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VARIABLE STARS IN THE OPEN CLUSTER M29

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ABSTRACT

We present results of time-series CCD photometry for 178 stars in the young open cluster M29 (=NGC6913). Total 1036 V-band CCD frames were collected for five nights between August 12 and September 13, 1994. The photometric precision is about 7.6 mmag for 9th-10th mag stars in M29 with exposure times of 30 seconds. From the dispersion diagram and the light curves, one detached eclipsing binary (HD194378) and two suspected variables are newly discovered. A γ Cas type variable, V1322 Cyg, which has been known as a member of M29, did not show any light variations during the period of present observations, indicating that it passed the steady phase without the eruption during our observing runs.

Key Words : M29(=NGC6913), open cluster, variable, photometry

I. INTRODUCTION

M29 (=NGC6913; α_{2000}=$20^h24^m1.^s3$, δ_{2000}=+38°30′50″) is a member of OB star clusters in Cygnus and located near the bright star γ Cyg. The C-M diagram obtained from the UBV photometry (Hoag *et al.* 1961) shows a significant dispersion, indicating the existence of differential reddening and the contamination by non-member stars. Sanders (1973) calculated membership probability on the basis of relative proper motion for 228 stars in the field of M29 and found 92 probable members. Joshi *et al.* (1983) carried out the UBV photoelectric photometry for 103 stars having higher membership probabilities (mostly greater than 50%). They estimated the distance modulus, $(m-M)_o = 10.^m85 \pm 0.^m15$, and found the age spread from 0.3 to 1.75 Myr. Recently, Massey *et al.* (1995b) presented the results of UBV CCD photometry and multi-object fiber spectroscopy for eleven clusters in OB associations, including the cluster M29. The distance modulus derived from spectroscopic observation is $11.^m71 \pm 0.^m17$ and the age has the range of 4~6 Myr. For M29, they derived the IMF slope of Γ=-1.1±0.6, which is similar to that for the other OB clusters.

The purpose of time-series photometry is monitoring astronomical objects for long times in order to search their light variations. Recently, many observational programs for the survey of variable stars in star clusters and external galaxies have been processed actively by using the CCD camera; for examples, variable stars in the old open cluster NGC2243 (Kaluzny *et al.* 1996) and the globular cluster NGC6397 (Kaluzny 1996), Blue stragglers in the globular clusters (Mateo 1993), δ Scuti stars in the open cluster NGC6134 (Frandsen *et al.* 1996), β Cephei type variables in the open cluster NGC6231 (Balona & Laney 1995), variable stars in the Sagittarius dwarf spheroidal galaxy (Mateo *et al.* 1995) and the dwarf galaxy IC10 (Saha *et al.* 1996) etc.

In this paper, we present our observational results for M29 obtained in the Seoul National University Observatory (SNUO). The main purpose of this study is to search variable stars, particularly β Cephei stars, in the young open cluster M29 and to investigate the precision of our observation systems (SNUO 61cm telescope and CCD camera). The open cluster M29 was chosen as our observing target because it has several bright($9^m \sim 10^m$) B stars(i.e., β Cephei variable candidates) and it is moderately concentrated to observe effectively using our CCD system. The observation and data reduction are reported in section II. The C-M diagram of M29 is presented in section III. In section IV, we estimate the photometric precision and describe the characteristics of variable stars in M29. The

Table 1. Observation Log of M29

Date (1994)	Julian Date	No. frames	Running time (hours)
Aug. 12	2449577	176	4.0
Aug. 13	2449578	188	6.0
Aug. 19	2449584	224	6.7
Aug. 30	2449595	248	5.4
Sep. 13	2449609	200	5.1
Total		1036	27.2

results are discussed and summarized in section V.

II. OBSERVATION AND DATA REDUCTION

We have carried out time-series CCD photometry of M29 for five nights from August 12 to September 13, 1994. The observing log is listed in Table 1. The observations were made with a Photometrics PM512 CCD camera and Johnson V filter, which were attached to the 61cm Ritchey-Chrétien telescope at SNUO. The CCD chip has an area of 516×516 pixels whose pixel size is 20μm. The size of the field of view in the CCD image is 8.′1 × 8.′1 (0.945 arcsec pixel^{-1}) at the f/7 Cassegrain focus of the telescope. We used the 4X gain factor of which the gain is 4.11 electrons/ADU and the readout noise is 6.2 electrons. The exposure time and the duty cycle were 30 sec and 75 sec, respectively. The photometric seeing was typically 4.″5 during the observing period. Evening twilight flat field frames were obtained for each night to flatten raw CCD frames.

The finding chart of M29 is shown at Figure 1. We monitored 178 stars in M29, dividing into four fields. The observations were performed using the *SNUCCD* program (Kim *et al.* 1993) which was revised to save the raw CCD image. To minimize external errors due to pixel-to-pixel variations noted by Frandsen *et al.* (1989), we applied the autoguide and careful adjustment (offset less than seven pixels) in order to fix the star at the same CCD image position during the observing run.

