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A SEARCH FOR LOW-AMPLITUDE VARIABILITY IN SIX OPEN CLUSTERS USING THE ROBUST MEDIAN STATISTIC

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ABSTRACT

We used point-spread function fitting and a differential ensemble determined from a robust median statistic (RoMS) to examine stars in six open clusters in a search for δ Scuti variables. In the search for new variable stars among hundreds or thousands of stars, the RoMS is proved more effective for finding low-amplitude variables than the traditional error-curve approach. This high-precision differential approach was applied to the open clusters NGC 225, NGC 559, NGC 6811, NGC 6940, NGC 7142, and NGC 7160. Thirteen variables, 29 suspected variables, and 65 potential variables were found, and time-series data of the variables are presented. Among the 13 variables we found nine new δ Scuti variables.

Key words: δ Scuti — open clusters and associations: individual (NGC 225, NGC 559, NGC 6811, NGC 6940, NGC 7142, NGC 7160) — stars: variables: other

Online material: color figures

1. INTRODUCTION

As part of our ongoing program to examine the nature of δ Scuti variables and their evolution, we have examined methods to find low-amplitude variable stars in open clusters. In Enoch et al. (2003) they discuss the application of a robust median statistic (RoMS) in the search for light variations in brown dwarf objects. In Hintz & Rose (2005) they examined the RoMS of the open cluster NGC 6882/NGC 6885 in the search for low-amplitude δ Scuti variables. Although it was applied after the variables were established and not as part of the search process, the RoMS effectively highlighted the variables.

We have chosen to include the RoMS in the analysis of a group of open clusters in a systematic manner to find low-amplitude periodic variables near the main sequence and within the instability strip. Targets were selected to provide a group of clusters within 1000 pc that represent a range of ages. However, we originally used the distances in Becker & Fenkart (1971) to select our targets. This led to the inclusion of three clusters with distances greater than 1200 pc, as reported in the WEBDA database in 2006.[2] The clusters selected were NGC 225, NGC 559, NGC 6811, NGC 6940, NGC 7142, and NGC 7160 (see Table 1). Since the exposure times were set based on the older distances, the magnitudes of smallest error were not located in the instability strip, indicating we were less likely to find δ Scuti variables in these clusters than originally intended. However, since the primary purpose of the work was to test the RoMS we proceeded with the reduction. In this paper we discuss the application of the RoMS statistic to our data set and the resulting variable stars found.

2. OBSERVATIONS

All photometric observations of the selected clusters were secured between 2004 July and 2005 October at the Orson Pratt Observatory and the Dominion Astrophysical Observatory (OPO and DAO, respectively). At the OPO we used the 0.4 m David Derrick Telescope. For the first observations at the OPO the Newtonian focus was used with an Apogee AP47p CCD camera. The latter set of data from OPO were taken at the Cassegrain focus with a SBIG ST-1001 CCD system. Finally, the DAO observations were taken with the 1.8 m Plaskett Telescope equipped with the SITe-5 CCD. A summary of all the configurations can be found in Table 2. Images were taken using *BVRI* Johnson-Cousins broadband filters, which incorporate filter specifications set by Bessell (1990). On a number of nights standard fields were also collected (Landolt 1992) on both telescope systems. A summary of the observations can be found in Table 3. All frames were processed using standard methods in IRAF.

3. VARIABLE SEARCH METHODS

3.1. *Initial Differential Solution*

We began our analysis by obtaining instrumental magnitudes for a large sample of stars in each cluster. The magnitude range was about 5 mag below the brightest star in each field. We examined the following number of stars in each cluster; NGC 225 (112 stars), NGC 559 (390 stars), NGC 6811 (116 stars), NGC 6940 (278 stars), NGC 7142 (322 stars), and NGC 7160 (137 stars). Magnitudes were obtained using DAOPHOT (Stetson 1987, 1990, 1991) so that we could examine all stars of interest in each field, even in crowded regions.

The magnitudes produced by DAOPHOT were then used in a differential photometry solution to look for candidate variable stars. We began the reduction by removing any known variables and then using all remaining stars as the ensemble for each frame.

[1] Guest investigator; Dominion Astrophysical Observatory, Herzberg Institute of Astrophysics, National Research Council of Canada. Observations were made with the 1.8 m Plaskett Telescope.

[2] See http://www.univie.ac.at/webda/.

TABLE 1
Open Clusters Observed in This Study

Cluster	R.A. (J2000.0)	Decl. (J2000.0)	Distance (pc)	Mod. (mag)	$E(B-V)$ (mag)	Diameter (arcmin)	Age (10^x yr)	Sp. Type
NGC 225	00 43 42	+61 47 00	657	9.94	0.274	15	8.114	B8
NGC 559	01 29 22	+63 16 48	1258	12.95	0.790	7	7.748	B7
NGC 6811	19 37 10	+46 22 30	1215	10.92	0.160	15	8.799	A1
NGC 6940	20 34 24	+28 17 00	770	10.10	0.214	26	8.858	A0
NGC 7142	21 45 09	+65 46 30	1686	12.36	0.397	11	9.276	F
NGC 7160	21 53 36	+62 36 00	789	10.65	0.375	10	7.278	O–B

Notes.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds. Taken from Becker & Fenkart (1971), the 2006 SIMBAD database (http://simbad.harvard.edu/cgi-bin/WSimbad.pl), and the 2006 WEBDA database (http://www.univie.ac.at/webda/).

This provided a standard error curve of error versus magnitude (see Fig. 1). All stars more than 3 σ from the line were then removed from the ensemble, and the process repeated until no additional stars were found away from the error curve. The stars removed at this point are those with higher amplitude variations. As is shown below, this method does not identify low-amplitude variables, which would inadvertently leave variable stars in the ensemble.

3.2. *Robust Median Statistic*

The RoMS value, $\tilde{\eta}$, is defined by Enoch et al. (2003) as

$$\tilde{\eta} = \eta/d, \tag{1}$$

where d is the number of degrees of freedom or $(N-1)$, N is the number of observations, and η is represented by the relation

$$\eta = \sum_{i=1}^{N} \left| \frac{m_i - \bar{m}}{\sigma_i} \right|. \tag{2}$$

Equation (2) consists of the following terms: m_i is the magnitude of the ith observation, $\bar{m}$ is the *median* value (not the average) of the N observations, and σ_i is the error per observation for a given magnitude m_i as defined by an analytical function defining the bottom of the error curve. The best method discovered to calculate this function begins with taking the natural logarithm of the errors and plotting them versus the magnitude; note that this is the same thing as plotting the error curve on a semilog scale. Figure 2 is the semilog error curve for NGC 559, which is representative of such a curve for all the clusters.

The plot in Figure 2 cannot be defined by a single line function, but two intersecting lines with slopes labeled are sufficient. Once the two lines were found and transformed back to normal space, a piecewise continuous function of the form

$$\sigma_i(x) = \begin{cases} b_0 e^{b_1 x}, & x_0 \le x < x_1, \\ c_0 e^{c_1 x}, & x_1 \le x \le x_2 \end{cases} \tag{3}$$

was found to approximate the bottom of the entire error curve very well. In equation (3) the exponential coefficients b_1 and c_1 are the slopes s_1 and s_2, respectively. The coefficients b_0 and c_0 were found using a data point that lies along the first line and the value of the first function at the point where line 1 and line 2 intersect; this ensures that the piecewise function is continuous. The terms x_0, x_1, and x_2 are the boundary values determined from the lines drawn on the semilog mean-error diagram, as shown in Figure 2.

