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A NEW INVESTIGATION OF THE VARIABLE STARS IN THE GLOBULAR CLUSTER MESSIER 9

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ABSTRACT

New observations from the southern hemisphere have been used to check the periods for the 11 RR Lyrae variables in and around the globular cluster Messier 9. The periods were determined previously with data from northern observatories where M9 can only be observed over a small range in hour angle. Three of the eleven published periods were found to be in error. As a result of this, the mean period of the RRc variables has been revised from 0ᵈ279 to 0ᵈ341, the mean period of the RRab variables has been revised from 0ᵈ614 to 0ᵈ621, and a star previously believed to be an RR Lyrae has been reclassified as a Population II Cepheid. One of the RRc variables may be a double-mode pulsator. Another variable was studied, but the data were not sufficient for determining its period.

I. INTRODUCTION

Messier 9 (NGC 6333,C1716 − 184;$1^{\rm II}$ 5.5,$b^{\rm II}$ 10.7) is one of the many globular clusters in the constellation of Ophiuchus near the direction of the galactic center. The first investigation of the variables in this cluster was by Shapley (1916), who discovered one variable. Later, Bailey (1918) suggested that the cluster should be searched further, and so Sawyer (1951) conducted an extensive photographic program. She took 14 plates with the 36-in. reflector of the Steward Observatory in 1939, and 89 plates with the David Dunlap 74-in. reflector during the years 1940–1949. On these plates, she discovered 13 variables, including the one found by Shapley, and determined periods for 11 of them. All of the periods were of the RR Lyrae type, and the mean period of the ab types was 0.614 days, indicating that M9 belongs to Oosterhoff group II, the long-period group. According to Zinn (1980), its [Fe/H] value is − 1.81, indicating relatively low metal content, characteristic of the Oosterhoff group II clusters.

The motivation for the present investigation comes from a review paper by Rosino (1978). In Table III of his paper, there is a summary of the characteristics of the globular clusters of the two Oosterhoff groups. Messier 9 is anomalous because the mean period of its 3 c-type RR Lyrae variables is 0.279 days, a value shorter than that of all the group I clusters, even though its ab types have the longer periods indicative of group II. One possible reason for the unusual period distribution is that some of the periods may be incorrect. In fact, Cacciari (1974) has shown that a longer period fits the data for one of the c-type variables. Sawyer's periods were determined using observations where southern clusters like M9 can only be observed over a very limited range in hour angle. We decided, therefore, to make a new set of observations to redetermine the periods, using the University of Toronto's telescope in Chile, where M9 can be studied for as long as 9 hr in one night.

II. OBSERVATIONS

The present investigation is based on 50 *B* photographs (103aO + GG385) taken during the years 1979–1983 with the University of Toronto 24-in. reflector (plate scale 22.6 arcsec/mm) at the Las Campanas Observatory of the Carnegie Institution of Washington. The plates were measured on a Cuffey iris astrophotometer. We measured all of the 13 known variables except V11. V11 lies in the center of the cluster and we were unable to locate it because it did not vary on our plates. The 12 variables we measured are identified in Fig. 1 [Plate 85]. For a standard sequence, we selected 20 stars in the appropriate magnitude range, including among these the comparison stars used by Sawyer. Racine (Diamond 1976) made photoelectric observations of a few stars in this cluster, and we used his magnitudes to calibrate our standards on the *B* system. Only three of his photoelectric standards were in the appropriate magnitude range, however, and so our magnitudes may be uncertain, particularly at the faint end of the sequence. Our adopted magnitudes for Sawyer's comparison stars are listed in Table I.

For our reductions, we used parabolic calibration curves and determined the *B* magnitudes for both the variables and the standards on each plate. The σ for a standard star was typically 0.05. The *B* magnitudes for the variables are listed in Table II.

We used our observations to determine periods for the variables and Sawyer's published data to refine them.