The preprocessing of CCD images was made with the IRAF/CCDRED package. Defective pixels of our CCD chip (Sung 1995) were corrected and the trimming of unreliable subsection was applied. And then, we proceeded the bias, dark and flat field corrections. The PSF (point spread function) showed variations over time and, sometimes, stellar images appeared to be elongated due to the incomplete telescope tracking. So we adopted simple aperture photometry to obtain instrumental magnitudes, using the IRAF/APPHOT package (Massey & Davis 1992). We developed the program designed for handling a number of CCD frames effectively. The reduction procedure is as follows:

(1) We derived interactively reference coordinates (X_{ref}, Y_{ref}) for all stars in reference frames (only four frames in this work), using the IRAF/IMAGES/TVMARK routine. Of course, if the coordinates were previously known in other studies, this step can be omitted.

(2) The DAOFIND routine is used to get the coordinates of some bright stars for all CCD frames.

(3) We obtained instrumental magnitudes of the bright stars, using the IRAF/APPHOT/PHOT routine and found the coordinate (x_o, y_o) of the brightest star for each CCD frame.

(4) Coordinates (x_i, y_i) of all stars within each CCD image are calculated from the coordinate difference between the brightest star and the others as follows;

$$x_i = x_o + (X_{ref,i} - X_{ref,o}), \qquad y_i = y_o + (Y_{ref,i} - Y_{ref,o}). \tag{1}$$

(5) Again, using the IRAF/APPHOT/PHOT routine, we derived instrumental magnitudes of all stars.

This procedure is very simple and useful for the less-concentrated star clusters. Its primary advantage is to avoid the mis-identification of non-stellar features (cosmic rays etc.).

We applied the classical two-star differential photometry to get standard magnitudes. Instrumental magnitudes were scaled by comparing with the comparison star (HD 229239, ID_{ours}=4) as follows;

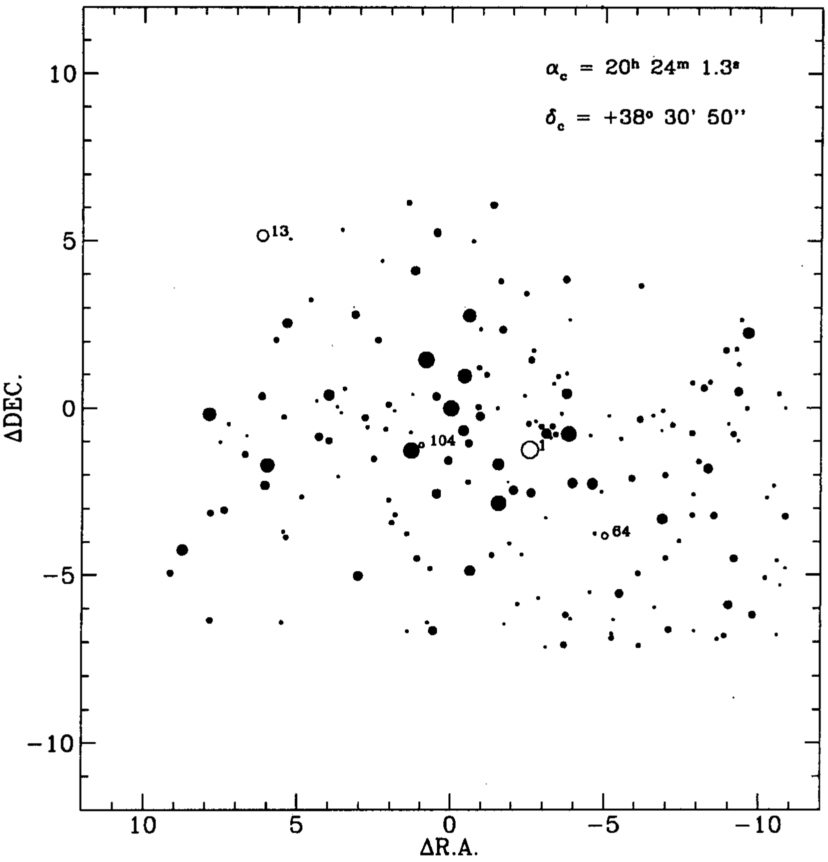

Fig. 1. Finding chart of M29. One eclipsing binary (1) and three suspected variables (13,64,104) are denoted as open circles.

$$V_i = v_i + (V_4 - v_4), \tag{2}$$

where v_i is the instrumental magnitude of the i-th star and the magnitude of the comparison star, V_4=8.927, was calculated from previously known values (Mermilliod 1986). It corresponds to the standard magnitude if the difference of the color correction term between the comparison star and the others, $\alpha_V \cdot \Delta(B-V)$, is negligible; the color coefficient, α_V, of our filter system is nearly zero (Sung 1995) and the color difference is mostly less than $0.^m5$. Our results were compared with others (Fig. 2). Two photoelectric results (Hoag *et al.* 1961 and Joshi *et al.* 1983) are similar to ours. But the CCD magnitudes of Massey *et al.* (1995b) are fainter than ours. This effect also appears in the results of Massey *et al.* (1995b) for stars fainter than V=$12.^m0$.

Total photometric data of 178 stars in M29 are listed in Table 2, including the identification numbers (ID : ours, H61 : Hoag *et al.* 1961, S73 : Sanders 1973), coordinate values ($\Delta\alpha$, $\Delta\delta$), average magnitudes V, standard deviations σ_V (see section IV) and observed numbers N.

III. C-M DIAGRAM

In their successive papers, Balona and his co-workers found several β Cephei variables in young open clusters; eleven variables in NGC3293 (Balona 1994), nine variables in NGC4755 (Balona & Koen 1994) and six variables in NGC6231 (Balona & Laney 1995). Variable stars in three open clusters showed the different distribution one from the other on the instability strip, probably due to the difference of the metal abundance (Balona & Laney 1995). Three open clusters have a well-defined instability strip, i.e., most of stars in the instability strip might turn out to be β Cephei variables. So, using the previous two observational results (Joshi *et al.* 1983 and Massey *et al.* 1995b), we investigated the C-M diagram of M29 to find which stars are located in the instability strip.

