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WIYN OPEN CLUSTER STUDY. XX. PHOTOMETRIC MONITORING OF THE GALACTIC CLUSTER NGC 6939

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ABSTRACT

A photometric monitoring program in the field of the Galactic cluster NGC 6939 was conducted using the 0.91 m WIYN and the US Naval Observatory Flagstaff Station 1.3 m and 1 m telescopes, with the primary goal being to search for cataclysmic variables (CVs) in the cluster. Although no CVs were found during the 5 months of monitoring, a number of short-period variables were discovered in the field of the cluster. A large portion of them are of the W Ursae Majoris type, whereas WOCS V7 is an RR Lyrae star. Although the survey was somewhat compromised by the bright stars around the center of the cluster, it is intriguing that NGC 6939 appears to be deficient in faint variables.

Key words: binaries: eclipsing — binaries: general — open clusters and associations: individual (NGC 6939) — RR Lyrae variable — stars: variables: general

1. INTRODUCTION

Star clusters are ideal for the study of different stages of stellar evolution, providing a uniform stellar population in terms of age, distance, and metallicity. Therefore, they constitute a promising environment to investigate their variable star population because of the information they provide regarding evolutionary histories. Our motivation for studying variability among open cluster stars is to identify more examples of cluster cataclysmic variables (CVs)—compact binaries, generally consisting of a white dwarf accreting gas from a low-mass, main-sequence companion. More than 2000 systems of this class are now cataloged (Downes, Webbink, & Shara 1997), with only a handful of them populating star clusters. These mainly inhabit globular clusters, in which the very high central densities allow frequent stellar interactions leading to the formation of compact binaries by means of tidal capture at the core—a theory supported by observational results (see, e.g., Grindlay 1999). An intriguing aspect is that a large fraction of the globular cluster CVs appear to be magnetic, raising the possibility that they reflect a new class of objects (Grindlay et al. 1995).

On the other hand, only three CVs are known in all open clusters, two in NGC 6791 (Kaluzny et al. 1997) and one in M67 (Gilliland et al. 1991). This, despite the fact that computer *N*-body simulations predict that open clusters as young as 1 Gyr old and hosting $\sim 10^5$ stars form one or two CVs (Hurley & Shara 2002). Systematic searches can eventually put useful constraints on the existing CV formation age and evolution scenarios. Thus, we have initiated a survey to search for them in open clusters, as a part of the WIYN Open Cluster Study (WOCS) collaboration.[5]

Field CVs present a variety of variability signatures. For example, dwarf novae (DNs) have outbursts of 2–6 mag, lasting a week or so and occurring at intervals ranging from a few weeks to a few months, that can be detected quite reliably via photometric monitoring over several months. On the other hand, old novae and nova-like CVs (NLs) are stable against the thermal disk instability thought to be responsible for DN outbursts, and some DNs (the SU UMa stars) have only rare outbursts. Those CV subclasses may be more challenging to identify; however, *all* CVs appear to be variable at the ~ 0.1 mag level because of flickering, orbital modulations or both.

Our first WOCS variability target, NGC 188, did not reveal any new CVs among 2800 stars examined down to $V \sim 20$–21 mag (Kafka & Honeycutt 2003). Because of the large angular diameter of NGC 188, the study was restricted to the central $\sim 17' \times 17'$, ensuring that a large fraction of the stars were cluster members. Our second target, NGC 6939 ($\alpha = 20^{\rm h}31^{\rm m}30^{\rm s}$, $\delta = +60°39'42''$; J2000.0) is a rich (Lyngå richness class 4) yet understudied open cluster. Although the first published work goes back to Küstner (1923), only a handful of studies of the cluster have been conducted since then. Earlier studies (Cannon & Lloyd 1969; Mermilliod, Huestamendia, & del Rio 1994) revealed a prominent main sequence and giant branch and an age of $\sim 10^9$ yr. Recent membership studies include radial velocity work by Geisler (1988) and Milone & Latham (1994) and a proper-motion investigation by Glushkova & Rastorguev (1991). The only published CCD photometry aiming at the determination of the cluster parameters (Rosvick & Balam 2002) revealed an age of 1.6 ± 0.3 Gyr and a variable reddening across the cluster, with $E(B-V)$ ranging from 0.29 to 0.41 mag, which leads to a distance modulus $(m-M)$ within the range 12.21–12.39. In quiescence and outburst DNs typically have $M_V \sim 8$ and $M_V \sim 4$, respectively, while NLs typically have $M_V \sim 4$. For $m-M \sim 12$, cluster DNs should appear at $V \sim 20$ in quiescence, flaring to $V \sim 16$ in outburst. Therefore, a search for these objects in NGC 6939 is not an unreasonable task.

Surprisingly, there is only one CCD variability study for NGC 6939, leading to the discovery of six variable stars among the red giants of the cluster (Robb & Cardinal 1998); two of them are Algol eclipsing binaries, whereas one appears

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[5] WOCS is a collaboration of scientists from the WIYN institutions. For more information, see Mathieu (2000).