III. RESULTS

Table III summarizes the data for the individual variables. It gives in successive columns the variable number; the *x*, *y* coordinates in arcseconds; the period (in days); the heliocentric Julian date chosen as the epoch of maximum light; the arithmetic mean *B* magnitude, the maximum and minimum *B* magnitude and *B* amplitude (which have all been determined from smoothed light curves drawn by eye through the

TABLE I. *B* magnitudes for Sawyer's sequence stars.

Star	*B*
a	12.85
b	13.59
c	14.42
d	14.47
e	15.09
f	15.52
g	*
h	16.35
k	16.70
l	17.10
m	17.27
n	17.46

Note to TABLE I
*Star g was resolved as a double on Las Campanas plates and therefore not used.

TABLE II. *B* Magnitudes for the variable stars.

(Hel.J.D. -2440000)	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V12	V13
4016.755	16.43	15.96	16.93	16.07	16.05	16.80	17.10	16.48	16.43	15.91	17.09	17.44
21.679	16.02	15.86	16.97	16.43	15.98	16.76	17.06	16.40	16.80	16.10	16.55	17.36
.741	16.97	15.98	15.96	16.52	15.77	15.65	17.23	16.43	16.83	16.40	16.85	17.41
.830	16.78	15.93	16.17	16.54	15.74	16.19	17.15	16.50	16.26	16.09	16.80	17.45
.881	15.60	15.88	16.33	16.38	15.62	16.26	17.21	16.43	16.24	15.84	16.88	17.52
22.663	16.66	15.27	16.92	15.31	15.43	16.57	16.10	16.45	16.81	16.21	16.10	17.39
.759	16.83	15.48	16.88	15.98	16.05	16.62	16.51	16.36	16.35	16.40	16.12	17.44
.828	16.87	15.64	16.90	16.12	15.96	16.62	16.80	16.45	16.19	15.83	16.10	17.54
.891	16.81	15.67	16.73	16.29	15.69	16.21	16.88	16.36	16.35	15.95	16.21	17.51
23.628	15.69	15.84	16.09	16.40	15.58	15.86	17.09	16.43	16.99	16.29	17.18	17.42
.684	15.84	15.86	16.13	16.52	15.65	16.33	17.15	16.48	16.67	16.47	16.83	17.41
.721	16.09	15.93	16.41	16.48	15.51	16.38	17.09	16.41	16.41	16.31	16.62	17.49
.784	16.45	15.77	16.61	16.47	15.62	16.48	17.10	16.43	16.19	15.77	16.48	17.45
.854	16.66	15.70	16.87	16.54	15.78	16.54	17.21	16.43	16.43	15.83	16.19	17.48
.907	16.70	15.41	16.78	16.15	16.00	16.66	16.19	16.40	16.57	16.10	16.01	17.42
24.603	16.92	14.98	16.97	15.60	15.76	16.67	16.38	16.40	16.92	16.31	16.92	17.45
.641	16.91	15.22	16.91	15.32	16.00	16.81	16.59	16.47	16.92	16.38	16.90	17.44
.719	16.97	15.46	16.70	15.74	15.95	16.07	16.81	16.40	16.24	15.90	16.90	17.55
.778	16.19	15.64	15.91	16.02	15.67	15.69	16.96	16.43	16.26	15.93	17.09	17.51
.827	15.67	15.83	16.00	16.15	15.69	15.95	17.12	16.32	16.29	16.07	17.09	17.36