The resulting piecewise continuous function for NGC 559 is

$$\sigma_i(x) = \begin{cases} 8.4 \times 10^{-4} e^{0.096x}, & 9.0 \le x < 12.1, \\ 9.5 \times 10^{-8} e^{0.846x}, & 12.1 \le x \le 16.0, \end{cases} \tag{4}$$

and is drawn in Figure 3. Similar equations were found for the remaining clusters.

3.3. *Potential Variable Stars*

RoMS values were calculated for all stars in the fields of NGC 225, NGC 559, NGC 6811, NGC 6940, NGC 7142, and NGC 7160. Stars with RoMS values greater than 0.9 were removed from the ensemble. Then each light curve was visually inspected for any evidence of variation. The stars were then separated into four groups; variable, suspected variable, potential variable, and stable. Suspected variables are those that show a clear pattern but need a larger data set to confirm that they are truly variable. The potential variables show some indiction of variation and should be watched carefully in any analysis of the cluster. In total we found 13 variable stars, 29 suspected variable stars, and 65 potential variable stars. Below we examine a number of the new variables found in this survey. The results for each cluster are summarized in Tables 4–9. For those stars with an apparent periodic variation we have examined the data with Period04 (Lenz & Breger 2005).

3.3.1. *Field of NGC 225*

The open cluster NGC 225 had three previously known variable stars in the field. There is a Be star (V594 Cas), a T Tauri star (V828 Cas), and a Mira variable (V383 Cas). V383 Cas was out of our field of view, and we did not find any significant variations in the star reported as V828 Cas. However, we did find

TABLE 2
Telescope and CCD Specifications

Telescope/Focus	CCD	Pixel Size (μm)	Plate Scale (arcsec pixel^{-1})	Array Size (pixels)
DDT/Cassegrain	SBIG ST-1001	24	0.98	1024 × 1024
DDT/Newtonian	Apogee Ap47p	13	1.32	1024 × 1024
DAO/Newtonian	Site-5	24	0.54	1024 × 1024

TABLE 3
Photometric Observations of Open Clusters

Target	Date (UT)	Site	B	V	R	I
NGC 225	2004 Nov 2	OPO[a]	...	100	100	...
	2004 Nov 3	OPO[a]	...	130	...	...
	2005 Sep 6	DAO	...	83	...	...
	2005 Sep 7	DAO	...	49	...	...
	2005 Sep 8	DAO	...	15	...	...
NGC 559	2004 Dec 14	OPO[a]	...	50	50	...
	2005 Sep 7	DAO	...	25	...	...
	2005 Sep 8	DAO	...	15	...	...
NGC 6811	2004 Jul 29	OPO[a]	...	3	3	3
	2004 Aug 9	OPO[a]	...	7	7	7
	2005 Sep 6	DAO	...	125	...	...
	2005 Sep 8	DAO	...	25	...	...
	2005 Oct 15	OPO[b]	6	6	6	...
NGC 6940	2004 Jul 29	OPO[a]	...	3	3	3
	2004 Aug 8	OPO[a]	...	10	10	10
	2004 Aug 9	OPO[a]	...	12	12	12
	2004 Aug 12	OPO[a]	...	75	75	...
	2005 Sep 8	DAO	...	25	...	...
	2005 Oct 15	OPO[b]	6	6	6	...
NGC 7142	2005 Sep 7	DAO	...	41	...	...
NGC 7160	2004 Aug 9	OPO[a]	...	10	10	10
	2004 Aug 28	OPO[a]	...	5	5	...
	2004 Nov 3	OPO[a]	...	50	50	...
	2005 Sep 8	DAO	...	15	...	...
	2005 Oct 15	OPO[b]	6	6	6	...

[a] Apogee Ap47p configuration.
[b] SBIG ST-1001 configuration.

variations in V594 Cas, which is denominated as our star 66. In addition, 18 stars exhibited some form of variability.

Figure 4 shows the time-series data for star 35 over two adjacent nights. Unfortunately, neither of the nights were long enough to include one full cycle of oscillation. However, the data include one maximum on each night, which suggests periodic variability with a period of ≈4.2 hr. In addition, the maxima appear to occur at the same luminosity, which suggests that there is no zero-point offset between the two nights of data. Further observations of star 35 are required in order to perform a full-period analysis and establish the type of variation.

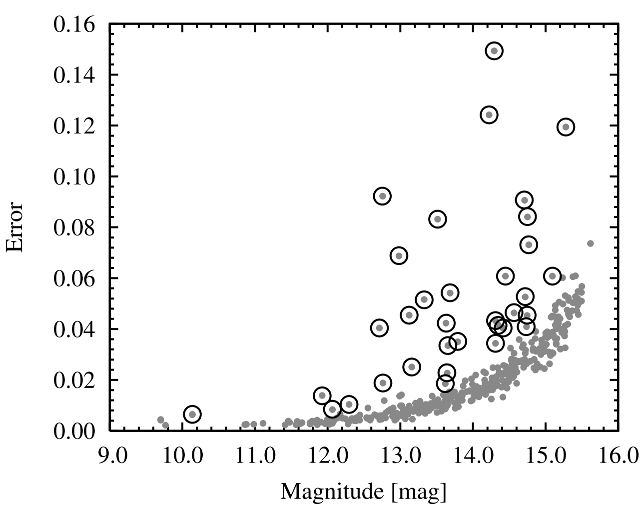

Fig. 1.— Error curve for NGC 559. Circled stars are those selected for further examination.

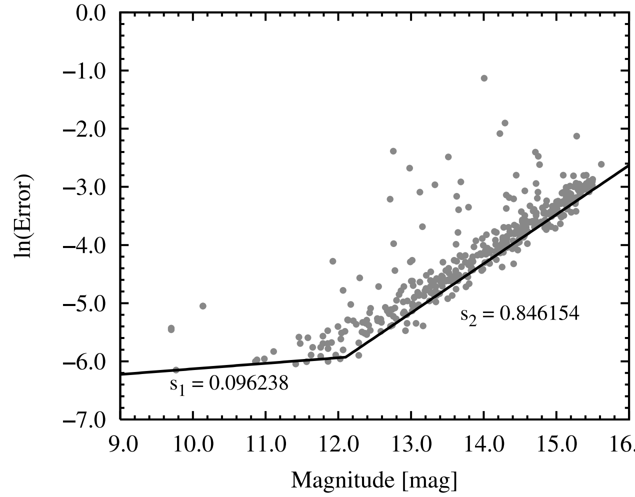

Fig. 2.— Semilog plot of the error curve for NGC 559. The two lines are the two fits to the bottom edge of the distribution with slopes of s_1 and s_2, respectively.

The next three stars (42, 66, and 68) appear to exhibit similar trends in brightness over time, which are shown in Figure 5. All of the stars exhibit some change in luminosity during each night with an offset from night to night. This offset does not appear in any of the nonvariable stars or in star 35, which suggests that these stars may be long-period variables. Further observations of these stars are also required. In Figure 6 two potential variables are shown. Star 16 shows a rapid drop in brightness, which might indicate an eclipsing system. For star 34 there is one night (as shown in Fig. 6) of a clear variation near a magnitude of 12.8 in the V filter. However, one night later the star is at 11.1 mag. Clearly star 34 is variable, but the nature of that variation is still unclear.