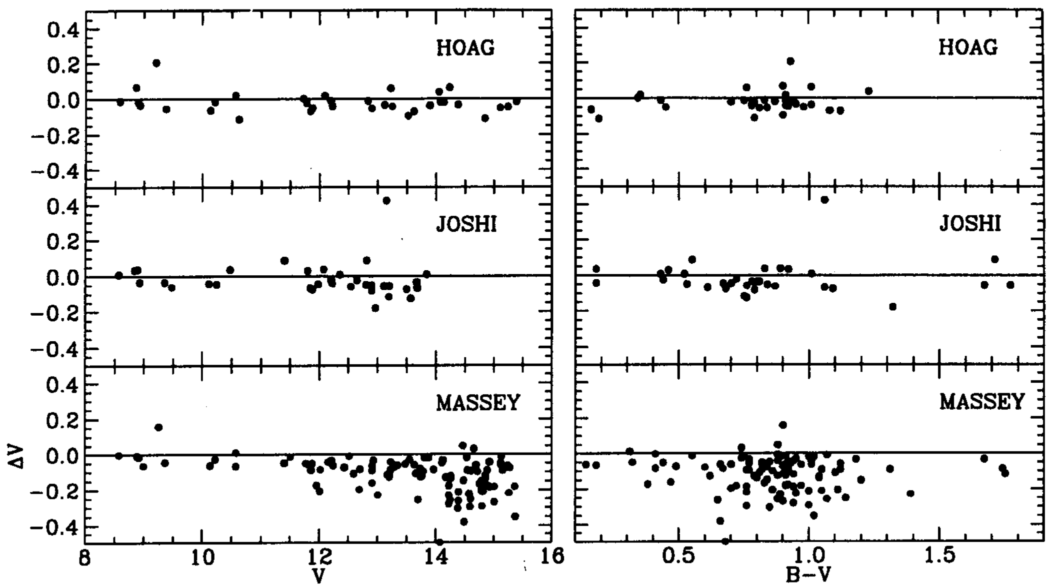

Fig. 2. Magnitude differences(ΔV) between our result and that by Hoag *et al.* (1961), Joshi *et al.* (1973), Massey *et al.* (1995b) as a function of CCD magnitude and color given by Massey *et al.* CCD magnitudes of Massey *et al.* are fainter than the others, which also appeared in their results for stars fainter than $12.^m0$.

The reddening uncorrected C-M diagram of M29 (Hoag *et al.* 1961) showed severe dispersion, indicating that there are considerable differential reddening and contamination by non-members. Joshi *et al.* (1983) had carried out the UBV photoelectric photometry for stars in M29 of which the membership probabilities computed from the proper motions (Sanders 1973) are higher than 50%. They estimated the interstellar reddening of each star in M29 by using the three different methods; spectral class, photometric color and interpolation of nearby stars. Recently, Massey *et al.* (1995b) had performed the UBV CCD photometry for 209 stars in M29. They derived the distance modulus, $(m-M)_o = 11.71$, via spectroscopy, which was much different from that by Joshi et al., $(m-M)_o = 10.85$. Crawford & Barnes (1977) noted that the distance modulus ($\sim 10.^m3$) derived from the photometry alone was much different from that ($\sim 11.^m5$) obtained from spectroscopic observation. Until now, the distance modulus of M29 remains to be uncertain.

Using their data(Joshi *et al.* 1983 and Massey *et al.* 1995b), we have studied the C-M diagram of M29. To get the dereddened color from the UBV data of Massey *et al.* we used the following procedures(Massey *et al.* 1995a) for each star;

$$\begin{array}{lll} IF & Q < -0.4, & (B-V)_o = -0.013 + 0.325Q \\ IF & Q \geq -0.4, & (B-V)_o = (B-V) - \overline{E(B-V)}, \end{array} \tag{3}$$

where the reddening-free color is defined as $Q = (U-B) - 0.72(B-V)$. The averaged reddening value of M29 is $\overline{E(B-V)}$=1.03 (Massey *et al.* 1995b). The C-M diagram of M29 is shown in Figure 3, where the solid lines are the mean main sequence tracks by Allen (1976) and the dashed lines represent the β Cephei instability strip (Sterken & Jerzykiewicz 1990). Unfortunately, we found the only 1~2 stars located in the instability strip. We investigated with caution these β Cephei variable candidates to search their variability in the following section.

IV. VARIABLE STARS IN M29

(a) Estimate of Photometric Errors

We calculated photometric errors to estimate the noise level in our observations. The intrinsic noise sources are scintillation noise and photon noise. The external noises are arisen from the atmospheric variation, the instrumental drift and the offset error (Frandsen *et al.* 1989).