.899	16.12	15.69	16.35	16.15	15.50	16.12	17.26	16.36	16.76	16.05	17.21	17.65
372.724	15.70	15.34	17.02	16.28	15.76	16.59	16.15	16.48	16.67	15.70	16.33	17.49
755.682	16.95	15.79	16.80	15.36	15.86	16.62	16.90	16.54	16.26	16.22	16.02	17.49
59.737	16.95	15.50	16.15	15.36	15.60	16.26	17.16	16.40	16.76	15.83	16.05	17.38
.825	16.94	15.36	16.50	15.76	15.70	16.61	16.31	16.43	16.35	16.17	16.09	17.39
5462.637	16.88	15.62	16.54	15.65	15.55	16.73	16.78	16.41	16.62	16.24	16.93	17.03
.691	17.09	15.81	16.61	15.91	-	16.71	-	16.52	-	16.02	-	17.19
63.706	16.93	15.27	15.79	16.47	15.65	16.64	16.22	16.40	16.24	15.90	16.57	17.26
.740	16.85	15.01	15.91	16.52	15.64	16.69	16.12	16.38	16.38	16.12	16.62	17.38
.793	16.95	15.31	16.28	16.61	15.74	16.69	16.47	16.41	16.67	16.29	16.78	17.41
.851	16.97	15.58	16.47	16.29	15.74	16.64	16.64	16.35	16.69	16.36	16.83	17.45
.894	16.92	15.46	16.64	15.62	15.90	16.69	16.85	16.35	16.73	16.31	16.87	17.51
64.811	17.09	15.88	17.09	16.35	15.83	16.38	17.16	16.31	16.87	16.48	16.02	17.54
.842	16.90	15.83	16.93	16.22	15.58	16.33	17.06	16.38	16.71	16.29	16.09	17.52
.886	16.94	15.98	16.41	16.33	15.64	16.62	17.19	16.45	16.69	16.12	16.10	17.49
.918	16.97	15.93	15.81	16.28	15.64	16.55	17.21	16.36	16.40	15.69	16.15	17.55
65.599	17.02	15.36	16.09	16.36	15.62	16.69	16.15	16.29	16.28	15.81	17.06	17.26
.640	16.92	15.39	16.28	16.45	15.50	-	16.22	16.35	16.21	15.90	17.13	17.41
.672	16.26	15.58	16.41	16.45	15.50	16.66	16.45	16.29	16.31	15.98	17.14	17.44
.720	15.77	15.70	16.59	16.40	15.57	16.62	16.59	16.33	16.54	16.15	16.95	17.49
.752	15.88	15.48	16.67	16.41	15.57	16.69	16.76	16.36	16.59	16.22	16.88	17.51
.818	16.24	15.84	16.95	16.47	15.76	15.91	17.02	16.31	16.78	16.09	16.64	17.48
.873	16.41	15.83	16.97	16.08	15.74	15.57	17.09	16.29	16.38	15.76	16.43	17.49
.915	16.67	15.81	17.00	15.46	15.84	15.79	17.19	16.31	16.21	15.72	16.29	17.51
66.618	16.88	15.93	16.95	15.39	15.76	16.17	17.14	16.26	16.29	15.84	16.88	17.42
.725	16.87	16.03	15.70	15.88	15.62	16.61	17.12	16.36	16.61	16.36	16.95	17.51
.821	16.97	15.72	16.17	16.26	15.60	16.76	16.83	16.33	16.71	15.96	17.06	17.54
67.613	16.41	15.77	16.88	16.35	15.51	16.59	16.69	16.33	16.38	16.02	16.17	17.47
.718	16.76	15.96	16.92	16.48	16.07	15.86	17.02	16.40	16.69	16.40	16.50	17.51
.881	17.02	15.90	17.09	16.38	15.64	16.47	17.25	16.33	16.31	16.02	16.80	17.48