3.3.2. *Field of NGC 559*

The field of NGC 559 produced 18 stars with some indication of variation in their light curves. However, due to the short timescales of the data sets for NGC 559, which are on the order of half an hour, no time-series plots of the potential variable stars are presented. While applying the RoMS to the data, it was discovered that the time frames should be no shorter than a few hours, and for the best results the data sets should span ≥4 hr. Therefore, further observations of NGC 559 are required to determine if the suspected variables exhibit periodic oscillations in luminosity.

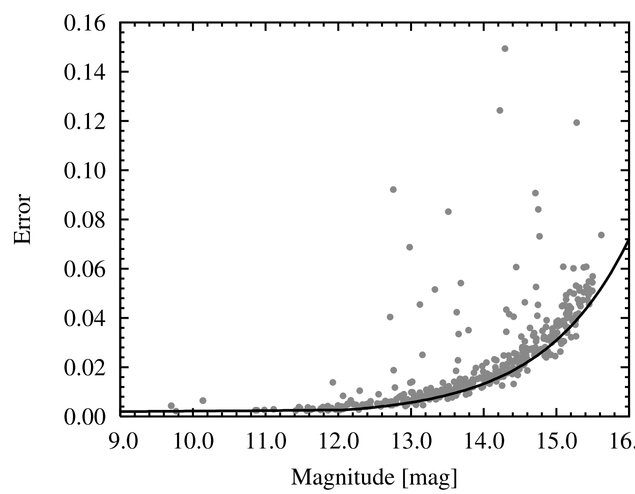

Fig. 3.— Final fit to error curve from the semilog fit for NGC 559.

TABLE 4
Variable Stars in NGC 225

Star	Pub.	R.A. (J2000.0)	Decl. (J2000.0)	RoMS	$\bar{V}$	Variable?	Comments
6	...	00 45 26.4	+61 46 12	0.967	12.415	Potential	No distinct pattern
16	...	00 44 47.5	+61 56 50	0.987	11.422	Suspected	Long-period variable?
19	1	00 44 40.8	+61 48 44	1.238	8.924	Potential	No distinct pattern
22	...	00 44 28.9	+61 55 40	0.974	14.138	Potential	No distinct pattern
34	...	00 44 12.8	+61 51 02	1.108	11.142	Yes	One night of clear variation with large jump
35	23	00 44 11.5	+61 45 32	1.482	12.822	Yes	Period: 0.173 days; amplitude: ≈0.02 mag
40	22	00 43 52.3	+61 43 05	0.774	12.380	Potential	No distinct pattern
42	...	00 43 51.6	+61 47 14	1.339	10.579	Suspected	Long-period variable?
47	28	00 43 42.7	+61 46 07	1.260	13.378	Potential	No distinct pattern
53	18	00 43 37.0	+61 53 40	0.889	11.764	Potential	No distinct pattern
57	...	00 43 31.1	+61 48 11	1.143	10.484	Potential	No distinct pattern
61	17	00 43 25.7	+61 48 52	1.082	11.330	Potential	No distinct pattern
66	...	00 43 18.3	+61 54 41	2.022	10.397	Suspected	Small variation (V594 Cas)
68	8	00 43 10.9	+61 47 20	1.249	9.817	Suspected	Long-period variable?
74	1285	00 43 05.2	+61 54 21	0.909	13.762	Potential	No distinct pattern
86	...	00 42 39.5	+61 55 07	1.052	13.885	Potential	No distinct pattern
87	4054	00 42 35.4	+61 41 14	1.007	11.347	Potential	No distinct pattern
105	1221	00 42 04.3	+61 54 22	0.911	12.751	Potential	No distinct pattern
107	...	00 42 00.0	+61 45 30	0.857	13.609	Potential	No distinct pattern
109	1219	00 41 56.1	+61 56 09	0.955	13.731	Potential	No distinct pattern
111	2	00 44 30.7	+61 46 50	1.247	9.335	Potential	No distinct pattern

Notes.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds. Published star numbers less than 1000 are from Hoag et al. (1961), and numbers greater than 1000 are from Ponomareva (1983).

TABLE 5
Variable Stars in NGC 559

Star	Pub.	R.A. (J2000.0)	Decl. (J2000.0)	RoMS	$\bar{V}$	Variable?	Comments
38	...	01 29 31.9	+63 14 39	1.758	14.720	Potential	Slight increase in brightness
71	...	01 29 30.7	+63 15 27	6.167	14.224	Potential	No distinct pattern
86	64	01 29 18.5	+63 15 54	3.316	13.159	Potential	No distinct pattern
95	...	01 29 31.4	+63 16 05	1.846	14.350	Potential	No distinct pattern
102	...	01 29 14.6	+63 16 27	3.138	12.763	Potential	No distinct pattern
103	...	01 29 14.3	+63 16 32	2.664	12.296	Potential	No distinct pattern
155	...	01 29 31.0	+63 17 40	2.578	13.655	Suspected	Slight upward trend
171	...	01 29 50.8	+63 17 46	2.811	14.750	Suspected	Curved shape
185	...	01 28 54.7	+63 18 17	7.418	14.291	Potential	No distinct pattern
226	...	01 29 47.3	+63 18 34	24.366	14.008	Potential	No distinct pattern
237	...	01 29 32.1	+63 18 44	4.269	11.923	Potential	No distinct pattern
256	56	01 29 08.1	+63 19 07	5.248	13.330	Potential	No distinct pattern
261	...	01 29 08.7	+63 19 13	2.021	14.308	Potential	No distinct pattern
294	52	01 29 26.2	+63 19 51	7.322	12.713	Potential	No distinct pattern
297	...	01 29 48.4	+63 19 47	5.454	13.124	Potential	No distinct pattern
298	...	01 29 48.1	+63 19 49	7.487	12.982	Potential	No distinct pattern
334	...	01 29 22.6	+63 20 51	2.867	14.449	Suspected	Increase in brightness of ≈0.15 mag
353	...	01 29 36.7	+63 21 24	1.741	13.619	Suspected	Slight decrease in brightness

Notes.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds. Published star numbers are from Lindoff (1969).

TABLE 6

Variable Stars in NGC 6811

Star	Pub.	R.A. (J2000.0)	Decl. (J2000.0)	RoMS	$\bar{V}$	Variable?	Comments
8	39	19 37 24.0	+46 23 52	1.395	9.506	Yes	Period: 0.1309 days, amplitude: ≈0.020 mag
30	32	19 37 02.7	+46 23 12	1.715	9.288	Suspected	Brightness increase of 0.03 mag
35	18	19 36 58.2	+46 20 22	1.207	10.071	Yes	Period: 0.0436 days, amplitude: ≈0.016 mag
41	70	19 37 03.2	+46 19 25	1.916	8.867	Yes	Period: 0.1024 days, amplitude: ≈0.028 mag
46	124	19 36 55.8	+46 18 36	1.217	11.332	Suspected	Decrease in magnitude, no increase evident
48	62	19 37 14.3	+46 18 57	1.419	10.724	Suspected	Long-period variable?
50	58	19 37 18.1	+46 18 35	1.274	11.838	Suspected	Long-period variable?
57	56	19 37 22.1	+46 18 50	1.276	10.072	Suspected	Multiperiodic, decrease in magnitude
61	113	19 37 32.1	+46 19 15	2.015	9.454	Suspected	Drastic jump or increase in magnitude
62	54	19 37 25.3	+46 19 35	2.260	10.243	Suspected	Multiperiodic, eclipse?
63	53	19 37 21.4	+46 19 53	2.159	10.558	Suspected	Decrease in magnitude, no increase evident
65	9	19 37 19.8	+46 20 54	1.159	9.975	Suspected	Multiperiodic pattern
66	51	19 37 22.0	+46 20 50	1.574	11.288	Suspected	Multiperiodic pattern
82	4	19 37 12.5	+46 23 29	1.684	10.656	Suspected	Multiperiodic pattern
93	...	19 37 22.1	+46 22 47	1.830	13.936	Potential	No distinct pattern
102	...	19 36 54.7	+46 21 08	1.790	13.262	Suspected	Slight increase in brightness
113	...	19 37 26.3	+46 24 05	1.478	14.378	Potential	No distinct pattern

Notes.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds. Published star numbers are from Lindoff (1972).

