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Searching for Variable Stars in and around Open Clusters

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Abstract We present a snapshot of our recent results of a variable star survey in 1 degree fields around three open clusters: NGC 188, NGC 7789 and M67. A total number of 39 variable stars are newly discovered, including 22 W UMa stars, 10 EA (Algol) type binaries, one RR-lyr and one RRd pulsator, and five unclassified variables.

Key words: open clusters: individual: NGC 188, NGC 7789 and M67 — stars: variables

1 INTRODUCTION

Open clusters provide an ideal ground for studies of stellar evolution, since the same distance, age, chemical abundance and reddening can be assumed for all the stars in the same cluster (Kim et al. 2001). Such a diagnosis becomes especially important considering the variable population in the clusters. In the Hertzsprung-Russell Diagram (HRD), variabilities due to both intrinsic properties or geometric eclipsing can happen in all evolutionary stages. For pulsating stars, they usually group in certain places on the HRD called instability strips. Binary systems in clusters, whether or not resolved, will show in the HRD as a sequence parallel to the main sequence of the cluster, which is a common observational fact (eg. Anthony-Twarog et al. 1990; Bergbusch et al. 1991). The occurrence of binary systems in star clusters is very frequent (Abt 1983), indicating the relationship between the dynamical processes and physical content. Thus, statistical studies of close binary systems in open clusters can be taken as a good diagnosis for the dynamical evolutionary history of the host cluster. Descendants of interactive binary systems, such as blue stragglers, can be traced also from the present nature of their progenitors, i.e., contact or semi-detached binary systems (Kaluzny & Rucinski 1993). After all, variable stars in the open clusters can provide independent measurements for the physical parameters of the host clusters, such as age, distance, metallicity and so on. To photometrically search for variable stars in the open clusters, a large observational field of view is needed. As a wide field sky survey project, BATC (Beijing-Arizona-Taiwan-Connecticut) facility fits our goals very well (Fan et al. 1996). With the use of CCD camera, we can go to much fainter

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magnitudes compared with the previous techniques applied for variable star observations. In the meantime, large field simultaneous CCD imaging of all stars in the cluster and in the field enables statistical studies of the variable star contents in the cluster and field, therefore allows physical insight on the formation and evolution of binaries, and independent measure of stellar evolution through the intrinsic variables. Taking advantages of CCD photometry, accurate light-curves and precise time-series data can be obtained (Kim et al. 2001).

Being one of the major issues in open cluster research, detection of variable stars is copiously referenced in the literature. The earliest discovery of four W UMa systems (EP Cep., EQ Cep., ER Cep., and ES Cep.) in NGC 188 was in 1964 by Hoffmeister. Kaluzny and Shara (1987) added three new W UMa stars to the cluster. Three contact binaries were found by Gilliland et al. (1991) in a survey covering only a part of the M67 field. Recently, 25 variable stars were found in the field of the open cluster NGC 6819 (Street et al. 2002), including 12 eclipsing binaries, 9 BY Draconis systems and 4 other types. In M37 three W UMa-type stars were newly discovered (Kiss et al. 2001), together with 2 δ Scuti stars and 2 long-period eclipsing binaries. Based on these and many other results in open clusters, such as NGC 2506 and NGC 2420 (Kim et al. 2001), NGC 2301 (Kim et al. 2001), NGC 7790 (Gupta et al. 2000) and so on, we can say that the open cluster is really a fruitful field for the investigation of variable stars.

As a preliminary work, three open clusters (NGC 188, NGC 7789 and M67) have been chosen as the targets for our variable star survey. In the following, we will briefly describe the gain and reduction process of our observational data. The results of the survey and discussion are presented in Sections 3 and 4, respectively.

2 OBSERVATIONS AND DATA REDUCTION

All of the photometry of the three open clusters (NGC 188, NGC 7789 and M67) are carried out at the Xinglong station of National Astronomical Observatory, with the 60/90 cm Schmidt telescope. The telescope is equipped with a 2048 × 2048 CCD camera. The field of view is about 1 degree with an image scale of 1.67 arcsec/pixel. Our observations use the BATC[09] i filter centered at 6660 Å with a passband of 490Å.