points); and the fraction of the period from minimum to maximum light, $\Delta\phi_{\rm rise}$, a parameter used by Sandage *et al.* (1981). All of the variables lie well within 15.5 arcmin, the tidal radius determined by Peterson (1976). However, V13 is considered a field star because it is much fainter than the others. We have determined periods for the eleven stars that Sawyer studied and for three of them (V5, V10, and V12), the new periods are all substantially longer than the previously published values. In each case, the new period is related to the previously published period by the relation: $1/P(\text{new}) = 1/P - 1$. With our new results, the mean period of the three type-c stars (V5, V9, and V10) has been revised from 0.279 to 0.341, which is more appropriate for an Oosterhoff type II cluster. The mean period of the six ab stars (V1, V2, V3, V4, V6, and V7) has also changed slightly from 0.614 to 0.621. This change results because V12, formerly

TABLE III. Elements of the variables.

Var		x''		y''	P(days)	HJD of maximum	$\langle B \rangle$	B_{max}	B_{min}	A_B	$\Delta\phi_{rise}$	Notes
1	+	91	−	76	0.585 728	45465.701	16.63	15.60	17.02	1.42	0.10	
2	+	40	−	31	0.628 186	45465.628	15.66	14.98	15.92	0.94	0.13	(1)
3	+	207	−	210	0.605 353	45465.515	16.54	15.70	17.02	1.32	0.10	(2)
4	+	23	−	35	0.671 3021	45465.928	16.14	15.31	16.53	1.22	0.16	
5	+	34	−	7	0.378 756	45465.672	15.72	15.54	16.02	0.48	0.45	(3)
6	−	70	−	14	0.607 795	45465.868	16.42	15.60	16.73	1.13	0.12	
7	−	111	−	80	0.628 4615	45465.614	16.83	16.10	17.16	1.16	0.12	
8	−	73	−	99			16.39					(4)
9	+	334	−	191	0.322 989	45465.618	16.52	16.22	16.78	0.56	0.29	
10	+	37	+	26	0.319 820	45465.877	16.08	15.74	16.42	0.68	0.24	(5)
11	−	4	−	7								(6)
12	−	275	−	136	1.340 204	45464.705	16.62	16.00	17.16	1.16		(7)
13	+	259	+	11	0.479 874	45465.518	17.45	17.04	17.52	0.48		(8)

Notes to TABLE III

(1) The scatter on the light curve for V2 is due to contamination by nearby stars.
(2) The period of V3 appears to have decreased since Sawyer made her observations. A period of $0^d605397$ fits her data best, but causes our 1983 data to be phase shifted relative to our 1979 data. The best period for our data is $0^d605353$.
(3) We have found that Sawyer's period $0^d274708$ for V5 is too short for our data. On several nights, we have series of observations extending over an interval as long as 0^d27 and the star does not complete one cycle. We have therefore adopted a period of $0^d378756$.
(4) We have found two possible periods, 407^d08 and 1^d00027, that fit Sawyer's data. Our own observations do not indicate any substantial variation.
(5) We have found that Sawyer's period $0^d242322$ for V10 is too short for our data. We have adopted a period of $0^d319820$. See note (3). Cacciari (1974) noted that a period of $0^d319822$ fit Sawyer's data.
(6) V11 lies in a very crowded area, and we were unable to identify it. We assume that either it is not variable, or it did not vary on our plates.
(7) V12 is now classified as a Population II Cepheid with a period of $1^d340204$. The period may have increased since Sawyer made her observations because a period of 1^d34024 gives a better rising branch on the light curve for our data. Our new period is related to Sawyer's period of $0^d571784$ by the relationship: $1/P(\text{new}) = 1/P(\text{Sawyer}) - 1$.
(8) The light curve for V13 is unusual for a star with a period of 0.48 days. Perhaps none of our observations occurred at the phase of maximum light, or possibly the period is incorrect. This star, which is considerably fainter than the others, is close to the limit of detection on our plates, and so our data are not sufficient for determining a new period. If the true period is approximately 0^d48, then it has increased since Sawyer made her observations because the best period for her data, $P = 0^d47985$, does not give a good light curve for our data. Sawyer assumed this was a field star and not a cluster member.

believed to be an RRab variable, is now classified as a Population II Cepheid and is therefore omitted from the calculation.

The B light curves, plotted in order of increasing period, are shown in Fig. 2. In Fig. 3, we show the period-rise time correlation and the period-amplitude relation for the nine RR Lyrae variables in M9 and compare them with the mean relations for M3 (Sandage *et al.* 1981). Using the period-rise time correlation, we find that the periods for the RR Lyrae variables in M9 are shifted by $\log P = -0.07$ with respect to those in M3. This is typical for an Oosterhoff type II cluster.

