Variable Stars in the Open Cluster NGC 2099 (M37)

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ABSTRACT
Time-series CCD photometric observations of the intermediate-age open cluster NGC 2099 were performed to search for variable stars. We also carried out $BV$ photometry to study physical properties of variables in the cluster. Using $V$-band time-series data, we carefully examined light variations of about 12,000 stars in the range of $10 < V < 22$ mag. A total of 24 variable stars have been identified; seven stars are previously known variables and 17 stars are newly identified. On the basis of observational properties such as light curve shape, period, and amplitude, we classified the new variable stars as nine $\delta$ Scuti-type pulsating stars, seven eclipsing binaries, and one peculiar variable star. Judging from the position of $\delta$ Scuti-type stars in the color-magnitude diagram, only two stars are likely to have the cluster membership. One new variable KV10 shows peculiar light variations with a $\delta$ Scuti-type short period of about 0.044 day as well as a long period of 0.417 day.

Subject headings: open clusters and associations: individual (NGC 2099) — $\delta$ Scuti — binaries: eclipsing

1. Introduction

Pulsating variable stars provide an ideal and important test bed for investigating the internal structure and evolution of stars; so-called asteroseismology. Open clusters have many benefits to investigate physical characteristics of Population I pulsating variables. Variable stars in a cluster can be restricted to their physical parameters by analysing the cluster with the same age, chemical abundance, distance, and interstellar reddening. Simultaneous photometry of hundreds of stars (both constant and variable) in a single CCD frame enables us to obtain accurate and effective time-series data. Furthermore, we can obtain high-precision photometric data for low-amplitude variables in open clusters since the crowding effect is not severe compared to the case of globular clusters. Consequently, the observations of open clusters are obviously important for the investigation on physical properties of small-amplitude variables such as $\delta$ Scuti-type pulsating stars (Kim et al. 2001). The open clusters with specific age range (e.g., intermediate-age of about 0.3 $\sim$ 1.0 Gyr) and at a reasonable distance of about 1 $\sim$ 2 kpc, are the best observing target for the asteroseismological study of $\delta$ Scuti-type stars (Viskum et al. 1997). Physical properties of $\delta$ Scuti-type stars in open clusters are reviewed in detail by Rodríguez & Breger (2001).

$\delta$ Scuti-type pulsating stars are main sequence or subgiant stars in lower part of the classical Cepheid instability strip with spectral types between A3 and F0. They have short pulsation periods of 0.02 $\sim$ 0.25 day (Breger 2000). Generally, high amplitude $\delta$ Scuti-type
stars with visual amplitude greater than 0.3 mag rotate slowly with \( v \sin i \) less than 30 km s\(^{-1}\) and appear to be excited in single or double radial pulsating modes (Breger 2000). However, most \( \delta \) Scuti-type stars have small amplitudes less than 0.1 mag and rotate fast with the average speed of about 150 km s\(^{-1}\). Their light curves are very complicated to indicate the overlap of multiple pulsating periods; e.g. Breger et al. (2005) detected 79 frequencies for FG Vir. These multi-periodic \( \delta \) Scuti-type stars excited in radial and non-radial modes are very important for asteroseismological tests on stellar structure and evolutionary models. Goupil et al. (1996) suggested that multi-periodic \( \delta \) Scuti-type stars near the zero-age main sequence are particularly suitable for determining the extent of the convective core and internal rotation rate. Asteroseismology on \( \delta \) Scuti-type stars, however, has produced very few convincing results until now. Main reason for the lack of success is probably that the stars often rotate very fast to result in severe complexity of observing frequencies by rotational splitting of non-radial modes. The asteroseismological importance of observations for \( \delta \) Scuti-type stars in open clusters was well described by Kjeldsen (2000).

As our long term project for the survey of variable stars in open clusters, extensive time-series CCD observations have been performing for intermediate-age open clusters using an 1.0 m telescope at Mt. Lemmon Optical Astronomy Observatory (LOAO) in Arizona, USA. The primary goal of this project is to search for short-period (less than a few days) pulsating variables such as \( \delta \) Scuti-type and \( \gamma \) Doradus-type stars. It is also intriguing to examine possible relevance of characteristics of pulsating stars to the cluster parameters.