Table 2. Photometric Data of M29
$\alpha(2000.0)=20^h24^m1.^s3$, $\delta(2000.0)=38°30'50''$

ID	H61	S73	$\Delta\alpha$	$\Delta\delta$	V	σ_V	N	ID	H61	S73	$\Delta\alpha$	$\Delta\delta$	V	σ_V	N
1	1	135	-2.565	-1.258	8.578	0.032	511	51			-8.217	+0.601	13.791	0.053	34
2	3	157	+0.843	+1.455	8.873	0.006	517	52		179	+6.721	-1.397	13.848	0.051	503
3	4	149	+0.007	-0.006	8.895	0.009	717	53	25		-2.618	+1.449	13.852	0.043	264
4	2	159	+1.325	-1.279	8.927	0.000	837	54			+2.827	-0.292	13.874	0.050	761
5	6	139	-1.554	-2.849	9.316	0.008	257	55			-5.885	-2.112	13.940	0.043	345
6	5	125	-3.829	-0.778	9.408	0.008	511	56			+9.144	-4.944	13.946	0.065	129
7	7	174	+6.002	-1.719	10.068	0.015	481	57			-3.697	-7.089	13.990	0.054	241
8	8	147	-0.436	+0.968	10.195	0.011	516	58			-7.083	-6.640	13.992	0.055	246
9	10	182	+7.884	-0.184	10.506	0.017	375	59			+7.841	-3.142	14.041	0.065	250
10	9		-0.589	+2.767	10.582	0.008	511	60			+1.120	-4.512	14.044	0.067	307
11			-1.545	-1.697	11.354	0.009	673	61	27		+2.065	+0.111	14.051	0.050	709
12		98	-9.646	+2.253	11.488	0.014	4	62			+7.855	-6.353	14.075	0.071	245
13	11		+6.171	+5.146	11.722	0.047	252	63	26		+2.404	+2.036	14.088	0.061	516
14	12		-4.605	-2.272	11.756	0.011	504	64			-5.019	-3.830	14.099	0.158	443
15	13	167	+3.995	+0.396	11.772	0.016	503	65	28		-6.150	-0.344	14.109	0.058	265
16			+8.756	-4.247	11.778	0.023	229	66			-7.839	-0.748	14.111	0.061	250
17		143	-0.624	-4.877	11.805	0.015	253	67			-10.857	-3.229	14.128	0.052	99
18	14	148	-0.400	-0.674	11.830	0.011	769	68			-0.889	+0.030	14.137	0.061	695
19		110	-6.882	-3.321	11.935	0.013	250	69			-3.745	-6.191	14.178	0.060	281
20	15	130	-3.097	-0.768	12.108	0.019	742	70	29		-3.304	-0.556	14.293	0.065	511
21	16	124	-3.956	-2.248	12.178	0.013	511	71			-8.929	+1.731	14.295	0.058	4
22	17	126	-3.762	+0.439	12.179	0.014	325	72			-9.177	-0.782	14.333	0.063	249
23		171	+5.360	+2.544	12.358	0.021	262	73	30		+2.533	-1.529	14.346	0.067	763
24		152	+0.492	-2.561	12.481	0.017	513	74			-3.409	-0.795	14.348	0.090	526
25			+3.036	-5.027	12.494	0.020	251	75			+1.415	+6.129	14.425	0.097	9
26			+1.204	+4.097	12.501	0.016	257	76			-6.976	-2.011	14.450	0.064	251
27		107	-8.354	-1.820	12.616	0.027	250	77			-2.938	-0.558	14.497	0.094	511
28		176	+6.072	-2.316	12.750	0.032	307	78			+5.718	+2.045	14.507	0.069	258
29		153	+0.593	-6.664	12.781	0.023	247	79			-1.608	+3.780	14.508	0.073	182
30	18	133	-2.604	-2.539	12.818	0.019	511	80			-1.159	+0.996	14.512	0.084	460
31	19	142	-0.943	-0.253	12.846	0.025	731	81			-1.331	-4.408	14.568	0.080	413
32			-2.035	-2.463	12.857	0.023	511	82			+1.954	-3.429	14.575	0.087	508
33		101	-9.332	+0.500	12.897	0.027	52	83			-6.979	-4.494	14.585	0.077	248
34		104	-9.011	-5.888	13.054	0.036	246	84			+5.383	-3.868	14.599	0.101	256
35		115	-5.493	-5.556	13.074	0.027	248	85			-6.092	-4.960	14.613	0.091	248
36	20		+0.091	-1.585	13.086	0.027	761	86			-7.202	-0.513	14.621	0.095	251
37		168	+4.321	-0.860	13.144	0.028	607	87			-2.524	-0.472	14.628	0.110	522
38			+0.488	+5.237	13.189	0.025	250	88			-0.918	+1.212	14.629	0.085	491
39	22		+0.506	+0.352	13.207	0.026	580	89			-2.438	+3.421	14.633	0.090	134
40	21		+3.145	+2.794	13.279	0.033	512	90			+5.450	-0.277	14.635	0.125	506
41	23	144	-0.571	-1.058	13.426	0.041	768	91			-5.251	-6.895	14.643	0.112	272
42		102	-9.188	-4.507	13.444	0.034	247	92			-6.171	+3.646	14.682	0.000	2
43			-1.681	+2.351	13.521	0.038	424	93			-8.883	-6.820	14.714	0.095	247
44	24		+6.175	+0.361	13.551	0.033	342	94			+0.697	-4.813	14.714	0.106	255
45			-9.794	-6.189	13.571	0.035	200	95			-0.557	-2.220	14.715	0.139	605
46		141	-1.366	+6.070	13.573	0.046	12	96			-8.052	-1.618	14.720	0.099	250
47		181	+7.393	-3.051	13.613	0.046	250	97	31		+4.873	-2.660	14.730	0.102	326
48		166	+3.994	-0.982	13.636	0.040	691	98			-7.850	-3.200	14.733	0.102	250
49			-3.742	+3.833	13.653	0.045	10	99			+2.049	-2.756	14.745	0.107	510
50			-8.550	-3.219	13.684	0.036	250	100			-7.844	+0.765	14.790	0.085	8