Variable 12, the Cepheid, has about the same brightness as the RR Lyrae variables. With its period of 1.340204, we would normally expect it to be about a magnitude brighter if it belonged to the cluster. Nevertheless, we believe it is a member whose light is absorbed more than that of the other variables because of its proximity to a heavy obscuring cloud to the southwest of the cluster. This cloud can be detected in Fig. 1, but is much more marked on plates E and O 1160 of the Palomar Sky Survey.

Our new B magnitudes for the RR Lyrae variables can be used to calculate the distance to the cluster. However, we must keep in mind that such a distance will be uncertain because of differential absorption in and around the cluster and also because of possible errors in our standard sequence. Since variables 2, 5, and 10 have large scatter in their light curves due to unresolved companions, it is best to exclude these three from our calculations. For the six other RR Lyrae variables (nos. 1, 3, 4, 6, 7, and 9), we find that the mean $\langle B \rangle$ is $16.51 + 0.23\sigma$. The σ value is rather large, and we attribute this, at least in part, to differential absorption. V7, which is closest to the obscuring cloud, is the faintest of the six variables. However, we continue the calculation in the hope of obtaining a mean value for the distance. Therefore, adopting $E(B-V) = 0.34$ (Zinn 1980) and assuming a mean $(B-V)$ of 0.28, we find that the mean $\langle V \rangle$ for the RR Lyrae variables in M9 is 15.89. Following Sandage (1982), we use Zinn's (1980) metallicity (-1.81) to calculate the absolute magnitude of the RR Lyrae variables, $M_V(\text{RR}) = 0.76$. Assuming $A/E(B-V) = 3.2$, we find that the distance to M9 is 6.4 kpc [$\pm 15\%$ due to uncertainties in the assumed values for V, M, $B-V$, and $E(B-V)$].

IV. DOUBLE-MODE RR LYRAE VARIABLES

In recent years, a number of double-mode RR Lyrae variables have been discovered or suspected in the galactic globular clusters and in galaxies of the local group:

M3 (Goranskij 1981; Cox *et al.* 1983)
M15 (Sandage *et al.* 1981; Cox *et al.* 1983; Nemec 1984c)
M68 (Andrews 1980; Cox *et al.* 1983)
NGC 2257 in the LMC (Nemec *et al.* 1984)
Draco (Goranskij 1982; Nemec 1984a,b)
Ursa Minor (Nemec 1984a).

In all cases investigated so far, the dominant mode of the pulsation is the first harmonic (H) with an amplitude typically about two times greater than that of the fundamental mode pulsation (F). The ratio of the periods P_H/P_F is approximately 0.745. Analysis of these stars provides information about masses, and there is evidence that the masses of the RR Lyrae variables in the Oosterhoff type II clusters are greater than in the type I clusters (Cox *et al.* 1983). We therefore decided to look for double-mode pulsation in the three RRc variables in M9 to see if we could verify this result.

