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New Variable Stars Discovered as By-product of the Beijing Astronomical Observatory Supernova Survey

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Abstract The Beijing Astronomical Observatory (BAO) 0.6 m telescope has been used for nearby supernova survey in more than 3000 fields, covering a total area of 235 $\deg^2$. More than 260 000 CCD images have been collected since April 1996, with 45 supernovae discovered. We searched for variables in about 90 000 images taken during 1996–1998. For the fields in which long period variables (LPVs) were discovered, we reduced further images taken from 1999 to 2000, for the period estimation. Among the 280 000 stars selected from the survey fields, i.e., brighter than 18 mag, we discovered seven new LPVs and reconfirmed three known LPVs. Additionally, we found 146 variable star candidates, and reconfirmed about 20 previously known or suspected objects.

Key words: stars: variables — supernovae — surveys

1 INTRODUCTION

Imaging surveys of the sky have been used to search for variable stars for over a century. Tens of thousands have been found so far (ref. GCVS, Kholopov et al. 1985). Since 1970's, and especially from the beginning of 1990's, thousands of new variables have been yielded by several key survey projects, e.g., the Optical Gravitational Lensing Experiment (OGLE) (Udalski et al. 1994) and the All Sky Survey Project (Pojmański 1997, 1998), thanks to the widespread use of small and medium telescopes and sensitive CCD cameras. Other projects, like searching for variables (Henden & Stone 1998) in the calibration fields of the Sloan Digital Sky Survey (SDSS) and searching for Cepheids and other variables in the Galactic plan of Crux and Centaurus (Caldwell, Keane & Schechter 1991), have also scored great successes.

The BAO Supernova Survey (BAOSS) began in 1996. With an automatic system of high efficiency, we have discovered 45 supernovae in the past 5 years (Qiu et al. 2001). More

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than 260 000 images have been collected in the course of the survey. Its long time span and massive observational data set make it a valuable resource to be used for the searching of long period variables (LPVs). We mainly reduced the complete data taken during 1996–1998, which contained about 90 000 images. For those confirmed as LPVs, we reduced their images during 1999–2000 to determine their periods.

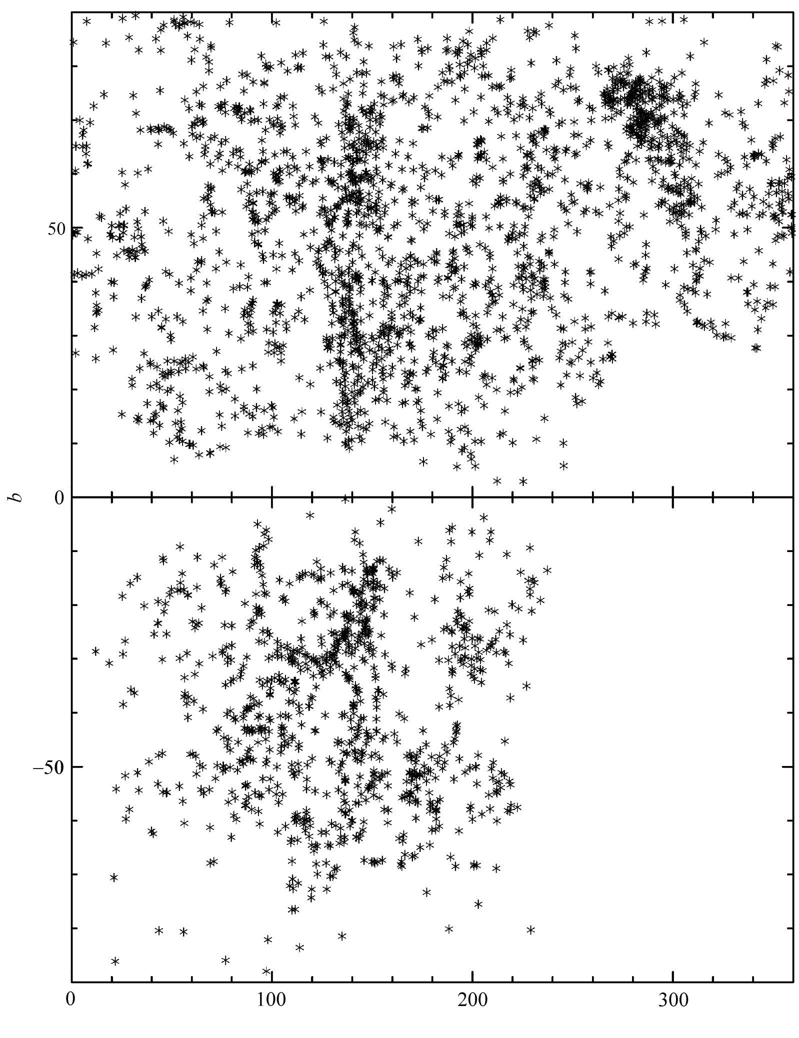

Fig. 1 Distribution of the BAOSS fields in Galactic coordinates.

Our fields are selected from the nearby galaxies, which are mostly located at high Galactic latitudes. It is important to search for variables in these fields for the study of high Galactic latitude behaviors. The project is also important in the study of the structure of the Galaxy. Figure 1 shows the distribution of all the survey fields in Galactic coordinates. It is easy to see that the fields of BAOSS are roughly uniformly distributed in Galactic latitudes, as distinguished from the fields of other projects, such as OGLE (Udalski et al. 1994), which are mostly limited to some specific areas. Thus our project should give a global view of the distribution of variable stars of various types along the Galactic latitude.