TABLE 1
Observation Log for NGC 6939

Telescope	UT Date	Filter	No. Obs.	Exp. Time (s)
Monitoring (Individual Nights)				
WIYN 0.91 m.........	2003 Jul 10	*R*	10	300
	2003 Jul 11	*R*	13	300
	2003 Jul 13	*R*	13	300
	2003 Jul 14	*R*	14	300
USNOFS 1.3 m	2003 May 2	*R*	15	120
	2003 May 5	*R*	40	120
	2003 May 9	*R*	17	120
	2003 May 10	*R*	21	120
	2003 May 11	*R*	31	120
	2003 May 12	*R*	36	120
	2003 May 26	*R*	37	240
Synoptic				
WIYN 0.91 m.........	2003 Mar 31–Sep 14	*R*	174	300–900
USNOFS 1.3 m	2003 Apr 07–Jun 16	*R*	120	30–480
Other Filters Available				
WIYN 0.91 m.........	2003 Jul 13	*BVI*	1	450–300
USNOFS 1.0 m	2003 Apr 3	*BVRI*	1	300–600
	2003 Apr 7	*BVRI*	1	300–600
	2003 May 12	*BVRI*	1	300–600
	2003 Jun 11	*BVRI*	1	300–600
	2003 Jun 23	*BVRI*	1	300–600

to be of the W Ursae Majoris type (s154 = V466 Cep). Although our study did not result in the detection of any CVs in the vicinity of the cluster down to our detection limit of $R_C \sim 19-20$, we did find a number of new variable stars, many of which are W UMa eclipsing binaries. In § 2 we present our data sample and reduction techniques, § 3 focuses on the characteristics of the new variable stars, and our conclusions are provided in § 4.

2. OBSERVATIONS AND DATA REDUCTION

Several sets of photometric data were used in this study, incorporating observations from the 0.91 m WIYN[6] telescope at Kitt Peak and the US Naval Observatory's 1.3 m and 1 m telescopes near Flagstaff, Arizona. All our images were acquired during the spring and summer of 2003.

The cluster was included in the synoptic service observing program of the 0.91 m WIYN telescope. The S2KB 2048 × 2048 CCD camera was used, providing a $\sim 20' \times 20'$ field of view at 0″.6 pixel^{-1}. Exposures (all with the Kron-Cousins *R* filter) varied between 300 and 900 s in length, depending on observing conditions. Except for two interruptions, when the Mosaic camera was scheduled on the telescope, two exposures were acquired on nearly each clear night during the interval 2003 March 31–September 14, yielding 174 usable images. We added exposures of NGC 6939 in *B*, *V*, and Kron-Cousins *I* during one night in 2003 July for a study of the cluster color-magnitude diagram and the determination of its fundamental parameters (age, metallicity, and distance), which will be the subject of a future paper.

The cluster was also observed during 2003 April, May, and June using the 2048 × 4096 CCD on the 1.3 m telescope of the US Naval Observatory, Flagstaff Station (USNOFS) providing a $\sim 20' \times 40'$ field of view at 0″.6 pixel^{-1}. These observations were concentrated during the gaps of the WIYN 0.91 m synoptic coverage; therefore, we managed to continuously monitor NGC 6939 for more than 5 months. Exposures were acquired on 38 different nights, with the number of exposures per night varying from six to 41.

Finally, the 1.0 m telescope at USNOFS with the SITe/Tektronix 1024 × 1024 CCD having an $11' \times 11'$ field of view with 0″.67 pixel^{-1} scale, was used on one night for continuous *R*-band monitoring. The primary use of the 1.0 m telescope was to establish a set of *BVRI* secondary standards in the

[6] The WIYN Observatory is a joint facility of the University of Wisconsin–Madison, Indiana University, Yale University, and the National Optical Astronomy Observatory.

TABLE 2
Secondary Standard Stars in the Field of NGC 6939

ID	R.A. (J2000)	Decl. (J2000)	*V*	Error	$B-V$	Error	$V-R_C$	Error	R_C-I_C	Error
1..................	20 32 00.28	+60 44 29.0	17.855	0.010	0.925	0.018	0.601	0.011	0.563	0.030
2..................	20 32 08.75	+60 43 00.3	18.551	0.009	1.416	0.031	0.852	0.011	0.726	0.014
3..................	20 31 50.73	+60 43 48.1	18.683	0.015	0.876	0.044	0.589	0.030	0.525	0.044
4..................	20 31 46.99	+60 41 19.6	16.411	0.017	0.855	0.005	0.522	0.010	0.526	0.013
5..................	20 31 54.17	+60 40 23.0	14.613	0.011	0.541	0.009	0.322	0.009	0.346	0.005
6..................	20 31 51.93	+60 38 04.1	14.220	0.011	1.557	0.005	0.861	0.011	0.785	0.051
7..................	20 31 53.35	+60 34 35.2	15.798	0.026	0.832	0.007	0.518	0.009	0.535	0.003
8..................	20 31 31.93	+60 38 16.2	12.573	0.006	0.330	0.005	0.209	0.001	0.236	0.006
9..................	20 31 22.75	+60 39 54.1	14.543	0.008	0.675	0.009	0.427	0.005	0.411	0.009
10................	20 31 24.68	+60 36 18.3	14.937	0.012	1.271	0.012	0.732	0.009	0.710	0.012
11................	20 31 04.98	+60 36 49.2	13.711	0.010	0.792	0.006	0.490	0.011	0.467	0.013
12................	20 30 50.24	+60 34 54.3	16.951	0.012	0.049	0.007	−0.082	0.009	−0.113	0.017
13................	20 31 10.97	+60 38 36.0	15.021	0.009	1.536	0.009	0.865	0.009	0.783	0.012
14................	20 30 47.86	+60 39 13.9	17.631	0.016	0.792	0.003	0.491	0.012	0.456	0.022
15................	20 31 04.86	+60 39 42.7	18.167	0.026	1.082	0.029	0.613	0.024	0.587	0.017
16................	20 31 09.01	+60 41 49.2	15.279	0.009	0.900	0.007	0.545	0.010	0.488	0.013
17................	20 31 25.40	+60 42 46.8	19.360	0.013	0.880	0.098	0.595	0.020	0.478	0.022