In this paper, we present results of time-series CCD photometry for NGC 2099 (\( \alpha_{\text{2000}} = 05^h52^m18.3^s, \delta_{\text{2000}} = +32^\circ33'10''.8 \)). The age of NGC 2099 about 400 Myr is relatively well-established putting the object among the intermediate-age open clusters from previous studies (see Kalirai et al. 2001; Nilakshi & Sagar 2002, and references therein). It is a relatively rich and large cluster located at the low galactic latitude (\( b = 3\circ1 \)). Kalirai et al. (2001) and Nilakshi & Sagar (2002) carried out deep CCD observations and obtained color-magnitude diagrams (CMDs) with well-defined main-sequence. However, there have been few systematic time-series observations for a large and representative sample of NGC 2099 so far. Kiss et al. (2001) discovered only seven variables from their CCD observations.

In Section 2, we present our observations and data analysis. Section 3 describes physical properties of pulsating variables and binary stars detected from our observations. The details of a peculiar variable KV10 with complex light variations are reported in Section 4. We discuss the cluster membership of the variable stars in Section 5. A brief summary and conclusions are given in Section 6.
2. Observations and data reductions

Time-series observations of NGC 2099 were carried out on 12 nights in 2004 January, using a 2K CCD camera attached to the LOAO 1.0 m telescope in Arizona, USA. The Korea Astronomy and Space Science Institute (KASI) has been operating the telescope by remote control from Korea via a network connection. The field of view of a CCD image is about $22.2 \times 22.2 \text{arcmin}^2$ at the f/7.5 Cassegrain focus of the telescope. Total 581 images were obtained in the $V$ filter with 600 sec exposure time. Additional observations were performed for three nights in 2006 February in order to secure bright $\delta$ Scuti-type stars which are mostly saturated in long-exposure images. From this observing run, we obtained 639 images in the $V$ filter with 10 sec exposure time. In order to minimize position-dependent external errors (Frandsen et al. 1989), we carefully controlled the telescope so that a star can be located at the same position in all CCD frames during our observing run. In order to construct the CMD of NGC 2099, $BV$ photometric observations were also made for two nights in 2004 October and one night in 2006 February. Typical seeing (FWHM) was about 2.2 arcsec. Figure 1 shows an observing field of the NGC 2099.

Instrumental signatures of each frame were removed and calibrated using the bias, dark, and flat field frames, with aid of the IRAF/CCDRED package. We obtained instrumental magnitudes of stars from the empirical point spread function (PSF) fitting method in the IRAF/DAOPHOT package (Massey & Davis 1992).

Since we did not make observations for standard stars, we have tied our data to the $BV$ CCD photometric secondary standards in NGC 2099 from the data of Kalirai et al. (2001). We compared our CCD photometry with the data from Kalirai et al. (2001). Our $B$ & $V$ magnitudes are in good agreement with those of Kalirai et al. (2001): $\Delta V = -0.022$ and $\Delta B = -0.032$.

In order to normalize instrumental magnitudes of our time-series $V$ frames, we applied an ensemble normalization technique (Gilliland & Brown 1988). We selected a few tens of bright and unsaturated normalization stars with $15 < V < 17$ mag, which are non-variable stars and are not located at the edge of CCD frame. Coefficients of the following equations are calculated for each CCD frame:

$$B = b + a_1 + a_2(B - V) + a_3X + a_4Y,$$

$$V = v + c_1 + c_2(B - V) + c_3X + c_4Y,$$

where $B$ & $V$ are standard magnitudes and $b$ & $v$ are instrumental magnitudes of time-series images for normalization stars respectively. $X$ and $Y$ are coordinates of the normalization
stars in a CCD frame. Using the above equations, we normalized all stars for each CCD frame. With this technique, we corrected color \((a_2, c_2)\) and position \((a_3, c_3\) and \(a_4, c_4)\) dependent variations of the observation system and/or atmospheric differential extinction for all time-series CCD frames (Kim et al. 2001).

3. Physical properties of variable stars

We examined light variations of about 12,000 stars by visual inspection. Excluding saturated stars brighter than \(V = 13\) and 10 mag in the long and short exposure images, respectively, we identified 24 variable stars in the observing field. Among these, 17 (KV1 - KV17) variables were newly discovered by our observations. A finding chart of variable stars is shown in Figure 1. Basic properties including mean magnitude \(<V>\), mean color \(<B-V>\), and variable types of variable stars are presented in Table 1.

We derived the periods of variable stars using the discrete Fourier analysis (Scargle 1989; Kim et al. 2001). Especially, for all stars in the \(\delta\) Scti instability strip, we investigated the signal to noise amplitude ratio (S/N) of a frequency with the biggest power in a power spectrum of each star, in order to search for variability. The S/N ratio greater than 4.0 (Breger et al. 1993) has been used as a detection criterion of pulsating frequencies; for example, analysis of the \(\delta\) Scti-type star 57 Tau by Paparó et al. (2000).