In this paper, we first present the observations of our supernova survey and the reduction methods used for variable searching. Then we catalog the variable candidates we found and draw light curves of some of the long period variables.

2 OBSERVATIONS AND DATA REDUCTION

The BAO 0.6 m telescope used in the supernova survey is fully described in Qiu et al. (1999, 2001). It is a completely automated telescope equipped with a TI 215 1024×1024 CCD at the prime focus with a $16.8' \times 16.8'$ field of view. Each pixel is about $0.98''$ in size. The supernova survey began in April 1996, but the intensive survey only started in October 1996. The normal exposure time in the survey is 60 seconds for each of the 300–500 images taken every night. We used the unfiltered CCD for the imaging. The limiting magnitude is about 19.0. The full width at half maximum (FWHM) varies among the images, due to different seeing conditions, the average being about $3.0''$.

Preliminary reductions, including bias subtractions, dark and flat corrections, were taken with standard IRAF packages in the course of the supernova survey.

We excluded bad-quality images with FWHM larger than $5.5''$. In the event, 90 000 image frames in about 3000 fields, accumulated during 1996–1998, were selected. Thus, we have about 30 frames for each field. The time interval between successive frames of a given field is about 20 days. For some fields where LPVs were found, we extended the data reduction to the end of 2000.

We chose the images of best quality in each field as templates. Firstly, we did the photometry of the templates. For each field we compiled a catalog of stars of magnitudes from 9 to 18. We excluded stars that are very close to any bright stars or are contaminated by close neighbors in crowded regions, so all the stars we selected are relatively isolated. In total, about 280 000 stars are selected and the average number of stars in each field is about 90.

The comparison stars in each filed were chosen manually. Too bright stars saturated the CCD pixels on very clear nights, while too faint ones were not well exposed and have low S/N. Typically, our selected comparison stars are of magnitudes 12–14. All the comparisons are located far from the centers of galaxies, to avoid contamination by the galaxy.

Since the selected stars are isolated, it is reasonable to use aperture photometry to measure the instrumental magnitudes of the stars. All the processing of photometry was done with the tasks in the APPHOT package of IRAF. Each frame was automatically aligned with its template. The aperture photometry of the images was also done automatically. We used an aperture 1.5 times the FWHM and a concentric sky annulus with inner radius 4 times the FWHM and outer radius 10 pixels larger than the inner one. After the differential photometry, each star was checked for variability using a set of criteria. First, we calculated the night to night RMS scatter of each star and then fitted a curve of RMS scatter versus magnitude (see Fig. 2) for each field. If a field has too few stars to fit a satisfactory curve, we used the default curve which was fitted by combining some fields. We regard only stars with RMS scatters 5 times ($5\,\sigma$) larger than the anticipated value, with respect to their magnitudes, as variable candidates. The circle with a dot in the middle in Fig. 2 marks such a candidate.

To derive the unfiltered CCD magnitudes of the variables, we compared the instrumental unfiltered magnitudes with those of local standards, and used the latter's R band magnitudes listed in the catalog USNO-A1.0 (Monet et al. 1996) as reference points. With the CCD response function known, it is possible to transform unfiltered CCD magnitudes to the standard (*UBVRI*) passband. For example, Riess et al. (1999) have given some transformation relations between the BAO CCD magnitudes and standard magnitudes. However, their relations are not general and are only suitable for supernovae. Since the CCD we used has its highest quantum efficiency from 6000 Å to 8000 Å (Riess et al. 1999), it is reasonable to assume that our unfiltered CCD magnitudes nearly follow the standard R magnitudes.

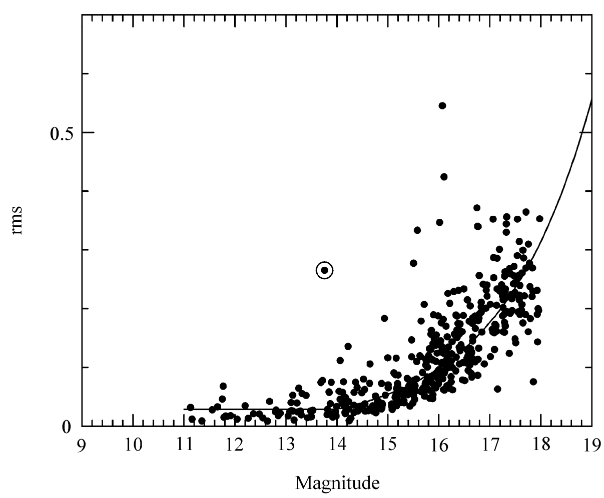

Fig. 2 Simulation of rms scatter versus magnitude.

3 RESULTS AND THE CATALOG OF VARIABLE STARS

We obtained a preliminary list of about 200 candidates on the $5\,\sigma$ criterion. We then manually checked all the images in the fields in which they are found, discarded all badly-tracked images, and recalculated the rms for the field. We ended with a list of 154 variable candidates of high reliability. Ten of them can be easily classified as LPVs, because of their large amplitudes and obvious periodic variations. Three of these LPVs are previously known in the General Catalog of Variable Stars (GCVS, Kholopov et al. 1985). We estimated the periods from their light curves. The light curves of the LPVs are shown In Fig. 3. For the rest of the candidates, we cannot determine the periods and make the classification. These candidates should be confirmed with the more intensive observations in the future.