Note.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

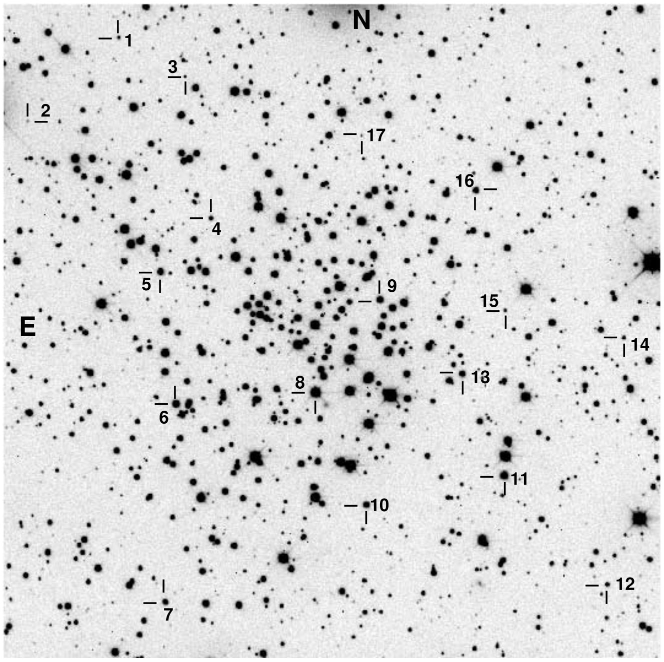

FIG. 1.—Finding chart for the secondary standard stars listed in Table 2. This *V*-band image was taken with the 1.0 m telescope of the US Naval Observatory and is 11′ on a side.

field of NGC 6939 in order to calibrate our monitoring data. Table 1 provides a detailed log of all of our observations.

Initial data processing (bias subtraction and flat-field correction) was performed using the standard IRAF routines; aperture photometry was conducted on the monitoring data using the IRAF APPHOT package. The all-sky photometry to establish secondary standards was performed on five photometric nights. Landolt (1983, 1992) standard stars covering a wide range in color and air mass were used to determine extinction and mean color coefficients, which were then applied to the cluster stars. These secondary standards served as calibrations for the rest of our stars. Each monitoring data set (the 0.91 m synoptic and the 1.3 m USNOFS) was analyzed separately in order to provide independent determinations of variability and periods. The instrumental magnitudes from APPHOT were then supplied to AstroVar, a custom interactive program based on the method of incomplete ensemble photometry (Honeycutt 1992), optimized for the detection and study of variables in large data sets.

Objects whose variability exceeded 1.7 σ of the scatter of constant stars at the same mean magnitude level were used as a preliminary list of candidate variables. Visual inspection of the images helped identify blended stars or close companions that could give false variability signatures due to seeing variations. Each light curve was inspected for possible outbursts that could reveal a CV. Furthermore, a periodogram (Horne & Baliunas 1986) was formed to search for periodicities. The light curve of each suspected variable was folded on trial periodogram peaks to produce the best phased curve for each star. In each periodogram, the reliability of the peak was checked by shuffling the magnitudes, retaining the observation dates, and generating a new periodogram for each shuffled data set—a procedure that was performed multiple times for each light curve. The stars for which the periodogram peaks significantly exceeded the noise of the shuffled data and showed periodicities other than various aliases were further considered.

3. DISCUSSION

3.1. *The Variables*

A sample of our secondary standards having relatively small errors and a range in color are provided in Table 2 for future reference. The first column of Table 2 gives the stellar identification number corresponding to the finding chart of Figure 1. Accurate astrometric solutions of all the stars in the field were derived using the USNO-A2.0 reference frame, with typical per-star error of about 0″.2.

Several blue stars in our sample ($B-V \leq 0$) did not show any signature of variability. On the other hand, 11 variables,

TABLE 3
VARIABLE STARS IN THE FIELD OF NGC 6939

Star[a] (1)	R.A. (J2000) (2)	Decl. (J2000) (3)	$\langle R_C \rangle$[b] (4)	Period (days) (5)	T_0 (HJD) (6)	δR_C (7)	Type (8)
WOCS V1	20 30 01.37	60 46 03.4	15.85	0.3601(4)	2,452,700.187(7), min.	0.23	W UMa
WOCS V2	20 29 24.64	60 29 44.4	15.9	0.4511(3)	2,452,700.329(9), min.	0.75	W UMa
WOCS V3	20 33 22.81	60 37 14.1	16.75	0.2951(4)	2,452,700.15(1), min.	0.50	W UMa
WOCS V4	20 30 16.20	60 36 32.1	17.70	0.2419(4)	2,452,700.025(4), min.	0.55	W UMa
WOCS V5	20 30 04.46	60 34 33.2	18.1	0.2946(6)	2,452,700.13(2), min.	0.65	W UMa
WOCS V6	20 32 40.41	60 45 41.5	17.6	0.11142(3)	2,452,700.08(1), max.	0.12	δ Scuti??
WOCS V7	20 29 35.22	60 38 34.5	16.2	0.5668(9)	2,452,700.46(1), max.	0.8	RR*ab*
WOCS V8	20 33 02.12	60 43 23.6	15.85	0.3379(4)	2,452,700.186(7), min.	0.23	Algol
WOCS V9	20 33 16.00	60 44 24.4	17.05	1.143(3)?	2,452,700.50(6), min.	0.3	?
WOCS V10	20 32 45.76	60 35 55.5	13.9	95(?)	. . .	0.55	LPV??
V466 Cep (s154)	20 31 13.98	60 36 47.4	15.5	0.3548(5)	2,452,700.241(7), min.	0.26	W UMa
V467 Cep (s63, K95)	20 31 18.81	60 38 09.7	*15.1*	*4.954(3)*	*2,450,653.8079(5), min.*	*0.34*	*Algol*
V470 Cep (s98, K147)	20 31 29.05	60 39 35.0	*15.6*	*3.598(3)*	*2,450,654.0244(8), min.*	*0.36*	*Algol*
s28 (K125)	20 31 24.58	60 40 18.1	*14.2*	*1.30(2)*	*2,450,655.75(9), max.*	*0.13*	*?*
s11 (K134)	20 31 27.10	60 38 18.0	*13.3*	*7.4(6)*	*2,450,657.5(7), max.*	*0.03:*	*?*
s33 (K80)	20 31 12.68	60 40 31.2	*14.4*	*10.5(20)*	*2,450,654.4(9), max*	*0.07:*	*?*

[a] For the known variables, we provide the "s" notation and the Kustner "K" ID as provided by Robb & Cardinal 1998.
[b] Values adopted from Robb & Cardinal 1998 are italicized.