Notes : H61 (Hoag *et al.* 1961), S73 (Sanders 1973)

Table 2. (Continue)
$\alpha(2000.0)=20^h24^m1.^s3$, $\delta(2000.0)=38^\circ30'50''$

ID	H61	S73	$\Delta\alpha$	$\Delta\delta$	V	σ_V	N
101			+1.456	-3.769	14.818	0.137	508
102			-6.126	-7.110	14.854	0.112	236
103			+2.154	-0.632	14.876	0.108	765
104			+0.988	-1.114	14.894	0.303	689
105			-10.652	+0.435	14.940	0.137	14
106			-9.609	-0.004	15.008	0.102	200
107			+1.843	-3.197	15.012	0.121	508
108			-3.489	+0.941	15.032	0.118	263
109	32		+4.592	+3.230	15.050	0.179	298
110			-9.340	+1.326	15.059	0.040	4
111			-9.420	+2.642	15.062	0.136	3
112			-8.425	+0.786	15.107	0.040	4
113			-10.208	-5.090	15.136	0.109	160
114			-9.273	+1.769	15.155	0.206	4
115			+3.476	+0.591	15.167	0.143	549
116			-2.689	+1.725	15.168	0.134	262
117	33		-6.898	-0.084	15.185	0.165	216
118			-0.716	+4.975	15.228	0.128	252
119			-7.879	-2.585	15.247	0.141	250
120			-7.424	-3.985	15.273	0.135	249
121			+5.518	-6.420	15.275	0.145	245
122			-2.185	-5.872	15.305	0.170	248
123			+7.260	-0.477	15.316	0.173	500
124			+2.746	-0.573	15.326	0.178	764
125			-5.538	-0.925	15.332	0.146	413
126			-3.597	-0.173	15.348	0.191	483
127			-10.266	-2.681	15.349	0.149	163
128	34		-1.516	-0.006	15.365	0.153	628
129			-10.486	-2.323	15.372	0.137	156
130			+3.573	+5.316	15.403	0.157	236
131			-8.656	-6.916	15.409	0.156	242
132			-3.767	+1.030	15.432	0.181	261
133			-6.580	-0.233	15.433	0.168	244
134			-1.910	-4.056	15.437	0.189	475
135			+0.783	-6.430	15.439	0.234	240
136			-0.958	+2.369	15.444	0.191	485
137			-4.695	-3.757	15.447	0.202	482
138			-3.345	+0.739	15.467	0.180	264
139			+5.470	-3.705	15.493	0.193	247
140			+1.332	-0.728	15.516	0.205	752
141			-2.312	-4.387	15.526	0.250	407
142			-2.855	-5.688	15.529	0.173	247
143			-4.546	-0.820	15.539	0.180	490
144			-2.397	+0.376	15.548	0.179	395
145			+1.432	-6.679	15.550	0.196	245
146			-9.332	-0.981	15.556	0.189	247
147			+2.285	+4.389	15.586	0.195	255
148			-10.592	-4.568	15.588	0.187	151
149			-2.750	-0.402	15.628	0.189	481
150			-5.244	-6.758	15.634	0.190	223
151			-10.859	+0.010	15.634	0.197	108
152			-4.535	-5.520	15.646	0.194	244
153			+1.871	-0.081	15.654	0.229	713
154			+3.691	-2.054	15.655	0.234	639
155			-6.636	-5.971	15.663	0.254	239
156			-3.250	-0.898	15.666	0.205	261
157			-3.911	-6.312	15.667	0.285	201
158			-4.905	-2.506	15.668	0.209	449
159			-10.585	-6.788	15.668	0.183	147
160			+7.529	-1.025	15.679	0.231	449
161			+3.594	-0.143	15.706	0.210	722
162			-3.868	+2.643	15.717	0.241	257
163			+4.390	+0.225	15.732	0.261	407
164			-10.860	-4.797	15.736	0.179	93
165			-5.302	-6.334	15.757	0.224	240
166			+3.720	+0.036	15.782	0.216	682
167			-3.093	-7.148	15.791	0.248	217
168			-1.754	-6.463	15.816	0.217	243
169			-7.910	-6.674	15.818	0.199	238
170			-9.018	-0.471	15.819	0.251	232
171			-3.090	-3.278	15.826	0.262	477
172			+6.665	-0.835	15.834	0.233	473
173			+5.265	+5.045	15.838	0.242	245
174			-10.689	-5.297	15.868	0.227	133
175			-5.155	-0.248	15.881	0.241	405
176			-6.855	-0.667	15.942	0.252	236
177			+1.284	+0.416	16.047	0.238	473
178			-1.862	-2.217	16.302	0.248	399

The scintillation error can be estimated by adopting Young's (1967) equation;

$$\sigma_{scin} = 0.09d^{-2/3}X^{3/2}exp(-h/h_0)(\Delta t)^{-1/2}, \qquad (4)$$

where d=telescope diameter in cm, X=airmass, h=observatory altitude in meter, h_0=8000m and Δt=integration time in second. In our observations (average airmass=1.57 and altitude of SNUO=145m), the scintillation error is estimated to be about $0.^m002$.