TABLE 7

Variable Stars in NGC 6940

Star	Pub.	R.A. (J2000.0)	Decl. (J2000.0)	RoMS	$\bar{V}$	Variable?	Comments
10	...	20 35 33.5	+28 16 48	1.123	10.324	Yes	Period: 0.0775 days, amplitude: ≈0.010 mag
32	...	20 25 20.5	+28 14 05	1.527	11.883	Yes	Period: 0.0470 days, amplitude: ≈0.023 mag
67	...	20 35 04.6	+28 18 52	1.954	12.484	Potential	No distinct pattern
91	...	20 34 53.0	+28 20 27	1.954	11.401	Yes	Period: 0.0494 days, amplitude: ≈0.011 mag
99	...	20 34 49.6	+28 15 15	1.512	11.359	Yes	Period: 0.1195 days, amplitude: ≈0.015 mag
134	...	20 34 35.0	+28 22 54	1.387	13.255	Potential	No distinct pattern
162	...	20 34 25.2	+28 16 17	1.182	11.927	Suspected	Multiperiodic?
173	...	20 34 22.6	+28 13 27	1.219	11.514	Potential	No distinct pattern
184	...	20 34 21.0	+28 15 50	1.595	13.385	Potential	No distinct pattern
192	...	20 34 16.0	+28 16 49	2.745	11.208	Yes	Period: 0.1103 days, amplitude: ≈0.030 mag
196	...	20 34 14.0	+28 12 19	1.829	13.109	Potential	No distinct pattern
198	...	20 34 13.6	+28 14 27	1.299	10.612	Yes	Period: 0.0486 days, amplitude: ≈0.010 mag
214	...	20 34 09.7	+28 24 34	2.610	10.783	Yes	Period: 0.1792 days, amplitude: ≈0.027 mag
243	...	20 33 56.1	+28 15 49	1.808	13.506	Potential	No distinct pattern
258	...	20 33 50.7	+28 12 35	1.109	13.157	Potential	No distinct pattern
262	...	20 33 50.4	+28 22 19	1.674	11.780	Yes	Period: 0.0455 days, amplitude: ≈0.025 mag

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

TABLE 8

Variable Stars in NGC 7142

Star	Pub.	R.A. (J2000.0)	Decl. (J2000.0)	RoMS	$\bar{V}$	Variable?	Comments
1	190	21 44 55.8	+65 42 35	3.148	10.765	Suspected	Decrease in brightness, no increase evident
11	171	21 45 04.4	+65 42 43	1.469	11.745	Potential	No distinct pattern
28	1413	21 44 54.0	+65 43 41	1.619	15.054	Potential	Multiperiodic pattern
34	235	21 45 51.0	+65 43 49	3.075	11.958	Suspected	Period: 0.0868 days, amplitude: ≈0.022 mag
56	135	21 45 34.7	+65 44 28	1.597	12.338	Suspected	Eclipser?
122	240	21 45 37.4	+65 45 51	1.301	11.393	Potential	No distinct pattern
137	59	21 45 20.3	+65 46 11	1.447	14.124	Suspected	Multiperiodic pattern
141	193	21 44 52.3	+65 46 23	3.412	11.617	Potential	No distinct pattern
170	...	21 45 30.4	+65 46 43	1.616	13.573	Potential	No distinct pattern
173	...	21 45 30.9	+65 46 43	1.616	13.573	Potential	No distinct pattern
215	1265	21 45 15.0	+65 47 39	4.505	14.018	Potential	No distinct pattern
228	198	21 45 11.6	+65 47 49	3.250	12.992	Potential	No distinct pattern
242	1057	21 44 45.8	+65 48 19	3.373	13.792	Potential	No distinct pattern
244	102	21 45 23.8	+65 48 16	2.763	12.528	Suspected	Increase in brightness
250	103	21 45 23.4	+65 48 22	3.222	13.338	Potential	No distinct pattern
279	148	21 45 15.4	+65 49 26	2.052	13.366	Suspected	Increase in brightness
286	149	21 45 13.2	+65 49 40	1.844	12.108	Potential	Multiperiodic, eclipser?
297	219	21 45 33.4	+65 50 05	1.557	13.524	Suspected	Decrease in brightness
300	1268	21 45 34.6	+65 50 07	3.426	14.765	Potential	No distinct pattern
320	...	21 44 51.8	+65 51 08	2.121	12.148	Suspected	Decrease in brightness

Notes.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds. Published star numbers are from van den Bergh & Heeringa (1970).

TABLE 9

Variable Stars in NGC 7160

Star	Pub.	R.A. (J2000.0)	Decl. (J2000.0)	RoMS	$\bar{V}$	Variable?	Comments
13	...	21 54 34.5	+62 37 29	1.097	11.198	Potential	Decrease in brightness
28	15	21 54 07.6	+62 32 19	0.839	10.492	Potential	Slightly curved shape
37	...	21 53 59.8	+62 26 42	1.579	12.969	Potential	No distinct pattern
44	47	21 53 55.5	+62 36 18	5.972	12.003	Potential	No distinct pattern
61	...	21 53 41.3	+62 48 20	1.180	13.570	Potential	No distinct pattern
67	55	21 53 32.8	+62 37 03	1.774	11.917	Potential	No distinct pattern
71	4	21 53 26.8	+62 35 13	1.156	8.572	Yes	Decrease in brightness (V497 Cep)
74	10	21 53 24.4	+62 33 37	0.825	10.800	Potential	Slightly curved shape
79	...	21 53 20.1	+62 45 54	1.320	13.619	Potential	No distinct pattern
95	...	21 52 54.2	+62 41 57	1.039	12.899	Potential	No distinct pattern
99	...	21 52 47.4	+62 38 57	1.084	13.7370	Potential	No distinct pattern
102	...	21 52 43.6	+62 41 04	1.048	13.117	Potential	No distinct pattern
117	...	21 52 13.5	+62 42 52	1.146	12.882	Potential	No distinct pattern
120	...	21 52 09.9	+62 25 35	1.044	13.010	Potential	No distinct pattern
125	...	21 52.00.7	+62 41 34	1.163	13.399	Potential	No distinct pattern
134	...	21 51 45.9	+62 43 03	1.190	12.638	Potential	No distinct pattern

Notes.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds. Published star numbers are from Hoag et al. (1961).