10 of which are new (and none of which is a CV candidate) emerged from our study. A practical difficulty is caused by the large concentration of bright stars at the central region: for long exposure times, the central stars were saturated, contaminating their fainter neighbors and thus making the detection of faint stars in this region a challenging task. Therefore, we made a separate study of ~28 short exposures, which had fewer saturated stars. This allowed us to create light curves of the five bright variable stars presented by Robb & Cardinal (1998). V467 Cep (s63) and V470 Cep (s98) are both confirmed as Algol variables; however, the small number of observations prevented our obtaining useful light curves. We verified the period of s28 but with the data in hand, we cannot address its variability type. Stars s11 and s33 were presented as low-amplitude variables in Robb & Cardinal (1998), having amplitudes of ~0.03 and ~0.07 mag, respectively, and periods of 7.4 and 14.4 days. Although we cover a time interval adequate to sample the periods reported, our data do not reveal any variability in those two stars at the level of 0.007 mag rms. Since our data were obtained at a different epoch than the Robb & Cardinal (1998) observations, an intriguing possibility is that the character of the long-term variability of the systems may have changed. Finally, we did not find any signature of variability among the rest of the bright stars—but we were not able to examine the blue stragglers of the cluster (Manteiga, Martínez Roger, & Pickles 1989; Milone & Latham 1994) because of saturation.

The 11 faint variables from our data are given in Table 3; Figure 2 presents finding charts, whereas Figure 3 displays their light curves folded on the adopted periods. Individual error bars are given on most of the plots except for V466 Cep and WOCS-V6, where they are omitted because of crowding. Filled circles correspond to USNOFS 1.3 m data, while open circles are from the WIYN 0.91 m synoptic program. Since the USNOFS 1.3 m telescope covers a wider field of view than the 0.9 m, we have data from both telescopes only for three of the systems. Table 4 contains BVR_CI_C photometry for the new variables and the variables found by Robb & Cardinal (1998). The means and errors in this table are based on two measures taken on 2003 May 10 and 12, respectively. Because of this, the photometry reflects random points on each variable's light curve and not maximum, minimum, or true mean. However, it is representative of each system and can be used for rough calibration and for classification.

WOCS V7 is clearly an RR Lyrae star. Based on $R_C \sim 16$ and $m - M \sim 12$ for the cluster, it is likely a background object. WOCS V6 has a well-defined, low-amplitude, sinusoidal light curve, and may be a δ Scuti star. WOCS V8 is most likely an Algol variable. WOCS V9 is certainly a variable, with a 1.143 day period; however, we are unable to assign a variability type based on this data set alone. Finally, WOCS V10 has an amplitude of 0.55 in R_C and a quite red color, indicating a long period variable (LPV) with a period of ~95 days.

The six W UMa systems, one of which was previously known (V466 Cep), appear to be rather representative of the class, having somewhat unequal minima in their light curves, periods in the range 0.25–0.45 days, and amplitudes of 0.23–0.75 mag in R_C. W UMa stars are considered to be tidally synchronized compact binary systems, known to exist in open clusters as young as Praesepe (700 Myr) and as old as NGC 6791 (7 Gyr; Rucinski 1998). They are thought to be an intermediate stage of binary evolution, which is believed to eventually result in coalescence and the formation of blue stragglers or FK Comae type systems; however, their progenitors remain unknown. Computer simulations suggest that the contact phase of those systems lasts for about 1–2 Gyr (e.g., Bradstreet & Guinan 1994); nonetheless, this cannot explain the fact that W UMa systems have been discovered within a wide age range of clusters (Rucinski 1998). NGC 6939, being in the proper age range, was expected to host a number of W UMa systems; nevertheless, it is surprising to us that all of our W UMa stars are found at the outskirts of the cluster, suggesting that most of them are not cluster members. Rucinski (1998) lists 11 open clusters with contact systems, averaging six W UMa stars per cluster. In addition, using the W UMa sample from the OGLE catalog, Rucinski (1997) concludes that one out of 250–300 main-sequence field stars is expected to be a contact system. Considering that NGC 6939 has a rich main sequence (Rosvick & Balam 2002), we expected to find a larger density of W UMa systems in the vicinity of the cluster.

Astrometric information on the variable stars is provided in Table 3 (cols. [2] and [3]). For completeness, we included in the table the information for V467 Cep, V470 Cep, s28, s11, and s33 adopted from Robb & Cardinal (1998; values in italic). We also searched the USNO-B catalog (Monet et al. 2003) for proper-motion information; only five of the variables have proper-motion measurements. These values are plotted in Figure 4 along with the mean proper motion of NGC 6939 of $\mu_\alpha = -0''.0012 \pm 0''.0031\,\mathrm{yr}^{-1}$ and $\mu_\delta = -0''.0011 \pm 0''.0029\,\mathrm{yr}^{-1}$ (Glushkova & Rastorguev 1991). With the possible exception of V9, the proper motions are several standard deviations from the motion of the cluster. However, these proper motions are small and difficult to measure and may not be a firm indication of membership for individual stars.