For a star with counts of 75000e^- (typical for V=$9.^m5$ star), the photon noise (Howell 1992) is given by

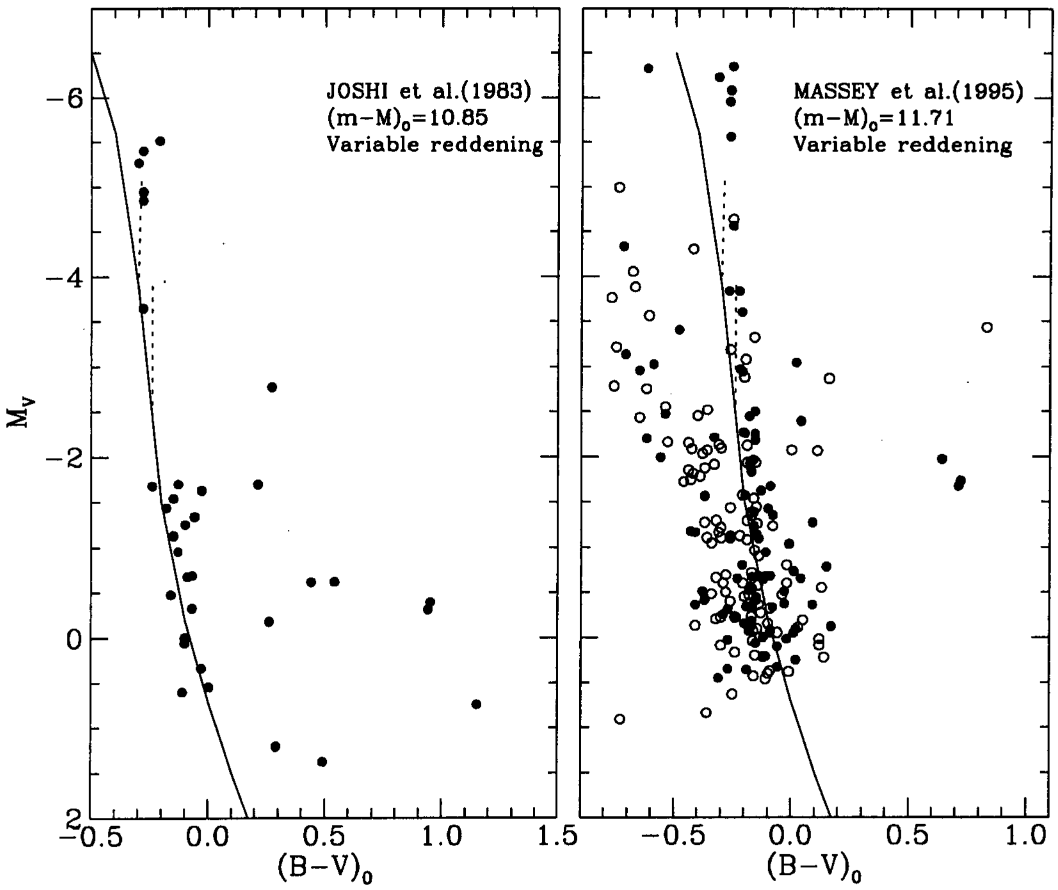

Fig. 3. C-M diagram of M29, using Joshi et al. (1973) data (*left*) and Massey et al. (1995b) data (*right*). The solid curves and dashed curves represent the mean main sequence tracks by Allen (1976) and the β Cephei instability strip, respectively. The observed stars in this study are denoted as filled circles.

$$\sigma_{photon} = \frac{1.086\sqrt{L_\star + n_{pixel}(N_{Sky} + N_{Read}^2)}}{L_\star} \simeq 0.^m004, \quad (5)$$

where n_{pixel} is the total number of pixels used in measuring aperture. Here N_{Sky} and N_{Read} are the sky level (typical 60e$^-$/pixels) and the readout noise (6.2e$^-$ in our CCD chip), respectively.

For stars in the same CCD frame, the effects of atmospheric variation are identical and so the error resulted from them becomes negligible. The noise due to the instrumental drift and the offset variations is not easily estimated. From the results of several bright stars, we found that the external noise(mostly, offset errors) is about $0.^m006$ in our observing systems. Then the total probable error is estimated to be about 7.6 mmag for $9.^m0 \sim 10.^m0$ stars.

(b) Searching Method of Variable Stars

We examined 178 stars in M29 to search their variability. Time gaps between each data points were 75sec and the durations of observation were about six hours in each night. This makes it possible to search variable stars having the short period from $0.^d02$ to $0.^d2$ (for examples, β Cephei stars and δ Scuti stars). Our data could be also used to search the long period variables such as classical Cepheids and eclipsing binaries because the observations were performed for long-time base lines(five out of 32 nights).