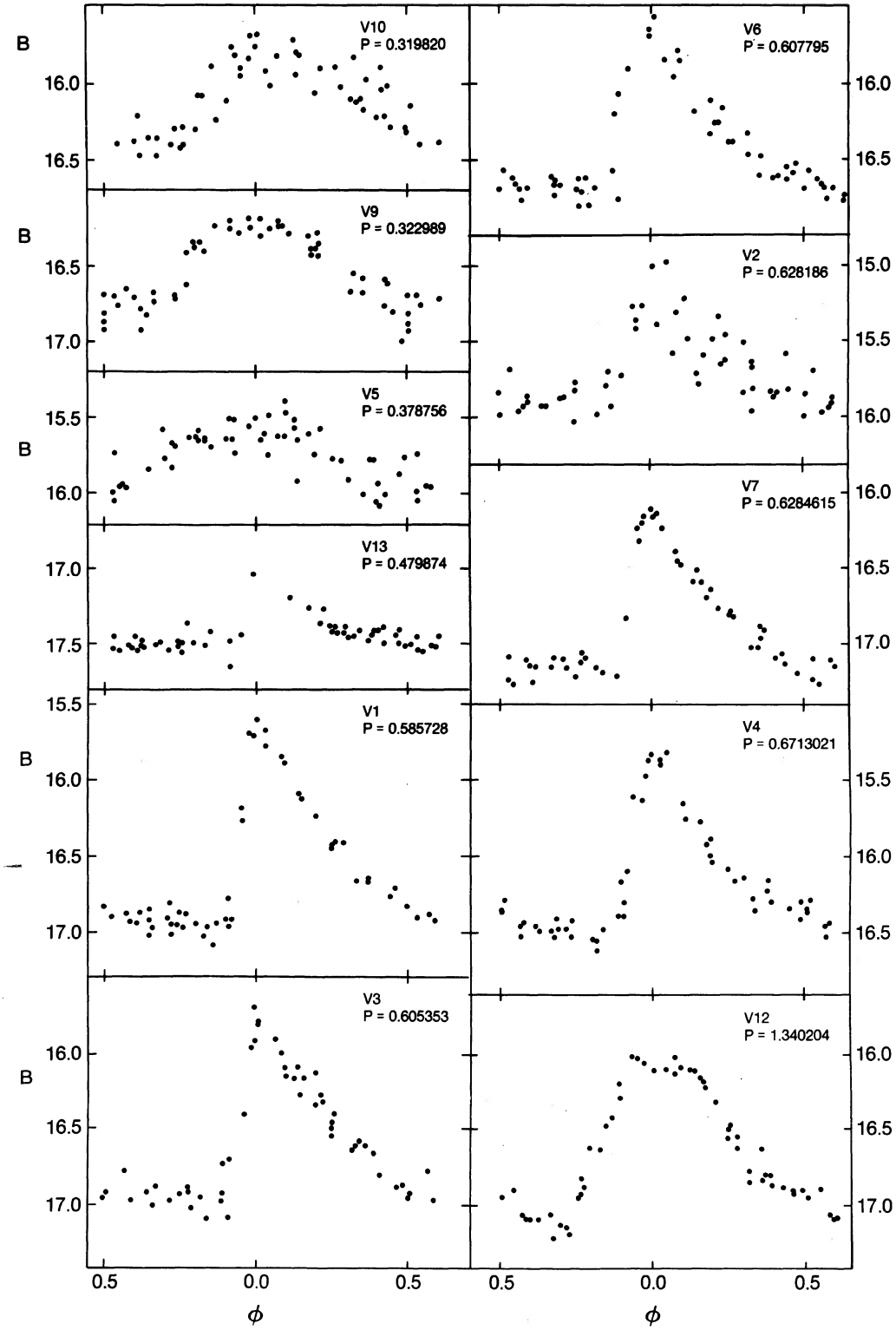

FIG. 2. Light curves (*B* magnitude versus phase) for 10 RR Lyrae variables and a Population II Cepheid, arranged in order of increasing period. All the variables except V13 are believed to be cluster members.

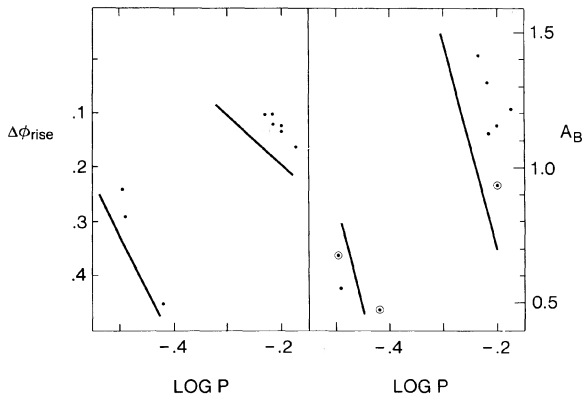

FIG. 3. Period-rise time (left) and period-*B* amplitude (right) diagrams for the nine RR Lyrae variables in M9. The open circles indicate that the amplitudes have low weight. The solid lines correspond to the relations for M3, taken from Sandage *et al.* (1981).