3.2. *Completeness*

The computer *N*-body simulations that motivate this study (Hurley & Shara 2002) predict one or two CVs for rich Galactic clusters that consist of $\sim 10^5$ stars. Therefore, it is important to assess the completeness of this variability survey, since our primary goal is the search for cluster CVs. Although ~5000 stars ranging in magnitude from 14.5 to 19.5 in *R* were examined for variability, subtraction of the star density in fields adjacent to the cluster shows that only about 650 of the stars in our sample are likely to be cluster members. Most of the stars we examined in the field of NGC 6939 are not expected to be cluster members, because field star contamination is significant and because the USNOFS CCD field extends well beyond the cluster. However, keep in mind that in our sample there was no indication of the presence of any outbursting DNs (the most common kind of CV) from below our magnitude limit.

For nova-like CVs and for DNs not undergoing outburst, we are dependent on flickering for CV detection. Therefore, in order to examine the completeness of this study in detecting variables at various magnitudes, we inserted artificial variables at magnitudes 16, 18, and 19 in order to determine how many were found with our software at 1.7 σ variation, our criterion in checking for variability. The artificial stars had peak-to-peak variations of 0.2, 0.1, and 0.05 mag. At 0.2 mag amplitude (~0.07 mag rms) we recovered all the fake variables at magnitudes 16, 18, and 19. At 0.1 mag amplitude (~0.035 mag rms) we found all the variables at magnitudes 16 and 18, but only half of them at magnitude 19. At 0.05 mag amplitude (~0.02 mag rms) we found half of the stars at magnitude 16, but none at magnitudes 18 and 19. From this we conclude that characteristic CV flickering at 0.1 mag would have been detected for most of the stars surveyed.

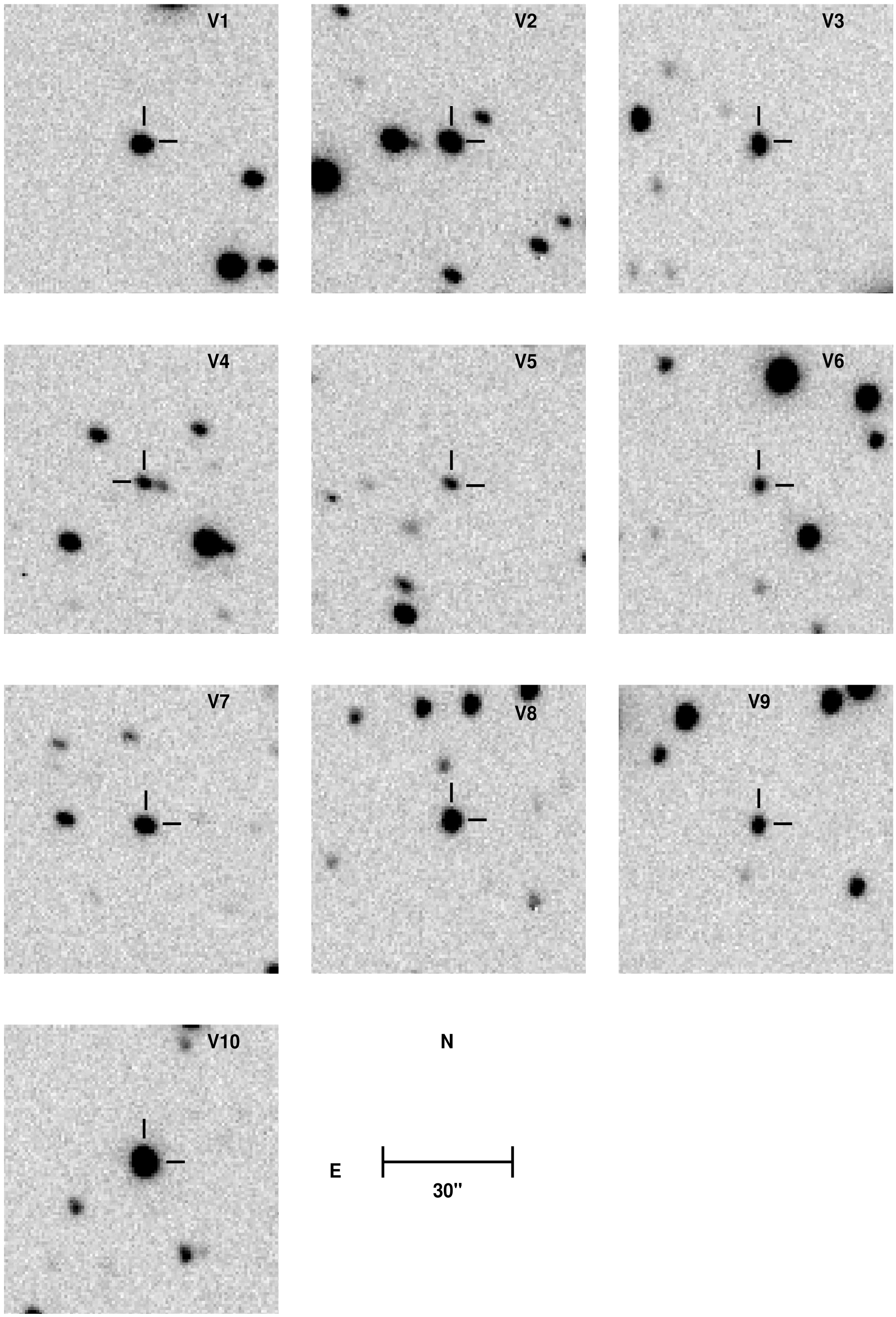

FIG. 2.—Finding chart for the variable stars in the field of NGC 6939. The WOCS notation was omitted for clarity. The nomenclature for s11, s28, and s33 is from Robb & Cardinal (1998).