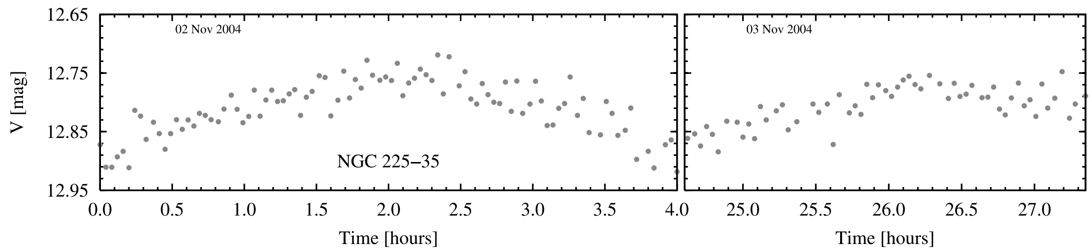

FIG. 4.—Light curve of star 35 from NGC 225.

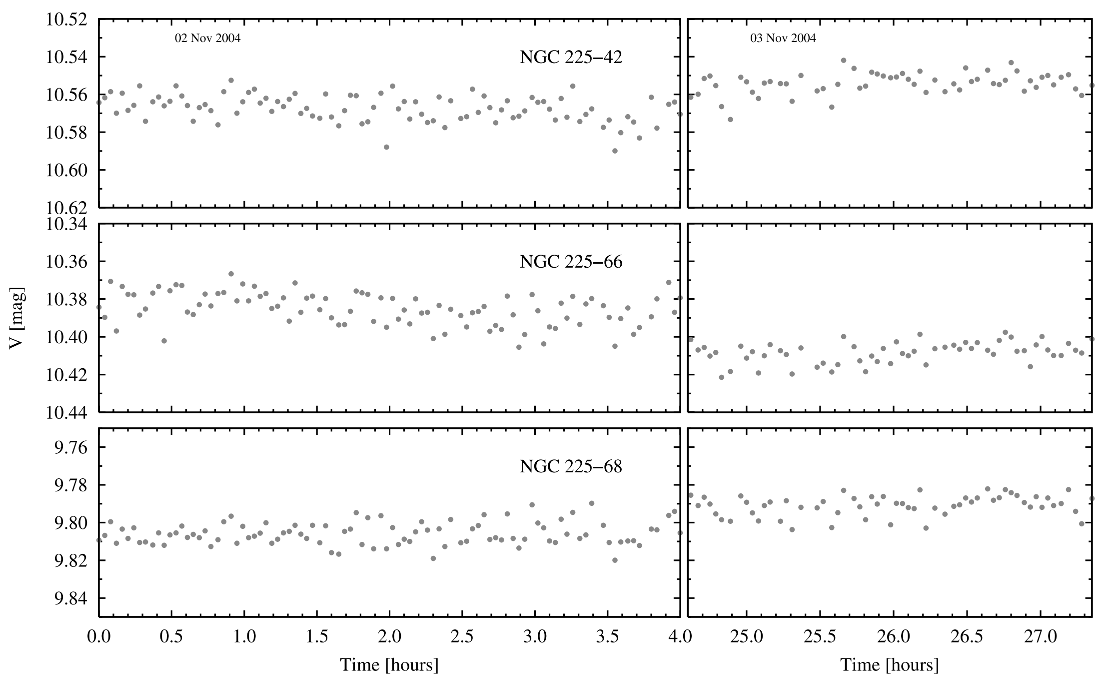

FIG. 5.—Light curves over two nights for stars 42, 66, and 68 in NGC 225.

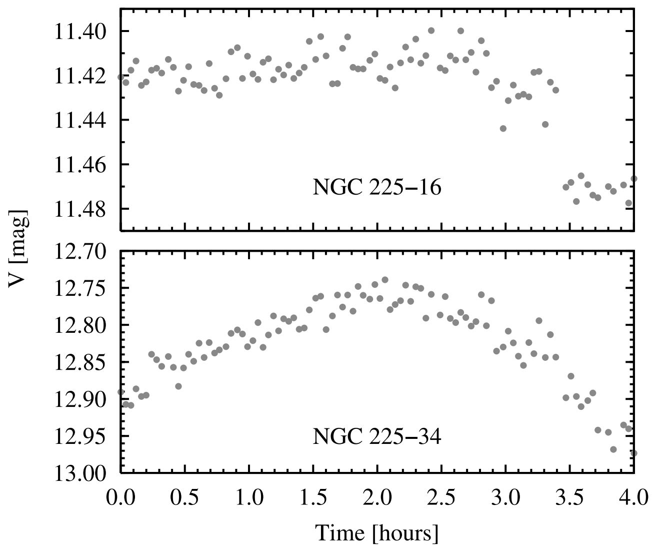

FIG. 6.—Stars 16 and 34 from the field of NGC 225.

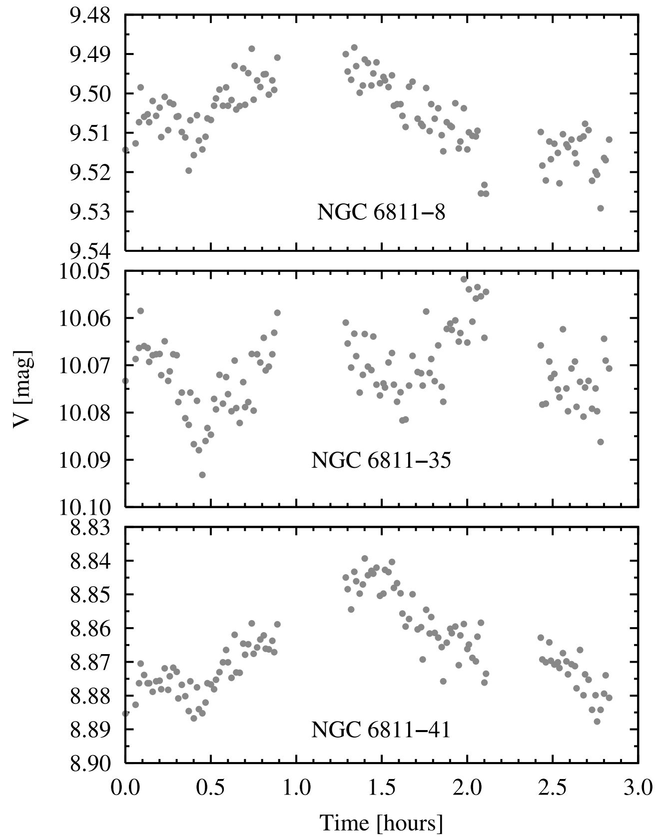

FIG. 7.—Three new variables in the field of NGC 6811.

3.3.3. *Field of NGC 6811*

Of the 17 stars that exhibited variability in NGC 6811, the three most distinct were stars 8, 35, and 41, as shown in Figure 7. The gaps that appear in the data are the result of acquiring standards and extinction stars throughout the night. These three stars are three of the brighter stars we examined in the cluster and are in the magnitude range where we would expect to find δ Scuti variables. With this in mind we applied Period04 to find rough estimates for period and amplitude for these stars. For star 8 we found a period of 0.1309 days with an amplitude of ≈0.02 mag. Star 35 appears to have a more complex variation, and the gaps in the data make it hard to determine the true nature of the changes. However, we give a period of 0.0436 days with an amplitude of ≈0.02. Of the three most distinct variables in NGC 6811 we find star 41 to be the most clear. For star 41 we determined a period of 0.1024 days with an amplitude near 0.03 mag.