We divided the variable candidates into three categories, according to Henden & Stone (1989): (1) stars with one or two bright points above the mean (High); (2) stars with one or two faint points below the mean (Low) and (3) all the remaining objects. In Fig. 4, we present three sample light curves, one from each of the three cases.

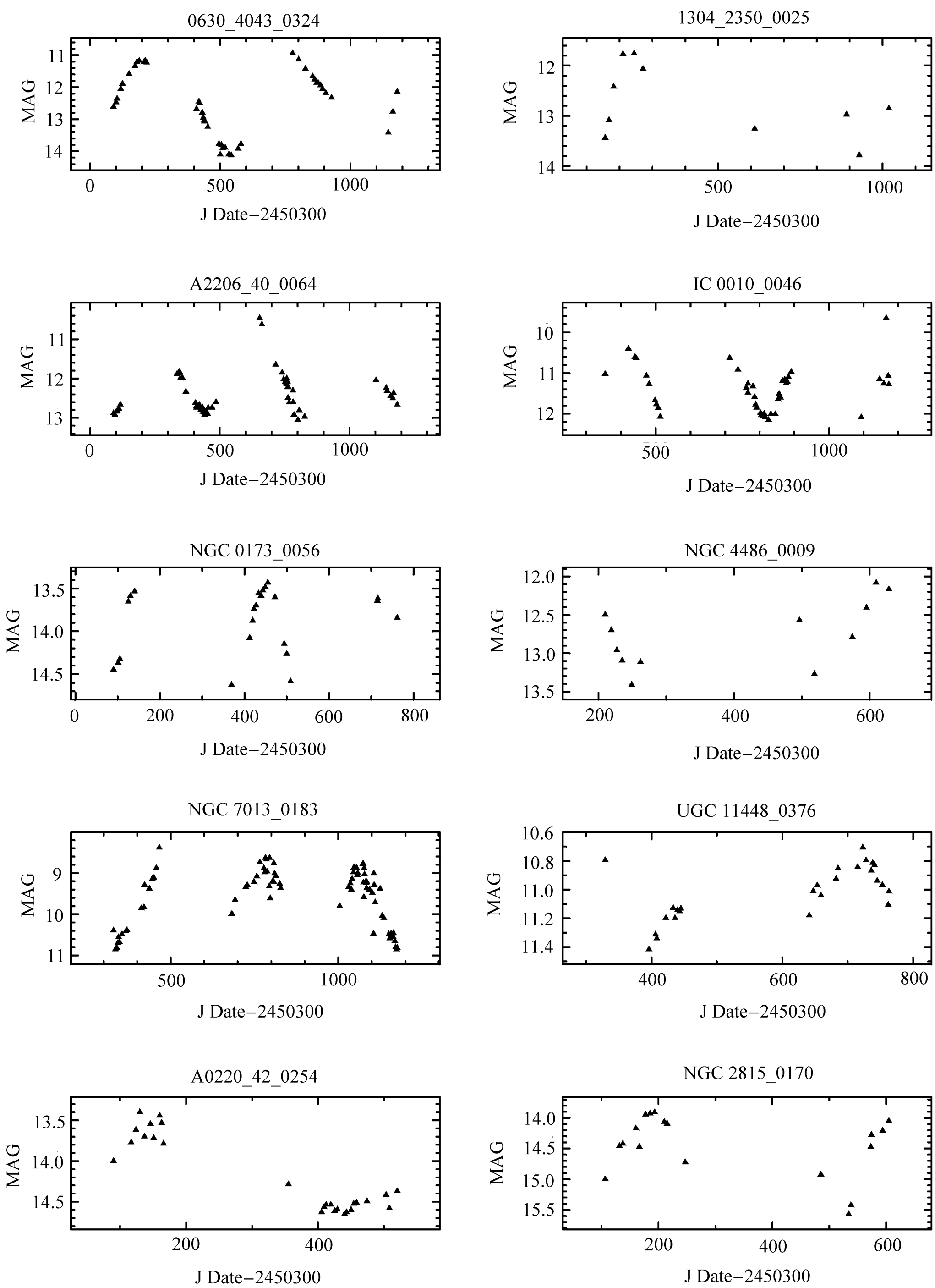

Fig. 3 The light curves of LPVs.

We obtained the coordinates of the candidates from the catalog USNO-A1.0 (Monet et al. 1996). Most of the candidates are listed in the catalog, and then we extract the coordinates directly. For those not listed, we used their differential positions with respect to some reference stars to calculate their coordinates.

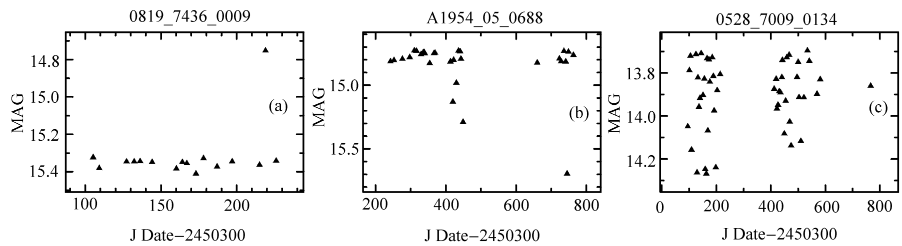

Fig. 4 Examples of the variable candidates.