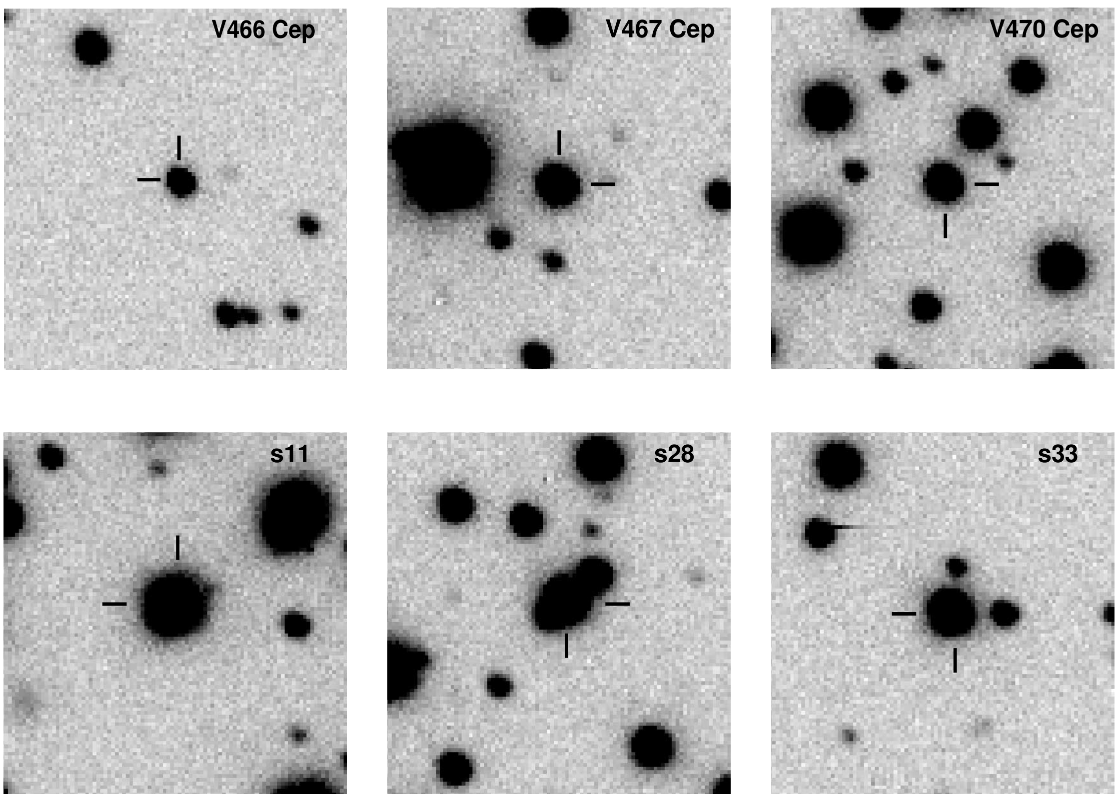

FIG. 2.—*Continued*

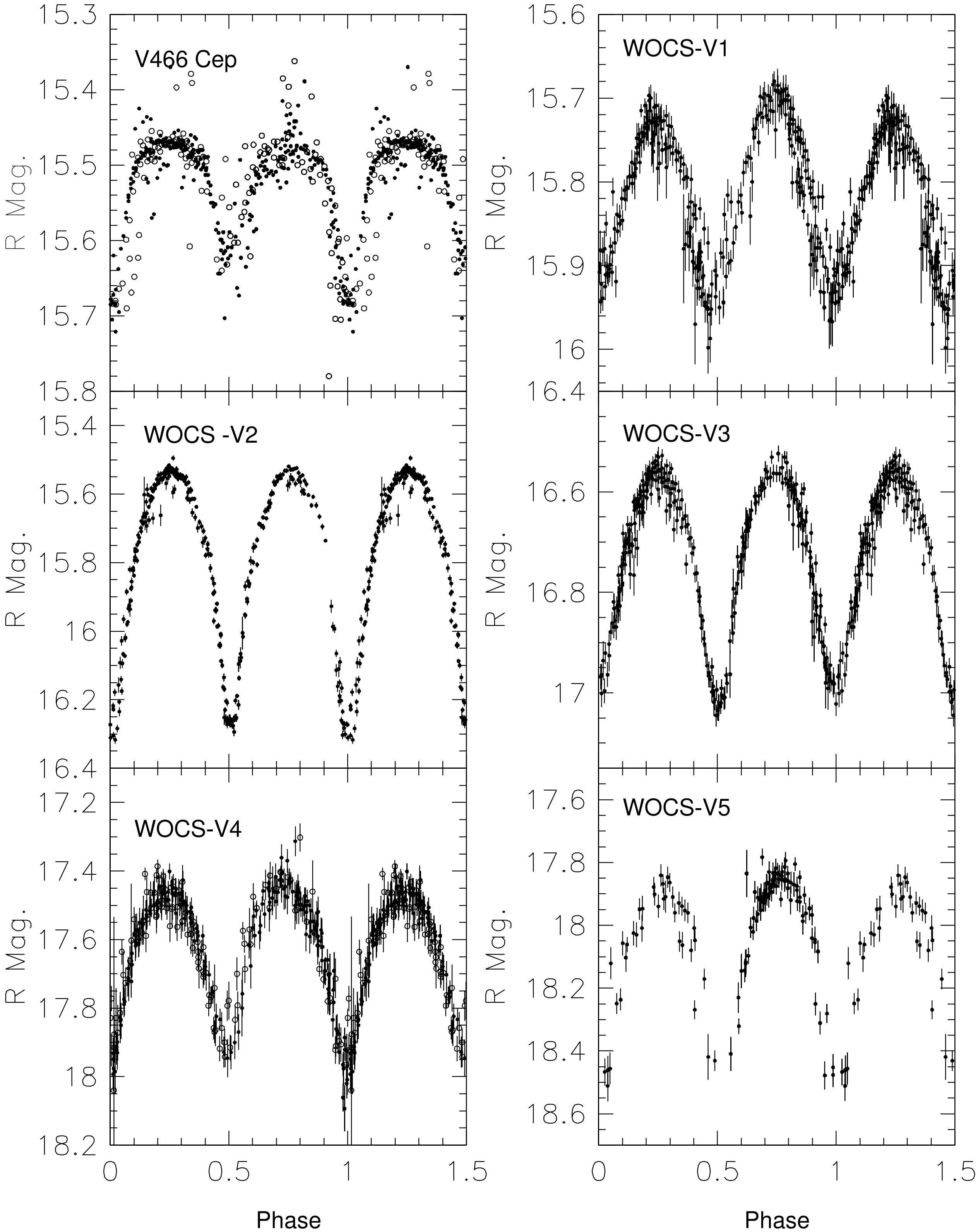

FIG. 3.—Folded light curves of V466 Cep and the WOCS variables V1–V10 in NGC 6939. The corresponding periods are given in Table 3. Open circles are from the WIYN 0.91 m synoptic program whereas solid points are data taken with the USNOFS 1.3 m telescope. For WOCS V7 (RR*ab*) the light curve was shifted in phase for a clearer presentation.