For each star, we chose a primary period using the phase dispersion minimization technique described by Stellingwerf (1978). We removed the primary oscillation from the data and then searched for secondary periods using the same method. We confined our search for secondary periods to the interval where the period ratio ranged from 0.73 to 0.76, the physically realistic range (Nemec 1984c). For the analysis, we used both our own observations and those of Sawyer (1951). There was no evidence for secondary periods in the appropriate range for V9 and V10 whose primary periods are around 0.32 days, but for V5, with a primary period of $0^{d}.37856$, there was weak evidence for a secondary period around 0.507 days ($P_H/P_F = 0.747$). Unfortunately, V5 is located in a crowded region and so there is a lot of noise in the data. This noise could mask the effect of the fundamental-mode pulsation in the light curve. Furthermore, the spacing of our observations is not appropriate. Almost all of the plates were taken in May 1979 and May 1983. For an analysis of this type, it is better to have the observations at more frequent intervals. Thus, at this stage, we can only say that V5 might be pulsating in both the first harmonic and fundamental modes, but we are not certain. More observations are needed.

V. VARIABLE 8

Sawyer was unable to determine a period for this variable, and our observations do not indicate any substantial variation. The standard deviation of our *B* magnitudes is 0.06, which is comparable to that for the standard stars. However, we examined Sawyer's data and found two possible periods,

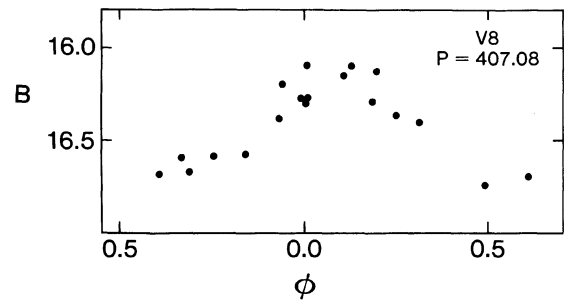

FIG. 4. Light curve for V8 plotted with Sawyer's (1951) data. The period used here is 407.08 days, but a period of 1.00027 days is also acceptable. Further observations are required to determine the true nature of the variation of this star.

$407^{d}.08$ and $1^{d}.00027$. In either case, the star is unusual. Its *B* amplitude of less than one magnitude is small for a star with a 400-day period, and a *V* plate indicates that its $(B - V)$ color is about 1.5, which is red for a star with a period around one day. Unfortunately, our observations at Las Campanas were all made around the phase of minimum. However, we plan to continue our observations in different months and years to see if we can determine the period for this unusual star. In Fig. 4, we show a light curve plotted using Sawyer's data and a period of $407^{d}.08$, but note that a period of $1^{d}.00027$ fits the observations just as well.

VI. SUMMARY

We have made new observations of the southern globular cluster Messier 9 from the southern hemisphere in order to check periods determined using northern hemisphere data. We found that for the eleven stars studied, three of the previously published periods were in error. In each case, the new period was related to the published period by the relation: $1/P(\text{new}) = 1/P - 1$. This indicates that there may be other cases where further observations should be made to check the periods published in the literature. We have also found that one of the RRc variables may be a double-mode pulsator.

We would like to thank Dr. R. J. Stellingwerf for sending us a listing of his PDM routine and for giving us advice on how to use it. Thanks are also due to Dr. J. M. Nemec for sending us copies of his papers on double-mode RR Lyrae variables in Draco and M15 in advance of publication. We are also grateful to Dr. Helen Sawyer Hogg for many helpful discussions. Financial support for this investigation by grants from the Natural Science and Engineering Research Council of Canada is gratefully acknowledged.