The magnitudes of all stars in the CCD frames were calculated by using the method of differential photometry. We have arranged the observed data (time and magnitude) for each star. Two methods were used for searching potential variable stars. First, we selected stars which has the large standard deviation as compared with the other

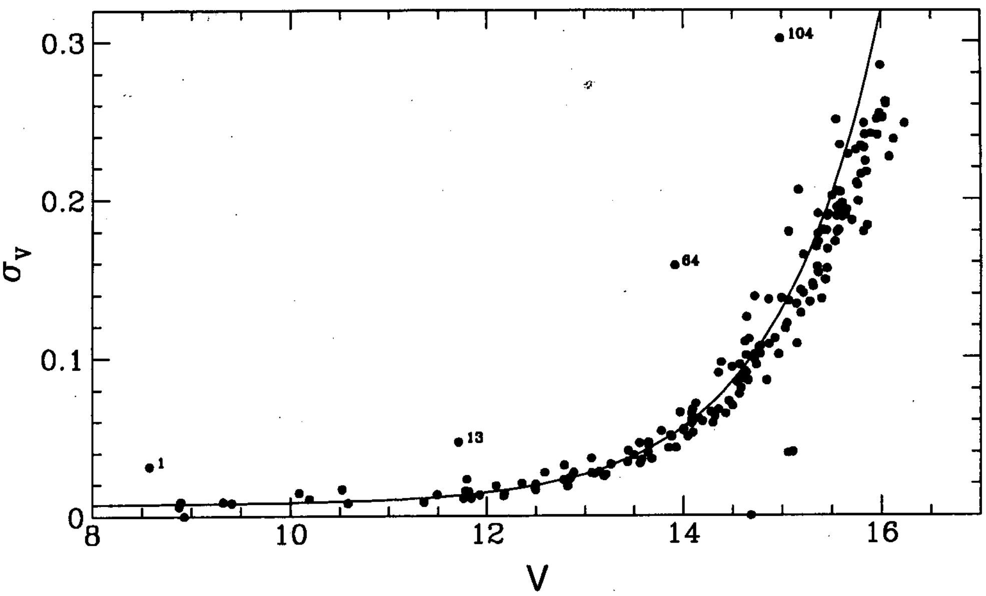

Fig. 4. Dispersion diagram for 178 stars. The solid curve represents the analytic errors, including the three error terms described in text (section IV(a)). The four stars far above the curve are selected as variable star candidates.

stars of similar magnitude. The standard deviation of each star was calculated (see Table 1) as follows;

$$\sigma_V = \sqrt{\frac{\sum_{i=0}^{N}(V_i - < V_i >)^2}{N-1}}, \tag{6}$$

where N and $< V_i >$ are the number of observation and the mean magnitude of each star, respectively. Variable stars are expected to have a large standard deviation due to their light variations. We plotted the standard deviation versus the average magnitude for each star (Fig. 4). The standard deviations of 178 stars are denoted as filled circles. The solid curve represents the analytic error estimated in the above section(a). Four stars far above the curve are considered as variable star candidates. The second method is to plot light curves to detect light variations. The light curves for eight stars, including the above four stars, three previously known variable stars and one star located in β Cephei instability strip, were shown in Figure 5. The light variation of the above four stars(ID♯1,13,64,104) were detected and the other four stars(ID♯2,5,6,8) show nearly constant brightness.

(c) Characteristics of Variable Star Candidates

The characteristics of eight variable star candidates are as follows.

ID♯1 (HD194378) : It has the high value (79%) of membership probability (Sanders 1973). But it does not locate at the normal evolution sequence in the C-M diagram, indicating that it is a evolutionary peculiar star (Joshi *et al.* 1983) or a non-member star (Crawford & Barnes 1977). From the radial-velocity measurements, it was known as a spectroscopic binary (Liu *et al.* 1989). We detected clearly its light variation for one night (HJD2449578.0). Its light curve is similar to that of Algol-type eclipsing binary (Hoffmeister *et al.* 1985). Though it is the brightest star in M29, its light variation has not been reported so far. But our observations suggest that it is a detached binary with a minimum brightness near HJD2449578.13, and an amplitude of at least $0.^m12$.

ID♯2 (HD229238), ID♯5 (HD229227) : Mermilliod (1992) referred them as spectroscopic binaries and suspected variable stars. But their photometric variabilities have not been reported. In the present study, the variation of their brightness could be hardly detected.

ID♯6 (HD229221) : It is only one star in M29 that is included in the GCVS (General Catalogue of Variable stars ; Kholopov *et al.* 1988), named as V1322 Cyg. It is known as a γ Cas type star, eruptive irregular variable. Its brightness is changed from $8.^m77$ to $9.^m70$. During our observing runs, its light curves show nearly to be flat with time, indicating that it did not experience the eruption phenomenon in the relevant period.