Beyond the three distinct variable stars found in NGC 6811 we found 10 stars with strong evidence of some type of variation. These 10 stars are shown in Figure 8. Many of these stars show either upward or downward trends, which indicate much longer periods (stars 46, 48, 50, 57, and 102). A few stars show shorter term oscillations but not complete cycles (stars 61, 63, 65, and 82). Finally, there is star 62, which has a slight downward trend but then an upward brightening. From an examination of the frames and the entire data set, we can find no equipment or imagining problems which could cause the variation seen in star 62. We therefore conclude that the variations are coming from the star itself. Further observations of all these stars will help establish the true nature of their variations.

3.3.4. *Field of NGC 6940*

The largest number of new variables that we suspect to be δ Scuti variables were found in the field of NGC 6940. The data for NGC 6940 were also unique in that we have sufficient data to standardize our observations and get a color term for each star. In Figure 9 we show the eight new variable stars found, and in Figure 10 is the color-magnitude diagram, adjusted for distance, for NGC 6940 with the variables marked. From these two figures we find that stars 32, 91, 99, 192, 214, and 262 all lie within the instability strip and have periods and amplitudes consistent with δ Scuti variables. Their periods and amplitudes were determined using Period04 and are reported in Table 7. Stars 10 and 198 are found outside the instability strip but also have periods and amplitudes consistent with δ Scuti variables.

3.3.5. *Field of NGC 7142*

NGC 7142 had two known variables. Of the two, one was out of the field of view (V582 Cep), and the second, V375 Cep, was too faint for our survey. In this region we found that only star 34 shows definitive signs of being a short-period variable star. The light curve for star 34 is shown in Figure 11 and could be interpreted either as a portion of an eclipse or as a pulsational curve. If we interpret the variation as a pulsating star we find a period of 0.0868 days with an amplitude of ≈0.022 mag. A much larger data set would be needed to determine the true nature of the star.

In addition to star 34, we found seven other stars that showed significant light variations. These stars are shown in Figure 12. Most of these stars show either upward or downward trends over the entire run of data and argue for long-period variation of unknown type. Star 56 has a light curve that might be more indicative of an eclipsing system, and star 137 might have a pulsational nature.

3.3.6. *Field of NGC 7160*

Again there are two known variable stars in this field. The β Lyrae star EM Cep was saturated in our data set and is therefore not recovered. However, we do find a downward trend for star 71, which is identified as an eclipsing binary system, V497 Cep. Given the reported period (Yakut et al. 2003) of 1.202 days, it is not surprising that we only see a small portion of the light curve.

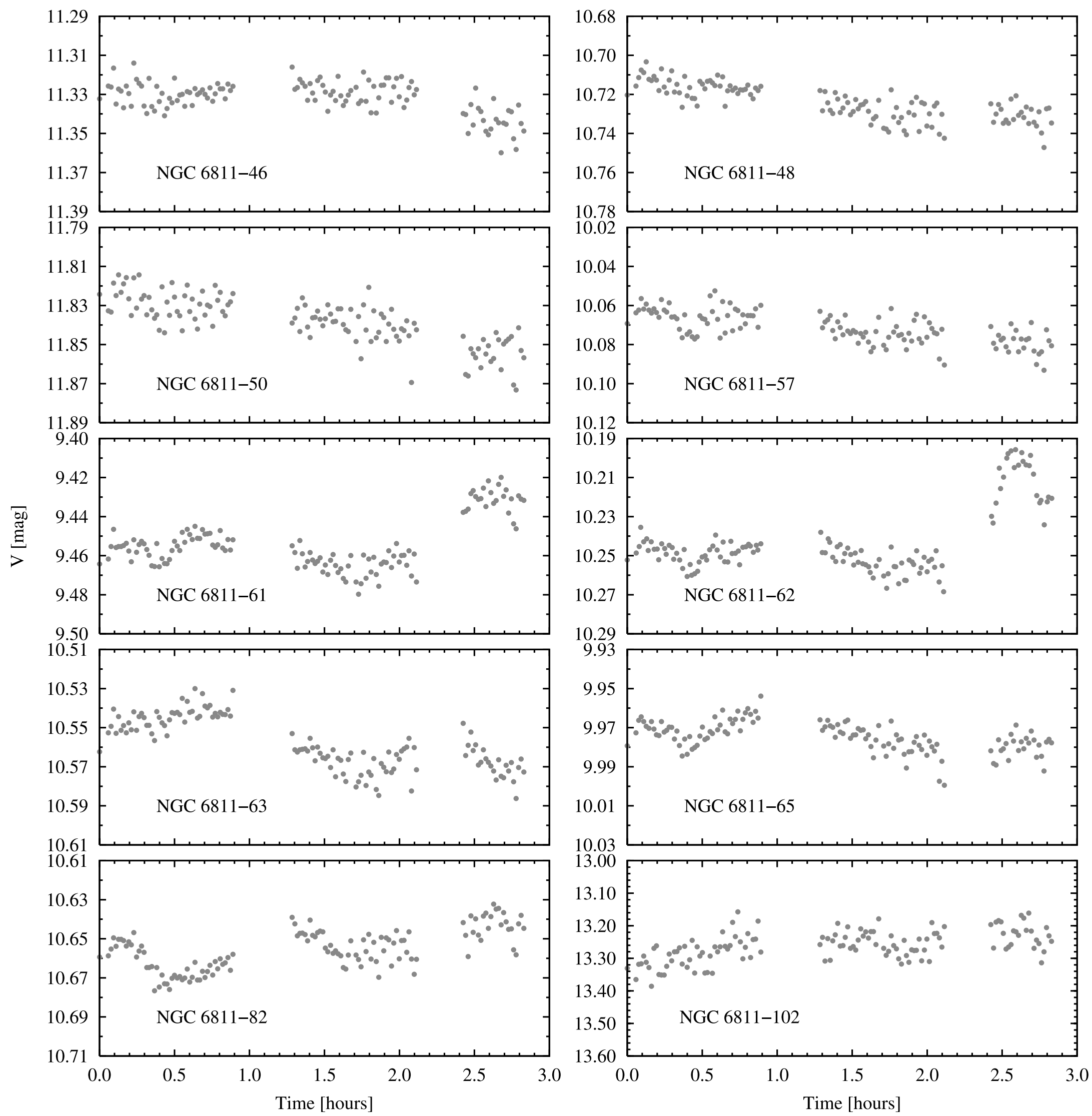

FIG. 8.— Potential variables in the field of NGC 6811.

