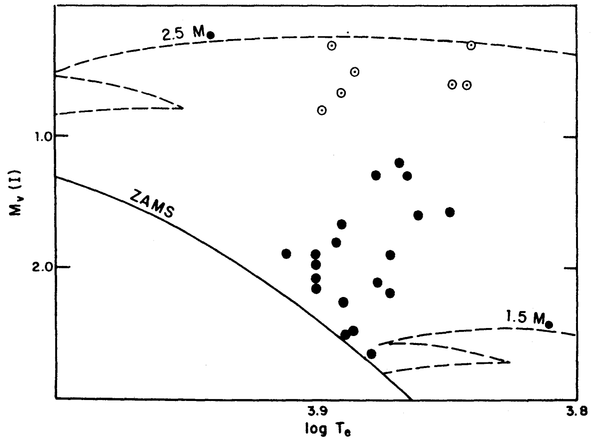

FIG. 17. $M_v(I)$–log T_e diagram for δ Sct stars. Dashed lines branching out from the main sequence (solid line) are Iben's (1967) evolutionary tracks for 1.5 $m_\odot$ and 2.5 $m_\odot$ stars. Dotted circles represent a proposed larger mass, longer period subgroup of δ Sct stars.

Leung (1970) believes there to be a separation of variables into a long- and short-period group in the $M_v(\beta) - (b-y)_o$ diagram. We find no such separation in this diagram; however, there is some slight evidence for a separation in the P–L diagram (Fig. 15) and the $M_v(I) - \log T_e$ diagram (Fig. 17). Variables with a mean mass $> 2m_\odot$ are found in a group with periods longer than 0ᵈ12 (Fig. 15). These same variables with independent absolute magnitude estimates are found near Iben's (1967) evolutionary track for $2.5_\odot$. Shorter period variables are found near the track for 1.5 $m_\odot$ in Fig. 17. We must regard this proposed separation as quite uncertain since the absolute magnitudes of the stars in the longer period group include some absolute magnitudes derived from moving group parallaxes and trigonometric parallaxes with errors over 25%; however, Dickens and Penny (1971) did find these same stars to have larger masses than the average mass for the δ Sct stars in their study. They did use the same $M_v(I)$, absolute magnitudes derived from nonphotometric methods, but did not use log g and log T_e based on the *uvbyβ* calibrations.

If this separation is real, the shorter period group has a mean period of $0^d_.06$, mean log $g \simeq 4.1$, and a mean mass of about 1.5 $m_\odot$. Similar quantities for the longer period group are: $P \simeq 0^d_.15$, log $g \simeq 3.7$, and 2.5 $m_\odot$. These are approximately the same values found by Leung (1970), but the stars in his instability boxes are not the same stars as those in our long- and short-period group.

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