In Tables 1 and 2, we present the list of identified LPVs and variable candidates. Each is designated by a serial number in column (1), and by a name in column(2) from the field coordinates and the star's ID number. An asterisk denotes a previously known variable. The table also gives their J2000.0 equatorial coordinates in columns (3) and (4), B and R magnitudes in columns (5) and (6) from in the catalog USNO-A1.0. The CCD magnitude, its RMS scatter, amplitude of variation in magnitude and number of observations are given in columns (7), (8) and (9), respectively. Preliminary classifications, if available, and some notes regarding the nature of variability are given in columns (11).

Table 1 List of Newly Discovered Long Period Variable Stars

No.	Star	R.A. (J2000.0)	Decl (J2000.0)	B (mag)	R (mag)	$M_{\rm CCD}$ (mag)	R.M.S (mag)	Amp	$N_{\rm obs}$	Type	Notes
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1	0630_4043_0324	06:33:15.76	40:42:51.5	13.4**	11.8**	12.8	0.699	2.94	52	LPV	$P >$500 days
2	1304_2350_0025	13:07:00.86	–24:05:31.6	20.9	16.9	17.7	0.641	1.68	17	LPV	$P >$150 days
3	A2206_40_0064	22:07:54.22	41:05:11.4	18.7	14.3	12.5	0.562	2.46	71	LPV	$P >$200 days
4*	IC0010_0046	00:21:25.60	59:13:55.7	15.3	11.3	13.5	0.509	1.67	50	LPV	$P >$200 days
5	NGC0173_0056	00:37:17.32	01:57:35.6	16.4	13.1	12.7	0.376	1.19	41	LPV	$P >$150 days
6*	NGC4486_0009	12:30:58.09	12:18:30.7	13.3	13.5	12.8	0.409	1.33	18	LPV	$P >$120 days
7*	NGC7013_0183	21:03:25.77	29:59:13.1	12.7	10.0	10.2	0.685	2.46	25	LPV	$P >$150 days
8	UGC11448_0376	19:30:59.99	35:48:36.0	15.0	11.6	11.0	0.170	0.71	32	LPV	$P >$100 days
9	NGC2815_0170	09:16:05.42	–23:39:19.0	18.4	15.0	14.5	0.484	1.66	18	LPV	$P >$200 days
10	A0220_42_0254	02:22:39.61	43:02:08.0	15.6	15.0	14.3	0.466	1.46	31	LPV	$P >$200 days

We found our list contains 16 known, and three suspected variables, after an examination of the General Catalog of Variable Stars (GCVS, Kholopov et al. 1985), and the New Suspected Variable Catalog (NSV, Kukarkin et al.1982). We list in Table 3 our survey variables that coincide with GCVS objects to within 2′ in position and have similar brightness and amplitudes. Table 4 lists those coinciding with NSV objects to within 5′ (taking into the consideration the poorer positioning accuracy of NSV). In the Column (5) of Table 3 and Column (4) of Table 4, we list the difference (in arcmin) between our position and the catalogue position. The columns of Tables 3 and 4 have the same meaning as those of Tables 1 and 2, except that Table 3 uses GCVS names.