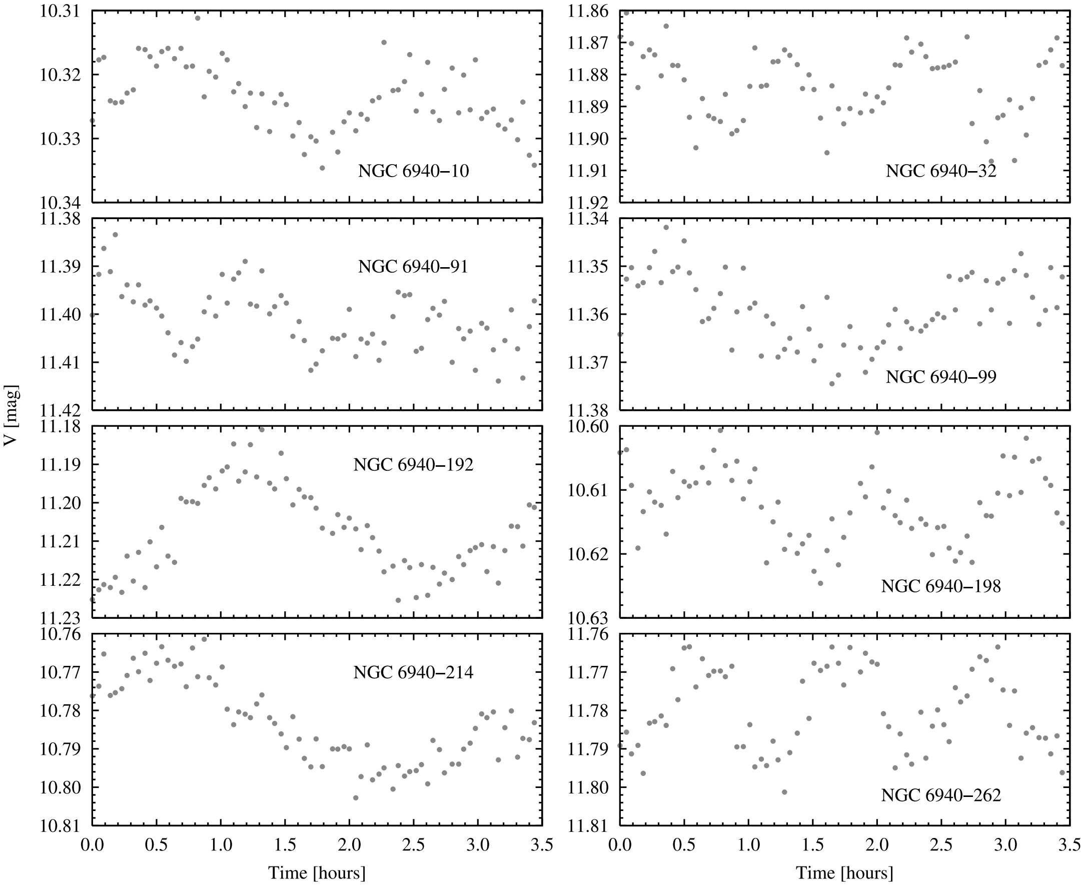

FIG. 9.— Variable stars found in the field of NGC 6940.

However, the small drop we see is consistent with the overall amplitude and period of V497 Cep.

Fifteen other potential variables were found in the field of NGC 7160; however, none of them exhibited a recognizable periodic pattern. As a result, no time-series plots are presented at this time.

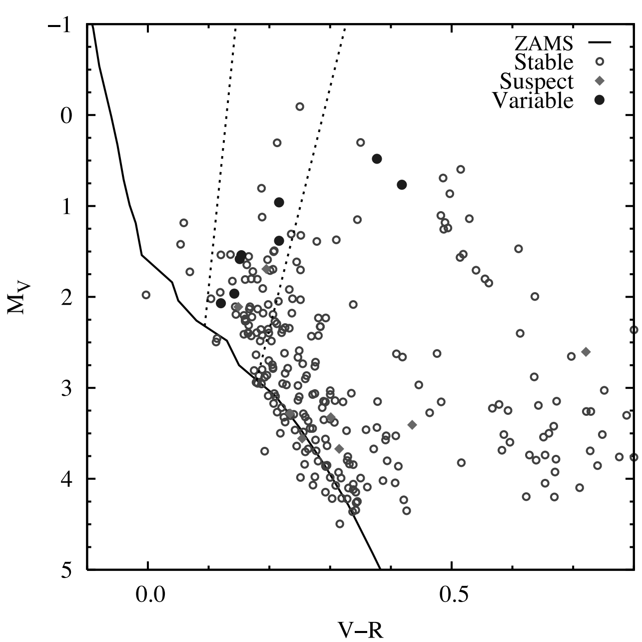

FIG. 10.— Color-magnitude diagram for NGC 6940. [*See the electronic edition of the Journal for a color version of this figure.*]

Further observations of NGC 7160 are required to determine if the potential variables are indeed variable or just noisy stars.

3.4. *Summary of RoMS Results*

Figure 13 presents the RoMS values for the cluster NGC 6811 in histogram form. The stars were separated into a variable group and a nonvariable group, based on the inspection of time-series data of all stars with a RoMS value above 0.9. The variable group, denoted by the dark bars, includes stars that exhibited periodic variability, as well as stars that displayed other forms of variability. The nonvariable group, denoted by the light bars, is comprised of stars with RoMS values below 0.9 or that did not exhibit any form of variability. For all clusters we find that the RoMS values of the nonvariable stars form essentially Gaussian-shaped statistical distributions which appear to be centered about a RoMS value of 0.9. The distribution for the potential variable stars for all six clusters

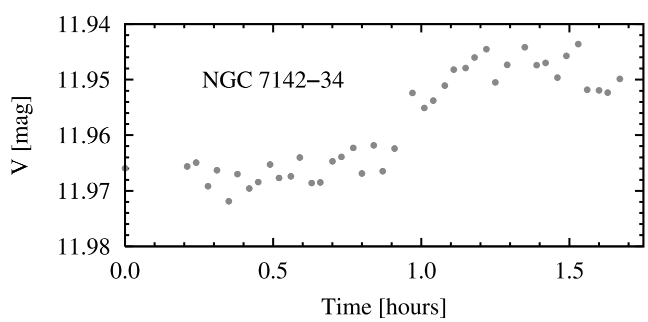

FIG. 11.— Variable star found in the field of NGC 7142.

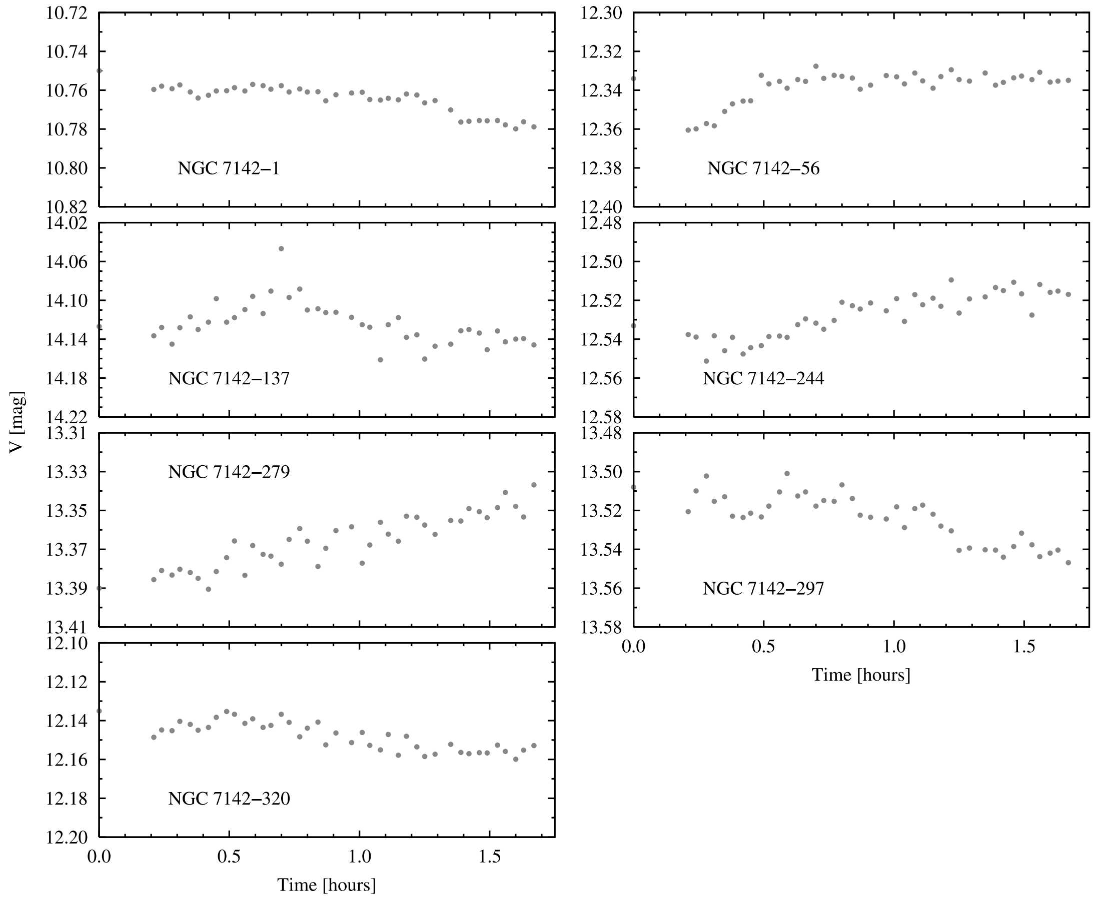

FIG. 12.— Variable stars found in the field of NGC 7142.