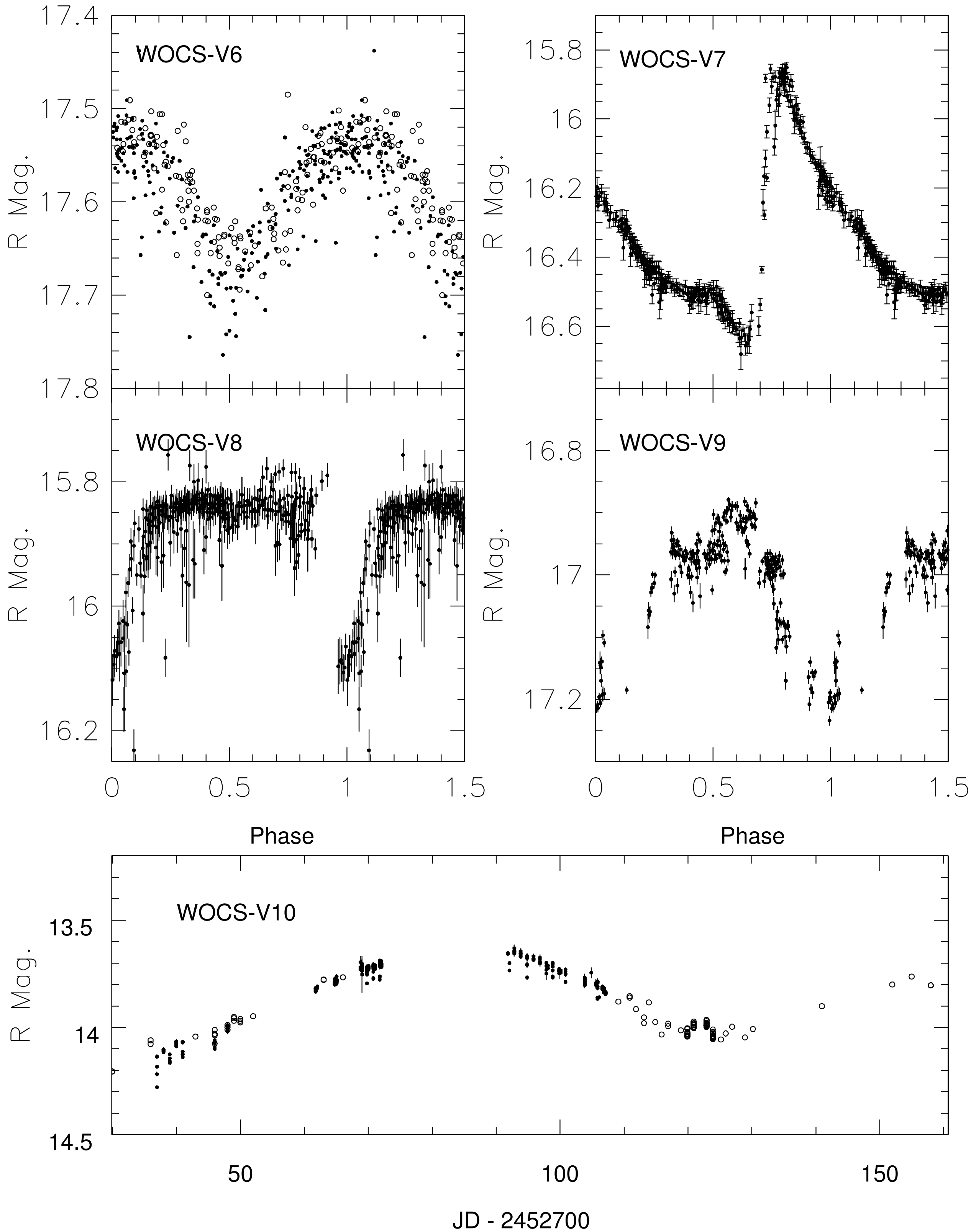

FIG. 3.—*Continued*

TABLE 4
PHOTOMETRY OF THE VARIABLE STARS IN THE FIELD OF NGC 6939

Star	V	$B-V$	$V-R$	$R-I$
WOCS V1	16.643 ± 0.025	1.139 ± 0.018	0.712 ± 0.026	0.636 ± 0.013
WOCS V2	16.360 ± 0.330	0.760 ± 0.070	0.600 ± 0.080	0.420 ± 0.120
WOCS V3	17.220 ± 0.100	1.010 ± 0.050	0.590 ± 0.060	0.620 ± 0.070
WOCS V4	18.008 ± 0.022	1.190 ± 0.050	0.682 ± 0.026	0.696 ± 0.022
WOCS V5	18.437 ± 0.032	0.940 ± 0.070	0.660 ± 0.040	0.590 ± 0.035
WOCS V6	18.251 ± 0.017	1.147 ± 0.021	0.660 ± 0.120	0.715 ± 0.025
WOCS V7	16.600 ± 0.500	0.630 ± 0.210	0.440 ± 0.120	0.440 ± 0.110
WOCS V8	16.650 ± 0.090	1.134 ± 0.016	0.775 ± 0.033	0.610 ± 0.060
WOCS V9	17.787 ± 0.018	1.280 ± 0.019	0.851 ± 0.016	0.804 ± 0.014
WOCS V10	15.100 ± 0.017	1.997 ± 0.015	1.401 ± 0.016	1.305 ± 0.031
V466 Cep (s154)	16.180 ± 0.016	1.113 ± 0.013	0.702 ± 0.004	0.650 ± 0.004
V467 Cep (s63, K95)	14.486 ± 0.012	0.715 ± 0.004	0.461 ± 0.006	0.456 ± 0.006
V470 Cep (s98, K147)	14.938 ± 0.004	0.743 ± 0.006	0.479 ± 0.011	0.452 ± 0.011
s28 (K125)	13.760 ± 0.050	0.816 ± 0.008	0.516 ± 0.006	0.526 ± 0.006
s11 (K134)	12.945 ± 0.011	1.204 ± 0.006	0.582 ± 0.012	...
s33 (K80)	13.873 ± 0.011	1.013 ± 0.004	0.615 ± 0.014	0.594 ± 0.007

4. CONCLUSIONS AND FUTURE WORK

We have conducted a variability study of the old open cluster NGC 6939, primarily aimed at the detection of CVs. None were discovered; however, the effective number of cluster members studied is significantly smaller than the number used in relevant computer simulations, and therefore our results are not inconsistent with the models. Nevertheless, this study can provide a useful datum that, combined with searches in other open clusters, will eventually help constrain models of the age and environment of CV formation and evolution.

On the positive side, we identified 10 new variables in the vicinity of the cluster, five of which are W UMa contact systems. Mass segregation is expected for a cluster as old as NGC 6939; therefore we expected to detect a significant number of faint cluster variables close to the center. Although we monitored the cluster for more than five months, we are puzzled by the small number of new variables discovered near the center and by the few longer period variables found.