Table 2 List of Variable Star Candidates

No.	Star	R.A. (J2000.0)	Decl (J2000.0)	B (mag)	R (mag)	$M_{\rm CCD}$ (mag)	R.M.S (mag)	Amp	$N_{\rm obs}$	Type
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1	0123_06_0032	01:25:43.37	–06:03:04.0	14.9	13.5	13.5	0.108	0.41	14	...
2	0509_1348_0225	05:11:36.89	13:50:56.3	17.6	15.7	15.9	0.176	0.57	32	...
3	0510_7125_0087	05:15:39.44	71:25:29.4	16.7	15.6	16.0	0.132	0.54	55	...
4	0518_0358_0072	05:21:12.13	03:57:09.7	15.1	13.8	13.3	0.097	0.29	38	...
5	0528_7009_0134	05:34:48.34	70:14:28.9	15.1	13.6	13.9	0.160	0.57	48	...
6	0621_7418_0200	06:28:02.47	74:24:22.4	15.1	14.3	13.8	0.227	0.99	30	...
8	0631_4853_0084	06:36:11.67	48:48:58.2	12.7	12.1	11.8	0.159	0.59	35	...
9	0707_4835_0047	07:11:00.04	48:26:07.4	16.9	15.0	14.9	0.106	0.42	45	...
10	0711_6712_0091	07:17:13.20	67:07:49.4	16.2	14.7	14.8	0.172	0.49	45	...
11	0749_7808_0141	07:54:30.65	78:06:46.7	...	11.1	10.9	0.117	0.35	22	...
12	0819_7436_0009	08:24:01.74	74:19:25.1	17.0	15.7	15.3	0.148	0.66	16	High
13	0819_7436_0083	08:24:17.39	74:30:25.2	13.6	12.8	12.6	0.098	0.36	34	...
14	0903_3449_0043	09:06:29.05	34:36:33.9	16.2	14.3	14.4	0.142	0.52	40	...
15	0908_3302_0054	09:11:01.84	32:49:01.9	17.1	14.6	14.5	0.075	0.24	22	...
16	0911_3020_0073	09:14:09.48	30:10:20.6	15.8	14.1	14.2	0.118	0.39	36	...
17	0932_0520_0034	09:35:04.21	05:04:54.7	17.2	15.0	15.1	0.134	0.55	32	...
18	1001_7037_0012	10:05:54.42	70:18:54.3	14.6	13.0	13.2	0.227	0.72	26	...
19	2006_06_0087	20:09:17.17	–06:18:18.4	16.6	13.3	13.3	0.090	0.33	53	...
20	A0055_36_0017	00:58:39.24	36:38:50.3	14.1	12.2	12.2	0.099	0.34	28	...
21	A0106_01_0051	01:08:47.44	01:40:08.0	15.3	14.2	13.9	0.218	0.72	24	...
22	A0118_12_0067	01:21:37.64	12:30:47.3	16.2	15.5	15.6	0.189	0.68	23	...
23	A0220_42_0131	02:22:52.32	42:57:10.8	14.7	14.1	14.3	0.204	0.65	31	...
24	A0233_23_0080	02:36:10.47	23:56:45.1	14.7	12.2	12.2	0.063	0.22	31	...
25	A0708_73_0067	07:14:14.39	73:27:29.9	16.0	14.3	13.9	0.132	0.44	48	...
26	A1107_24A_0040	11:09:42.44	24:17:35.3	15.4	11.8	11.9	0.087	0.39	28	...
27	A1906_42_0285	19:07:49.45	43:08:45.4	15.7	13.1	13.1	0.095	0.43	51	...
28	A1954_05_0688	19:57:22.21	06:00:53.3	16.0	14.6	14.8	0.206	0.96	29	Low
29	A2101_21_0044	21:04:21.04	–21:42:44.5	11.7	10.7	10.9	0.076	0.22	9	...
30	A2206_48_0016	22:08:16.53	48:19:38.8	14.7	13.4	13.2	0.122	0.38	32	...
31	A2206_48_0263	22:07:50.31	48:25:16.8	14.6	13.7	13.7	0.203	0.67	21	...
32	A2218_47_0883	22:19:29.60	47:46:52.7	15.4	14.2	14.2	0.084	0.96	22	High
33	ASPG0918_0061	09:21:06.26	02:43:11.5	15.7	14.8	14.3	0.132	0.55	57	..
34	IC0010_0134	00:20:40.01	59:14:31.8	...	9.9	9.8	0.106	0.49	18	...
35	IC0284_0368	03:05:33.73	42:23:56.6	14.8	14.1	14.0	0.078	0.33	45	...
36	IC0758_0034	12:03:18.22	62:30:53.9	16.2	15.0	14.8	0.142	0.38	17	...
37	IC0758_0041	12:04:04.73	62:33:45.9	16.0	15.4	15.6	0.295	0.95	20	...
38	IC0903_0031	13:38:48.87	–00:09:54.2	13.1	12.3	12.5	0.137	0.39	9	...
39	IC1784_0166	02:15:52.43	32:44:19.9	15.7	14.5	14.2	0.092	0.43	27	...
40	IC2226_0149	08:05:45.37	12:34:29.7	16.7	16.0	15.9	0.319	1.82	49	Low
41	MCG13027A_0031	11:44:45.17	–03:47:05.5	14.6	14.4	14.6	0.099	0.28	7	...
42	MCG24101_0008	16:17:27.22	–11:49:02.9	17.3	16.1	16.2	0.179	0.46	7	...
43	NGC0194_0034	00:39:28.74	02:58:03.6	13.5	12.6	12.8	0.076	0.22	16	...
44	NGC0198_0065	00:39:28.74	02:58:03.6	13.5	12.6	12.7	0.069	0.22	20	...
45	NGC0252_0072	00:48:41.48	27:45:03.0	15.3	14.4	14.3	0.088	0.40	16	Low