The data are initially processed with an automated PSF fitting photometry, based on the UNIX version of DAOPHOT II (Stetson 1992) with a modification on the PSF star selection procedure (Deng et al. 2001). Stetson's variability index (Stetson 1996) is applied for the search for variable stars. The detailed expressions of our data reduction can be found in Zhang et al. (2002a).

3 RESULTS OF THE SURVEYS

This work adopts the Phase Dispersion Minimization (PDM hereafter, Stellingwerf 1978) code for measuring the periods of variables.

The fundamental parameters of all the newly detected variables in the field of our program open clusters are presented in Table 1. The names of the clusters are in column 1, and the following columns are the ID numbers of the newly found variables in and around the clusters, their equatorial coordinates (2000), magnitudes in i-band (m_i), periods, amplitudes, types and proper motion membership probabilities (PMP). The PMP of variable stars in NGC 188 is from Dinescu et al. (1996), and that of variables in M67 is from Sanders (1977). It is worth emphasizing here that the magnitudes of variables in the fields of NGC 188 and M67 are calibrated, and, as no calibration data is yet available for NGC 7789 in the i-band from the survey, the magnitudes are left blank in this case. Nevertheless, calibration does not directly influence our results, since variabilities in the accurate instrumental magnitudes can ensure a correct determination of the properties of the variable stars.

Table 1 Properties of Newly Detected Variable Stars in Three Open Cluster Fields

Cluster	Star ID	R. A. (2000)	Decl. (2000)	m_i (mag)	P (d)	Amp.(mag)	Type	PMP
NGC 188	1	00:52:37.74	85:10:35.2	14.47	>1	0.55	EA	0.98
	2	00:51:15.15	85:24:51.7	15.42	0.3606	0.20	W UMa	0.76
	3	00:44:10.29	84:54:13.7	17.16	0.2766	0.52	W UMa	***
	4	01:01:50.73	85:24:00.7	12.62	0.3215	0.12	W UMa	0.00
	5	01:02:23.29	85:23:49.6	13.10	0.5005	0.58	RRd	0.00
	6	00:33:48.98	85:29:22.6	14.79	0.3165	0.43	W UMa	0.00
	7	01:07:39.69	85:23:59.8	16.86	0.2887	0.28	W UMa	***
	8	01:08:31.75	85:12:54.2	15.85	0.3072	0.39	W UMa	***
NGC 7789	1	23:58:16.38	56:31:20.5	***	0.3917	0.51	W UMa	***
	2	23:54:38.66	56:36:22.4	***	0.2719	0.52	W UMa	***
	3	23:56:53.75	56:21:49.1	***	0.3447	0.52	W UMa	***
	4	23:57:59.66	56:29:52.7	***	0.3776	0.39	W UMa	***
	5	23:57:22.56	56:59:35.4	***	0.3243	0.45	W UMa	***
	6	23:58:56.71	57:03:36.4	***	0.3998	0.51	W UMa	***
	7	23:59:02.75	57:05:37.1	***	0.3956	0.58	W UMa	***
	8	23:54:20.94	57:06:47.5	***	0.3556	0.69	W UMa	***
	9	23:53:42.48	57:07:06.8	***	0.7632	0.51	W UMa	***
	10	23:58:24.38	57:09:14.7	***	0.8442	0.31	W UMa	***
	11	23:55:08.20	57:10:12.1	***	0.2801	0.40	W UMa	***
	12	23:56:47.90	57:12:54.4	***	0.3893	0.53	W UMa	***
	13	23:53:37.39	57:13:02.8	***	0.3182	0.58	W UMa	***
	14	23:55:48.50	57:04:51.8	***	0.4520	0.58	RR Lyr	***
	15	23:54:05.16	56:56:11.4	***	***	0.80	EA	***
	16	23:53:57.42	56:39:47.2	***	0.6562	0.45	EA	***
	17	23:58:54.51	56:47:41.6	***	***	0.70	EA	***
	18	23:56:42.38	56:22:15.3	***	***	0.60	EA	***
	19	23:58:43.93	56:51:02.3	***	***	0.26	EA	***
	20	23:58:38.61	56:59:09.7	***	***	0.60	EA	***
	21	23:58:25.00	57:11:04.6	***	***	0.50	EA	***
	22	23:54:37.04	57:10:37.0	***	***	0.50	EA	***
	23	23:55:27.09	56:28:17.5	***	***	1.00	EA	***
	24	23:59:34.44	56:45:16.9	***	***	***	***	***
	25	23:56:33.24	56:26:00.3	***	***	0.16	***	***
	26	23:58:29.91	56:28:01.0	***	0.3304	0.45	W UMa	***
	27	23:54:12.78	56:29:48.9	***	***	0.30	***	***
	28	23:54:45.94	56:43:44.4	***	***	0.22	***	***
M67	1	08:51:04.84	11:45:56.9	13.16	0.3595	0.11	W UMa	0.95
	2	08:49:52.28	12:16:05.6	16.82	0.3941	0.57	W UMa	***
	3	08:49:21.38	11:19:28.4	14.82	***	0.30	W UMa	0.00