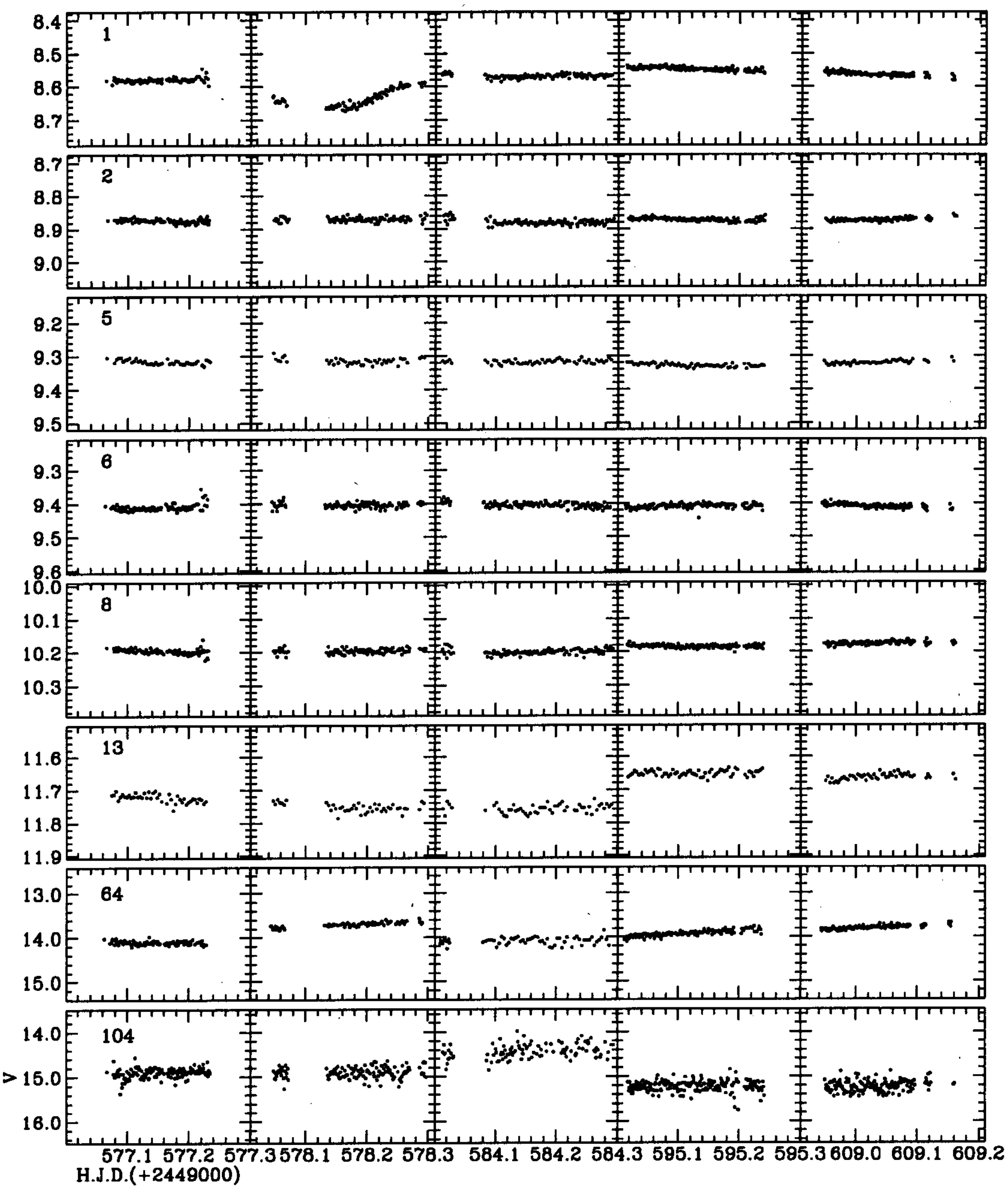

Fig. 5. Light curves of eight variable star candidates, four newly discovered variables (1,13,64,103) and three previously known variables (2,5,6) and one star (8) located in β Cephei instability strip.

ID♯8 (BD 38°4067) : In the C-M diagram of M29 (see Figure 3, *left*), we found one β Cephei variable candidate ID♯8. It is located within the instability strip and near the mean main sequence track. To search its light variation, we investigated the light curves in detail. However, we could not detect any sinusoidal variations of short periods (2-5 hours). It may be a non-variable star, although it is located within the instability strip.

ID♯13, ID♯64, ID♯104 : The variability of these stars was detected in the dispersion diagram (Figure 4). However, the high dispersion for ID♯104 might be arisen from the light contamination of the nearest bright star (ID♯4) for the third night with the poorest seeing condition. The former two stars may be newly discovered variable stars with long-periods (~days). ID♯13 is a non-member star of M29; its membership probability is only 5% (Sanders 1973). The photometric colors and spectral classification of ID♯64 have not been known yet. Their period could not be estimated because of our limited data sets. So at the present, it is not able to deduce the proper location in the C-M diagram and the variable type of these stars.

IV. SUMMARY AND DISCUSSION

We have carried out the time-series CCD photometry for 178 stars in the young open cluster M29 to search variable stars having periods of a few hours ~ a few days. The photometric precision of our observation systems was derived. From the dispersion diagram and the light curves, three variable star candidates were newly discovered. The main results obtained in this study are summarized as follows.

(1) The photometric precision for $9.^m0 \sim 10.^m0$ stars in M29 was estimated to be about 7.6 mmag. This high precision could be attained through the time-series CCD photometry even though a small telescope was used. The error is low enough to detect the light variations of variable stars such as β Cephei stars, 53 Per stars (Balona 1990) and eclipsing binaries etc.

(2) The bightest star (HD194378) in M29 was found to be an eclipsing binary. The epoch of a minimum brightness is near HJD2449578.13 and the brightness change is about at least $0.^m12$.

(3) Two variable star candidates(ID♯13 and ID♯64) were newly discovered. Unfortunately, we could not estimate the period and deduce the variable type of these stars because of our limited data sets.

(4) A variable, V1322 Cyg, which is known as a γ Cas type (eruptive irregular) variable in GCVS (Kholopov *et al.* 1988), did not show the light variation during our observing run, indicating that it was at the steady phase without the eruption phenomenon in the relevant period.

(5) A β Cephei variable candidate (BD 38^o4067), which is located in the instability strip, showed the constant brightness. And two suspected variable stars referred by Mermilliod (1992) did not show any change in brightness.

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