Table 2 Continued

No.	Star	R.A. (J2000.0)	Decl (J2000.0)	B (mag)	R (mag)	$M_{\rm CCD}$ (mag)	R.M.S (mag)	Amp	$N_{\rm obs}$	Type
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
46	NGC0266_0041	00:49:22.83	32:15:49.3	13.9	13.1	13.1	0.066	0.35	25	Low
47	NGC0295_0033	00:55:32.90	31:32:58.1	12.7	12.0	12.4	0.209	0.63	27	...
48	NGC0840_0065	02:09:50.10	07:52:10.2	16.4	14.3	13.9	0.136	0.48	23	...
49	NGC0914_0282	02:25:25.88	42:08:47.1	16.3	15.0	15.1	0.157	0.48	21	...
50	NGC1086_0299	02:47:28.56	41:19:14.6	13.6	12.5	12.3	0.080	0.31	35	...
51*	NGC2424_0171	07:40:45.66	39:18:50.7	15.0	13.9	14.0	0.249	0.84	33	...
52	NGC2500_0021	08:01:55.69	50:40:55.6	12.3	12.3	12.2	0.110	0.37	37	...
53	NGC2503_0009	08:00:16.45	22:16:46.6	15.7	13.3	13.4	0.093	0.32	34	...
54	NGC2591_0155	08:35:56.53	78:07:25.0	16.8	14.8	15.1	0.223	0.92	39	Low
55	NGC2604A_0034	08:33:02.40	29:28:19.7	14.2	13.1	13.4	0.182	0.54	36	...
56	NGC2604A_0091	08:33:07.62	29:35:05.9	15.0	13.9	14.0	0.103	0.31	41	...
57*	NGC2638_0038	08:42:18.17	37:11:04.6	13.5	12.7	12.6	0.163	0.68	25	...
58	NGC2661_0017	08:45:49.10	12:36:16.6	15.7	15.1	14.5	0.128	0.46	31	...
59	NGC1661_0065	08:45:44.63	12:40:02.2	13.0	12.1	12.2	0.119	0.37	30	...
60	NGC2681_0033	08:52:57.55	51:16:59.6	15.8	13.9	13.9	0.105	0.36	34	...
61	NGC2744_0018	09:04:38.15	18:22:31.0	16.3	15.6	16.2	0.328	1.03	29	...
62	NGC2815_0170	09:16:05.42	–23:39:19.0	18.4	15.0	14.5	0.484	1.66	18	...
63	NGC2815_0232	09:16:04.01	–23:36:06.3	14.9	14.0	14.3	0.188	0.56	18	...
64	NGC2889_0077	09:27:30.89	–11:35:47.3	15.7	14.7	14.1	0.100	0.35	15	...
65	NGC2974_0102	09:36:07.78	–12:24:04.7	16.2	15.3	15.5	0.330	0.96	9	...
66	NGC3049_0037	09:54:41.00	09:13:54.4	15.3	14.5	15.4	0.194	0.91	24	...
67*	NGC3312_0094	10:37:09.13	–27:35:12.6	10.8	11.1	11.1	0.415	1.37	11	...
68*	NGC3985_0041	11:57:06.80	48:24:25.9	14.4	14.0	13.4	0.250	0.83	19	...
69	NGC4026_0010	11:58:58.92	50:53:23.6	16.8	13.8	13.9	0.107	0.42	22	...
70	NGC4036_0023	12:01:04.32	61:56:08.0	15.0	13.8	13.7	0.103	0.48	12	...
71*	NGC4064_0004	12:03:52.03	18:18:04.3	16.2	14.7	15.1	0.154	0.57	13	...
72*	NGC4203_0007	12:14:50.59	33:06:06.2	15.2	14.2	13.9	0.225	0.89	13	...
73	NGC4413_0057	12:26:30.33	12:39:30.5	11.5	10.0	9.7	0.090	0.26	6	...
74	NGC4535_0031	12:33:54.56	08:16:37.3	16.6	14.0	15.1	0.172	0.63	13	...
75*	NGC4584_0007	12:38:26.28	13:00:57.1	14.1	12.0	12.3	0.199	0.61	18	...
76	NGC4662_0015	12:44:05.18	37:11:28.1	15.0	14.0	14.1	0.193	0.61	26	...
77	NGC5147_0020	13:25:53.04	02:09:32.4	16.2	14.7	14.3	0.351	0.99	17	...
78	NGC5184_0020	13:29:52.32	–01:45:17.3	16.7	13.8	13.7	0.060	0.21	16	...
79	NGC5190_0015	13:30:35.68	18:06:25.9	14.2	11.9	12.0	0.055	0.19	14	...
80	NGC5211_0002	13:33:24.79	–01:07:11.6	15.2	14.1	13.9	0.106	0.33	14	...
81	NGC5214_0021	13:33:19.35	41:54:51.4	14.6	11.7	11.8	0.289	1.06	20	...
82	NGC5278_0004	13:41:57.56	55:34:18.6	15.9	15.2	15.1	0.151	0.46	30	...
83	NGC5327_0020	13:51:50.83	–02:12:31.5	12.0	11.4	11.3	0.296	0.72	9	...
84	NGC5346_0012	13:52:36.37	39:32:38.1	15.7	15.0	14.7	0.206	0.73	23	...
85	NGC5364_0013	13:56:01.82	04:56:47.2	14.7	14.4	15.1	0.107	0.36	20	...
86	NGC5376_0018	13:54:55.80	59:26:54.3	16.4	15.3	14.8	0.211	0.71	28	...
87	NGC5692_0016	14:38:15.59	03:19:44.0	15.7	13.8	14.0	0.136	0.55	13	...
88	NGC5857_0040	15:07:47.74	19:40:36.8	14.1	12.7	12.8	0.103	0.32	22	...
89	NGC5861_0007	15:09:05.31	–11:27:39.4	16.5	15.7	15.2	0.214	0.65	11	...
90	NGC5898_0024	15:18:01.45	–24:13:29.0	15.2	12.6	12.6	0.059	0.18	7	...
91	NGC5915_0016	15:21:19.08	–13:12:44.8	14.9	13.7	13.5	0.241	0.83	11	...
92	NGC5949_0008	15:28:36.09	64:42:45.4	15.3	13.9	13.7	0.226	0.79	31	...
93	NGC6021_0070	15:57:39.40	16:00:01.2	11.9	11.8	11.7	0.117	0.36	24	...
94*	NGC6168_0039	16:31:40.73	20:10:58.7	16.6	15.4	15.1	0.268	1.01	50	...
95	NGC6232_0036	16:42:19.87	70:37:51.0	16.0	15.0	15.0	0.240	1.06	40	...