Specifically, 28 new variable stars are found in the 1 degree field of NGC 7789, including 23 eclipsing binaries with 14 W UMa, 9 EA systems, 1 RR Lyr star and 4 unclassified variables. For these unclassified variables, their partial light curves convincingly show that they possess variabilities in brightness which deserve further follow up observations. The types for such stars are also left blank in the table. In the same size field, eight new variables are detected in NGC 188, including 6 W UMa systems, 1 EA and 1 RRd type star. Among the 6 newly discovered W UMa stars, number 13 is definitely a member of the cluster, numbers 15 and 17 are probable cluster objects. Two W UMa stars are found in M67, together with 1 variable star of unknown type.

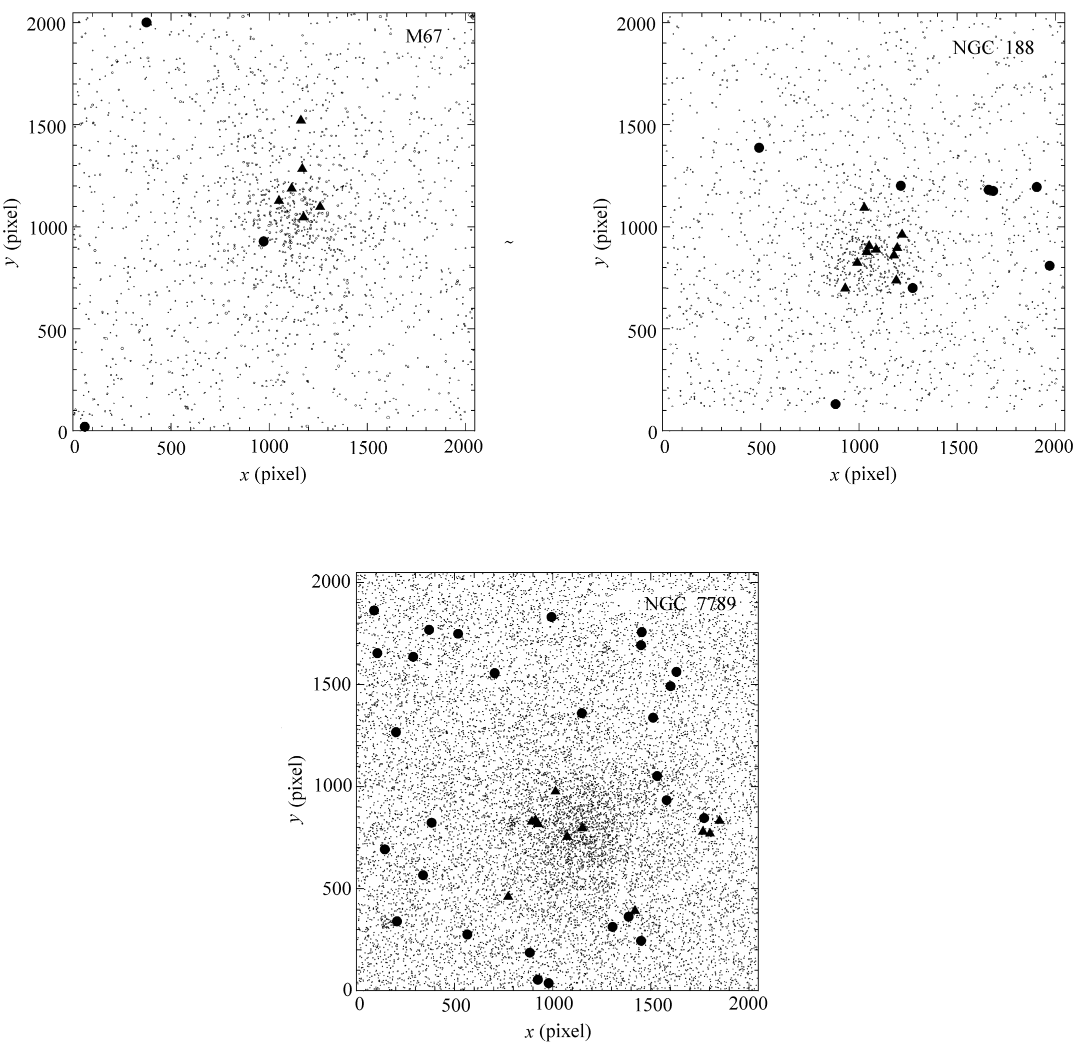

Fig. 1 Finding charts for variable stars in three open clusters. Normal stars are plotted as open circles, the newly detected variable stars as solid dots, previously found variables as triangles.

From the observations carried for the three open clusters, a large number of eclipsing binaries are found, including 22 W UMa stars and 10 EA type stars. All of them are short-period variables, with periods from 0.2^{d} to 1.0^{d} (Table 1). Judging from the properties of their light-curves and periods, these stars can be identified as either contact or semi-detached binary systems, which casts strong light on our understanding of the origin of blue stragglers. Only 2 pulsating stars are detected in our survey, a RR Lyr star in NGC 7789 with an unknown membership probability, and one in the field of NGC 188. In the latter case, the light-curve shows apparent period modulations. Fitted with the PDM method, the most probable period is about 0.5^{d}, which makes it look like an RR Lyr subclass d. More detailed observation is needed to unravel the mysterious light variability.

The separate panels of Figure 1 show the distributions of variables in the one degree fields around the clusters. Previously found variable stars are marked with triangles, our newly detected variables are in solid dots, while non-variable stars are in open circles, with size proportional to their brightness. Due to its low galactic latitude, the program field covering NGC 7789 is over-crowded, each image containing over thirty thousand stars on average, much more than the fields of NGC 188 and M67. The total number of newly found variables in and around NGC 7789 is also larger, as shown in Table 1. When considering the distribution of variable stars in the cluster