This cluster presents technical difficulties for the study of its faint members, in that its center contains many bright stars that saturate and contaminate their fainter neighbors during long exposures. While this may partly account for the lack of faint variables detected, it may well be that NGC 6939 is also physically deficient in contact binaries, a situation suspected for some other clusters (Rucinski 1998). However, demonstrating that a true deficiency of variables exists for a given cluster such as NGC 6939 is difficult. Not only are the expected numbers of W UMa stars relatively small, but the completeness of a variability survey in a rich field is also hard to determine, and it varies depending on the cluster and on the reduction techniques employed.

We note that X-ray studies have revealed interesting objects at the dense centers of open clusters. For example, an X-ray study of M67 revealed 22 X-ray sources, seven of which are known to have optical counterparts, including one CV (Belloni, Verbunt, & Schmitt 1993). Within the wide variety of main-sequence and post–main-sequence variables, including Algol, RS CVn, and BY Draconis systems, X-ray luminosities on the order of 10^{30}–10^{32} ergs s^{-1} are not unusual (see, e.g., Torres, Neuhäuser, & Wichmann 1998). In addition, it is known that CVs have typical X-ray luminosities of $\sim 10^{34}$ ergs s^{-1} (Warner 1995). Therefore, an X-ray study of NGC 6939 could reveal a large portion of its variable star population and the presence of any CVs in its central region.

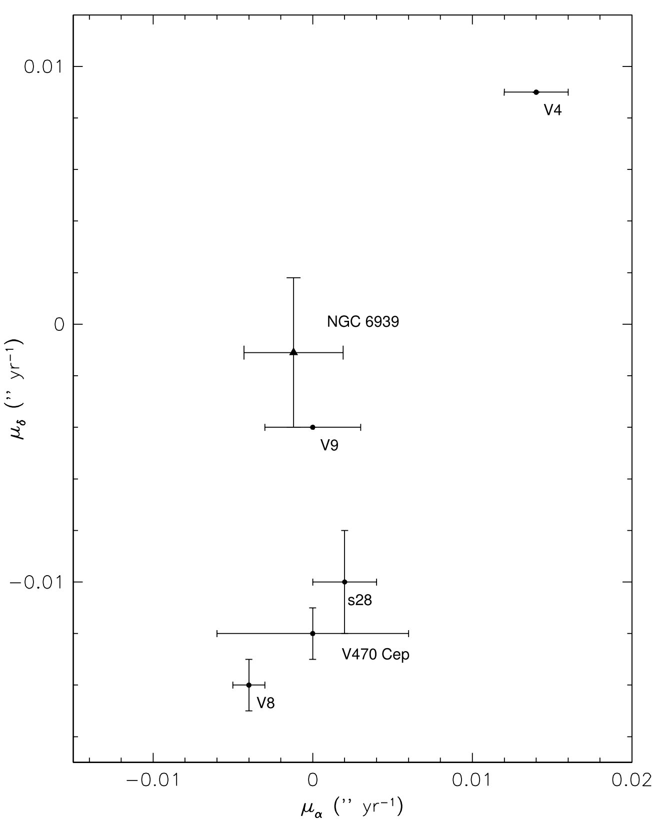

FIG. 4.—Proper motions of NGC 6939 and some of the variable stars. The proper-motion values for the variables were taken from the USNO-B catalog (Monet et al. 2003).

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