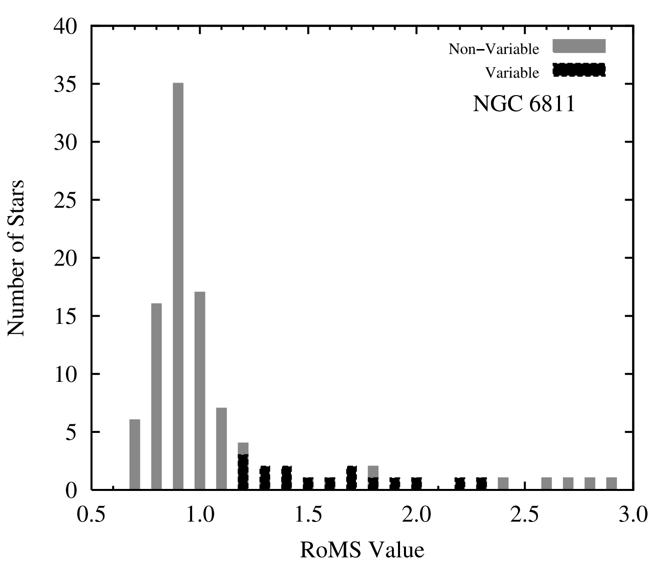

FIG. 13.— Histogram of RoMS values for NGC 6811.

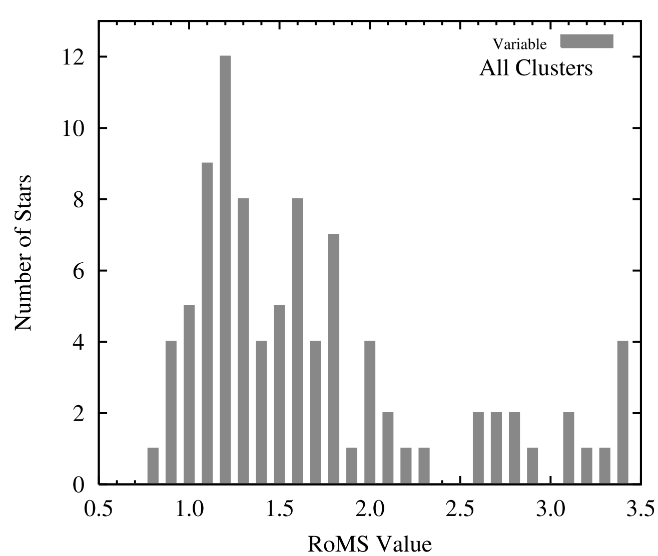

FIG. 14.— Histogram of RoMS values for all variables found in the fields of the selected clusters.

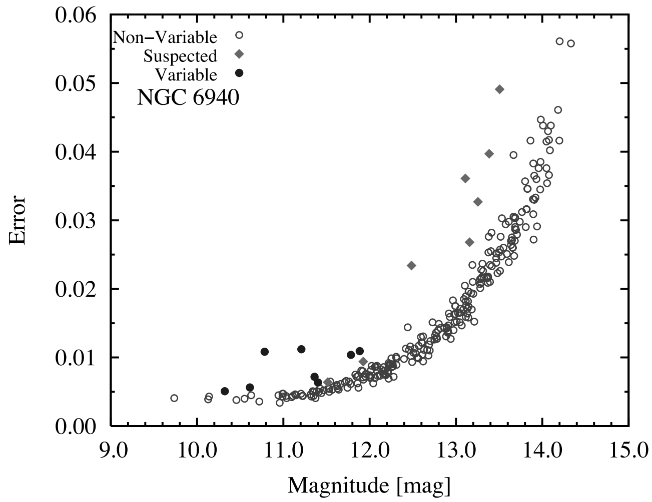

FIG. 15.— Error curve for NGC 6940 with variables, potential variables, and nonvariables marked. Four of the eight new variables would not have been found from a traditional error-curve approach. [*See the electronic edition of the Journal for a color version of this figure.*]

is shown in Figure 14. The majority of the variables clearly have a RoMS value greater than 1.0. The positions of the new variables found in NGC 6940 are shown on the cluster error curve in Figure 15. Four of the eight variables were only found from the RoMS value. The errors of these stars are very small (<0.01), and would not have been detected using a standard error-curve method.

4. CONCLUSION

We have examined six open clusters using a robust median statistic (RoMS) in search of variable stars near the instability strip and near the main sequence. In the six fields we examined a total of 1355 stars and found 13 stars which we classify as variables, 29 as suspected variables, and 65 as potential variables. Of the new variables we believe at least nine are δ Scuti type variables. Three δ Scuti variables are found in NGC 6811, and six are found in NGC 6940. These are both intermediate-age clusters with the turn-off point in the early A stars.

We found the RoMS method very powerful in the process of automating our differential reduction of cluster data and removing all stars from the ensemble that contribute even small amounts of variation. In determining an ensemble, all stars with RoMS values greater than 1.0 should be removed, even if they are later found not to be variable. All stars we labeled as new variables had RoMS values greater than 1.1.

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REFERENCES

Becker, W., & Fenkart, R. 1971, A&AS, 4, 241
Bessell, M. S. 1990, PASP, 102, 1181
Enoch, M. L., Brown, M. E., & Burgasser, A. J. 2003, AJ, 126, 1006
Hintz, E. G., & Rose, M. B. 2005, PASP, 117, 955
Hoag, A. A., Johnson, H. L., Iriarte, B., Mitchell, R. I., Hallam, K. L., & Sharpless, S. 1961, Publ. USNO, 17, 347
Landolt, A. U. 1992, AJ, 104, 340
Lenz, P., & Breger, M. 2005, Commun. Asteroseis., 146, 53
Lindoff, U. 1969, Ark. Astron., 5, 221
Lindoff, U. 1972, A&A, 16, 315
Ponomareva, G. A. 1983, Trudy Gosud. Astron. Inst. Shterneberga, LIII, 29
Stetson, P. B. 1987, PASP, 99, 191
———. 1990, PASP, 102, 932
———. 1991, J. R. Astron. Soc. Canada, 86, 71
van den Bergh, S., & Heeringa, R. 1970, A&A, 9, 209
Yakut, K., Tarasov, A. E., Ibanoglu, C., Harmanec, P., Kalomeni, B., Holmgren, D. E., Boic, H., & Eenens, P. 2003, A&A, 405, 1087