Table 2 Continued

No.	Star	R.A.	Decl	B	R	$M_{\rm CCD}$	R.M.S	Amp	$N_{\rm obs}$	Type
		(J2000.0)	(J2000.0)	(mag)	(mag)	(mag)	(mag)			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
96	NGC6240_0141	16:52:41.76	02:27:02.9	15.4	14.6	14.4	0.230	0.86	24	...
97	NGC6340_0015	17:11:06.02	72:15:12.8	15.7	15.0	15.1	0.291	1.16	54	...
98	NGC6368_0058	17:27:31.68	11:32:13.3	16.8	15.4	15.6	0.262	0.82	40	...
99	NGC6801_0190	19:27:12.03	54:26:19.6	14.1	12.6	12.7	0.080	0.41	53	...
100	NGC7013_0110	21:03:13.30	29:53:36.1	16.0	14.5	14.4	0.169	0.98	50	...
101*	NGC7137_0142	21:48:12.84	22:14:35.6	14.0	13.5	13.5	0.243	0.87	61	...
102	NGC7171_0057	22:00:50.54	–13:11:56.1	13.6	13.5	13.0	0.090	0.27	16	...
103*	NGC7218_0027	22:10:15.84	–16:39:46.3	12.2	12.7	12.8	0.322	1.01	16	...
104	NGC7303_0003	22:31:15.65	30:49:12.0	14.5	13.8	13.4	0.130	0.56	48	...
105	NGC7673_0063	23:28:02.80	23:36:58.6	12.6	12.5	12.5	0.086	0.30	41	...
106	NGC7691_0017	23:32:50.47	15:49:22.1	15.8	14.4	14.2	0.226	0.71	32	...
107	NGC7691_0048	23:31:59.67	15:53:34.9	13.2	13.2	13.0	0.107	0.34	31	...
108	NGC7738_0012	23:43:59.27	00:27:13.2	15.0	13.7	13.4	0.116	0.37	32	...
109	NGC7741_0007	23:44:06.43	25:59:48.4	14.1	13.3	13.5	0.111	0.35	43	...
110	UGC01721_0063	02:14:46.49	37:25:54.9	15.0	14.4	14.8	0.221	0.65	6	...
111	UGC02082_0032	02:36:24.84	25:26:18.0	16.0	13.4	13.5	0.131	0.42	11	...
112	UGC02550_0132	03:08:18.21	36:30:04.4	17.3	15.0	14.8	0.118	0.41	10	High
113	UGC02623_0060	03:17:06.41	35:03:47.1	12.2	11.0	11.1	0.103	0.27	5	Low
114	UGC02707_0064	03:23:45.72	36:58:59.9	15.1	13.8	13.7	0.122	0.43	11	...
115	UGC02729_0110	03:26:31.54	68:31:27.2	15.2	14.4	14.6	0.171	0.65	21	...
116	UGC02837_0116	03:44:32.05	39:59:37.0	14.3	12.0	12.0	0.087	0.31	10	Low
117	UGC02885_0186	03:52:34.41	35:33:58.6	16.6	14.0	13.7	0.123	0.56	28	...
118	UGC03110_0242	04:43:05.80	73:45:32.2	17.1	15.2	15.2	0.160	0.59	12	...
119	UGC03150_0229	04:49:10.56	73:34:09.6	15.2	14.0	13.9	0.152	0.47	27	...
120	UGC03742_0232	07:13:23.00	35:11:02.9	16.2	14.6	14.0	0.193	0.73	18	...
121	UGC03975_0005	07:44:12.28	72:40:04.5	14.8	14.2	14.0	0.169	0.52	13	...
122	UGC04115_0207	07:56:55.37	14:28:33.4	15.0	11.9	11.8	0.143	0.47	12	...
123	UGC05391_0043	10:02:08.39	37:19:37.5	16.6	14.6	14.6	0.113	0.38	16	...
124*	UGC06607_0035	11:38:36.06	20:43:34.6	17.2	16.3	16.2	0.269	0.96	15	High
125	UGC06711_0053	11:44:45.68	69:46:55.1	16.1	13.8	13.8	0.058	0.25	15	...
126	UGC07352_0009	12:19:18.40	08:45:43.8	15.8	14.4	14.3	0.119	0.38	10	...
127	UGC09083_0011	14:10:54.32	50:09:06.2	11.6	11.4	12.0	0.102	0.27	6	...
128	UGC09299_0034	14:29:58.08	00:03:18.9	15.7	15.2	15.1	0.168	0.52	8	...
129	UGC09858_0029	15:26:58.31	40:35:32.6	13.1	12.2	11.9	0.235	0.75	26	...
130	UGC10041_0066	15:48:42.72	05:14:01.0	16.4	14.1	14.2	0.091	0.41	17	...
131	UGC10529_0020	16:45:04.56	32:12:57.8	15.9	15.0	15.3	0.184	0.65	40	...
132	UGC10979_0073	17:46:46.18	20:48:26.6	14.9	13.9	13.4	0.202	0.63	30	...
133	UGC11057_0037	17:57:29.61	12:06:40.6	17.1	14.3	14.4	0.075	0.30	45	...
134	UGC11337_0041	18:43:12.84	18:37:51.4	15.1	14.1	14.2	0.152	0.80	58	...
135*	UGC11344_0440	18:43:59.38	24:12:49.4	14.6	11.9	11.2	0.223	0.89	96	...
136	UGC11393_0109	19:02:19.84	27:11:41.0	16.4	14.1	14.2	0.151	0.58	41	...
137	UGC11393_0202	19:02:58.49	27:16:49.3	15.5	14.0	13.9	0.102	0.36	51	...
138	UGC11537_0297	20:18:27.09	–00:03:43.3	12.7	12.5	12.9	0.188	0.55	44	...
139	UGC11697_0050	21:12:19.02	11:35:07.5	16.4	14.1	13.8	0.087	0.35	47	...
140	UGC11753_0402	21:28:28.32	31:55:52.3	16.2	13.5	13.5	0.086	0.34	31	...
141	UGC11806_0178	21:44:08.86	46:33:28.6	15.2	14.0	13.6	0.164	0.58	39	...
142	UGC12069_0008	22:31:31.13	76:24:33.8	14.9	13.5	13.4	0.054	0.21	52	...
143	UGC12184_0027	22:47:25.02	11:41:30.2	15.5	14.6	14.2	0.127	0.33	10	...
144	UGC12231_0037	22:54:06.61	31:38:39.0	17.1	15.6	15.5	0.278	3.04	25	...
145	UGC12713_0003	23:37:56.78	30:35:38.3	15.4	14.3	14.6	0.174	0.72	16	Low