field (Fig. 1), there are obvious high central concentrations in NGC 188 and M67. Unexpectedly, it is a completely different situation in NGC 7789. The detected variables are almost homogeneously distributed throughout the field of view. A possible reason can be attributed to the over-crowdedness in the cluster, especially in the central region, which does not allow good PSF fitting. The expected higher density of variables are overwhelmed by the bad photometry there.

4 DISCUSSION

When considering the physical properties of a cluster in terms of variable stars, the membership probabilities of the variables are very important. In the present work, only a few newly discovered variable stars possess PMP determinations. As for NGC 7789, a thorough study on the global properties and its variable star content is in preparation (Zhang et al. 2002b), and detailed discussions on the photometry including the membership determination will be presented.

Some of the newly discovered variables are not thoroughly observed. Their classification and properties are unknown even with our recent data. Follow up high precision photometry observations are needed for these objects. The close binary systems, such as the W UMa systems in the old clusters, deserve further work aimed at the orbital parameters. Presumably such work will provide valuable independent information on the global properties of the host clusters and cast new light on our understanding of stellar evolution and the dynamical evolution of the clusters (Branly et al. 1996).

Moreover, in order to obtain comprehensive statistics of variable stars and their relation with the physics of the host cluster, a complete sample of all variables is essential. With a complete catalog of all the variable stars within the cluster and in the field, one can study the respective ratio of binary systems. However, the present data set is limited by the selection effects due to the way the observations are made: variabilities with too short or too long periods, or too faint magnitudes, will be undetected. Using the present data, a certain conclusion can already be drawn on such problems as the high ratio of contact systems in old open clusters. Some detailed studies of the three open clusters have been done or are in preparation (Zhang et al. 2002a), Zhang et al. (2002b,c). In order to understand more delicate issues of stellar evolution and of cluster dynamics, long-term, high-precision and large-sample observation is necessary.

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