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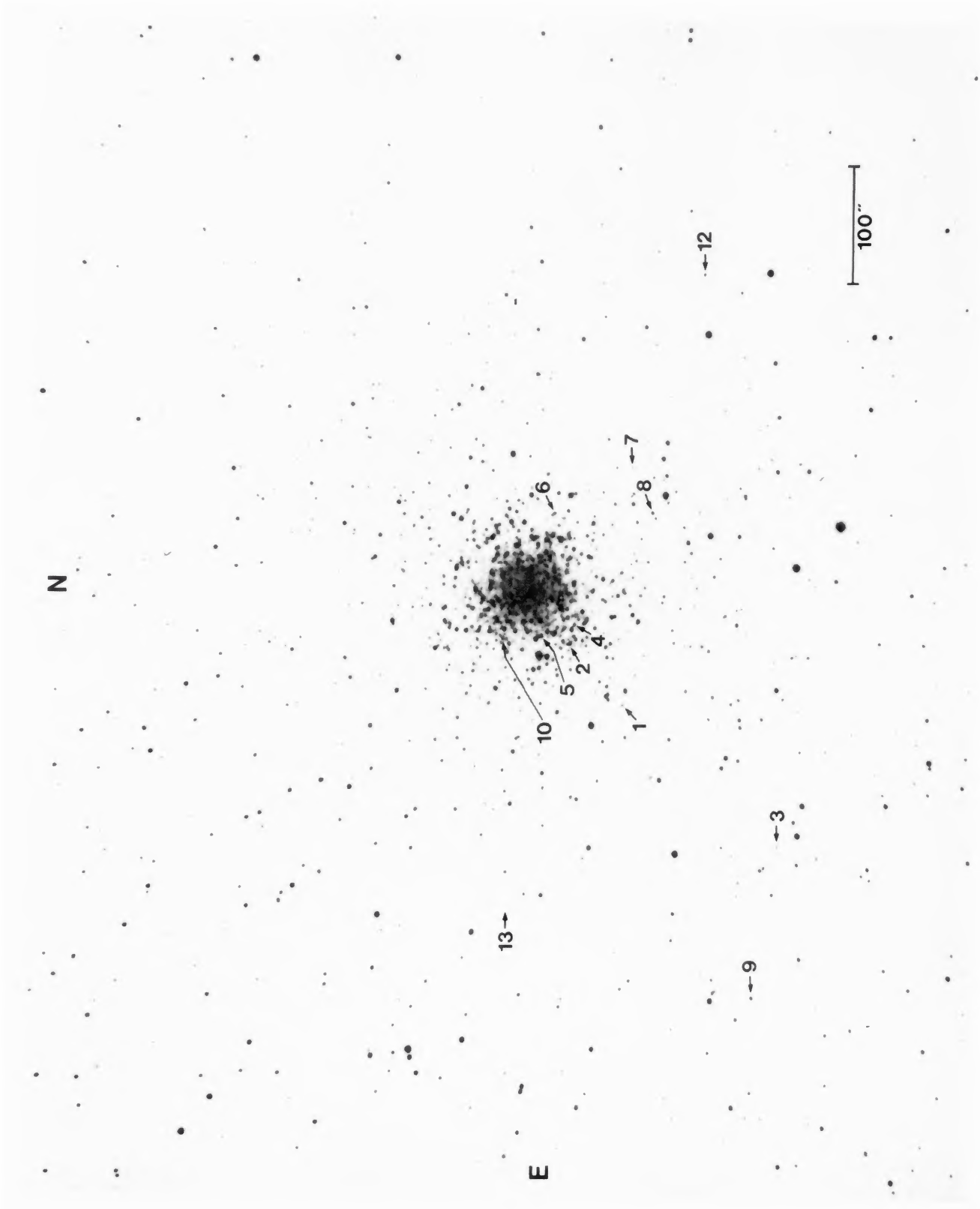

FIG. 1. *B* photograph of the globular cluster M9 (NGC 6333), taken with the 24-in. telescope in Chile. The exposure time is 40 min. Variable stars V1–V10, V12, and V13 are identified.

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