Table 3 Known Variable Stars in the General Catalogue of Variable Stars

Name	Star	R.A. (J2000.0)	Decl (J2000.0)	Error (arcmin)	Type	Max (mag)	Min (mag)	Mag	Period (d)	$M_{\rm CCD}$ (mag)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
FQ Cas	IC0010_0046	00:01:25.60	59:13:55.7	1.8	M	13.0	17.4	P	266.5	13.5
WZ Lyn	NGC2424_0171	07:40:45.66	39:18:50.7	0.8	RRAB	13.9	15.1	P	...	14.0
AH Lyn	NGC2638_0038	08:42:18.17	37:11:04.6	0.9	EA	13.5	14.3	P	...	12.6
LL Hya	NGC3312_0094	10:37:09.13	–27:35:12.6	0.6	EA	11.4	11.9	P	...	11.1
BC Leo	NGC06607_0035	11:38:36.06	20:43:34.6	1.0	RRAB	15.9	17.1	B	0.635627	16.2
BD UMa	NGC3985_0041	11:57:06.80	48:24:25.9	0.1	RRAB	12.2	13.8	P	0.681147	13.4
SU Com	NGC4064_0004	12:03:52.03	18:18:04.3	0.6	RRAB	15.4	16.4	B	0.603411	15.1
CV Vir	NGC4486_0009	12:30:58.09	12:18:30.7	1.8	M	14.2	16.5	P	146.38	12.8
FU Vir	NGC4584_0007	12:38:26.28	13:00:57.1	1.9	RRAB	12.0	13.1	P	0.574360	12.3
CK Com	NGC4203_0007	12:14:50.59	33:06:06.2	0.8	RRAB	14.2	15.5	P	0.693996	13.9
V0701 Her	NGC6168_0039	16:31:40.73	20:10:58.7	1.5	RRAB	14.5	16.4	P	0.503624	15.1
BP Her	UGC11344_0440	18:43:59.38	24:12:49.4	0.7	SRD	12.7	14.1	P	83.1	11.2
CY Dra	UGC11475_0009	19:46:05.27	59:34:25.7	1.0	RR	12.3	13.6	P	...	12.8
V0378 Cyg	NGC7013_0183	21:03:25.77	29:59:13.1	0.3	M	13.0	15.5	P	295.6	10.2
CV Peg	NGC7137_0142	21:48:12.84	22:14:35.6	0.8	RRAB	12.9	14.4	P	0.56288	13.5
WX Aqr	NGC7218_0027	22:10:15.84	–16:39:46.3	0.6	RRAB	12.9	14.0	V	0.550841	12.8

Table 4 Known Variable Stars in the New Catalogue of Suspected Variable Stars

Star	R.A. (J2000)	Decl (J2000.0)	Error (arcmin)	Type (mag)	Max (mag)	Min (mag)	Mag (mag)	$M_{\rm CCD}$ (mag)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
0749_7808_0141	07:54:30.65	78:06:46.7	0.5	L	13.0	13.50	P	10.9
0819_7436_0083	08:24:17.39	74:30:25.2	0.1	...	...	13.13	P	12.6
NGC6368_0058	17:27:31.68	11:32:13.3	0.9	RR	15.50	16.00	P	15.6

4 DISCUSSION

A total of 154 variable candidates (on $5\,\sigma$ criterion) have been found. Of these, 19 are previously known GCVS or NSV variables, the rest, about 88%, are new. They constitute 0.06% of all the stars identified in our survey. Considering the very stringent restrictions in making the BAO variable list the 0.06% is probably a lower limit of the actual proportion of variables in the survey fields. In particular, because of the long time gaps, typically 20 days, several classes of variables, such as eclipsing binaries, were poorly sampled by the survey.

There have been several other wide-field surveys for variable stars in recent years. Wetterer et al. (1996) surveyed 50 deg^2 with the CCD transit instruments, and reported on 42 RR Lyrae stars discovered during 145 observing nights. Caldwell, Keane & Schechler (1991) surveyed 9.4 deg along the southern Galactic plane, finding 1% of the 224 524 stars surveyed to be variable. Olech (1996) has reported 2288 variable discovered by OGLE survey out of 500 000 stars in 3 deg in dense Baade's window fields in the Galactic bulge. Henden & Stone surveyed 394 $\deg^2$ in SDSS calibration fields, finding about 0.24% of 661 591 stars to be variable. Pojmański (1998) found about 90 new periodic variables among 45 000 stars in the all-sky automated survey project. The percentage of variables in these surveys is higher than in ours, because we used a $5\,\sigma$ criterion to identify variables, rather than the $3\,\sigma$ or $2.5\,\sigma$ they used. In fact, we have also found more than 2000 variable candidates between $3\,\sigma$ and $5\,\sigma$, but the errors due to the quality of CCD imaging are so large that we can not be sure whether they are true variables. We limited our results with the $5\,\sigma$ criterion in order to maintain a high level of reliability. The variable candidates will be confirmed with more intensive observations in the future.

Ten LPVs were identified and seven of them are new discoveries. The periods of these LPVs ranges from about 120 days to over 500 days. The three known LPVs are Mira-type variables. The newly discovered ones probably belong to the same type.

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