3.1. Previously known variable stars

Kiss et al. (2001) discovered seven (V1 - V7) variable stars in the field of NGC 2099 through the time-series measurements with \(R_C\) filter. Table 2 compares the basic properties of variables obtained from our data with those of Kiss et al. (2001). They suggested that two (V1 and V2) stars are long period eclipsing binary candidates without any definite period determinations. Three (V3, V4, and V7) of them were considered to be W UMa-type eclipsing binaries. The other two (V5 and V6) stars were suggested to be high-amplitude \(\delta\) Scti-type stars.

From the detection of only one deep minimum in their light curves of V1 and V2, Kiss et al. (2001) classified these stars as long period binaries. However, we could not determine period and epoch of minimum, since most of their observations showed no significant light variation. As shown in the upper panels of Figure 2, any distinct feature of light variations of V1 and V2 were not found. Due to our limited data points obtained from short observing run (\(\sim 10\) hours), we failed to detect any fading and to confirm the characteristics
of these two stars. More time-series observations with long observing run should be made in order to clarify the properties of these stars.

Lower panels of Figure 2 show the overall shape of our phase diagrams for other five variables which are in good agreements with those of Kiss et al. (2001). Especially, we could determine more accurate periods and epochs for all variables since we have much more data points which fully cover the phase diagrams. The light curves of V3, V4, and V7 show typical shapes of W UMa-type binary. Especially, our data for V7 show remarkably clear and complete light curve compared to the previous one of Kiss et al. (2001), which allows us to verify this star as a typical W UMa-type binary. We confirmed that V3 and V4 show slightly different brightness of maxima between the orbital phases of 0.25 and of 0.75, which gives us a hint for the existence of spots on the stellar surface (Wilson 1994).

Kiss et al. (2001) suggested that V5 might be high-amplitude δ Scuti-type star or field RRc-type star. However, our light curve shows that V5 has a typical shape of RRc-type star rather than that of high amplitude δ Scuti-type star. Our light curves of V6 together with Kiss et al. (2001) definitely show a characteristic of high-amplitude δ Scuti-type star. We applied the multi-frequency analysis (Kim & Lee 1996) to the data of V5 and V6. V5 does not show any significant peak on the frequency spectra after prewhitening the main frequency of $f_1 = 3.588$ c/d (cycles per day). For the variable V6, we found two frequencies of $f_1 = 9.104$ c/d with amplitude of $A_1 = 204.2 \pm 1.4$ mmag (S/N = 37.2) and $f_2 = 15.016$ c/d with amplitude of $A_2 = 32.7 \pm 1.4$ mmag (S/N = 14.1). The frequency ratio of $f_1/f_2 = 0.606$ is very similar to that of theoretical radial modes $P_2/P_0 = 0.616$ (Breger 1979), indicating that $f_1$ is a fundamental radial mode (F-mode; $P_0$) and $f_2$ is a 2nd overtone radial mode (2H-mode; $P_2$). These indicate that V6 is a high amplitude δ Scuti-type star with double radial modes of $P_0$ and $P_2$. The larger dispersion shown in the phase diagram of V6 is caused by the double-mode nature of pulsation.

### 3.2. New pulsating variable stars

Among 17 new variable stars discovered by our observations, nine stars are identified as pulsating variables with characteristics of δ Scuti-type star (see Table 1 for identification). In Table 3, we list the pulsating frequencies of new variable stars derived from the multiple frequency analysis (Kim & Lee 1996). Their power spectra are shown in Figures 3 and 4. Light variations and phase diagrams of nine δ Scuti-type stars are shown in Figures 5 and 6. The solid lines in Figure 5 represent synthetic curves computed from our multiple frequency analysis.
The data of KV1 and KV2 are obtained from only short exposure observations due to their saturation in long exposure images. They have only one and two frequencies, respectively, with small amplitudes. Although we have short time span of the short exposure observations for these stars, we suggest that they are δ Scuti-type star (KV1) and δ Scuti-type star candidate (KV2). Five (KV3, KV4, KV5, KV6, and KV8) variable stars have more than three frequencies. They show frequencies in the range of 7.937 c/d $\sim$ 16.478 c/d which are typical values for the δ Scuti-type stars. They have closely-separated frequencies (frequency ratio around 1.0: $f_2/f_3 = 0.948$ for KV3, $f_1/f_4 = 1.037$ for KV4, $f_1/f_3 = 0.979$ for KV5, $f_1/f_2 = 0.959$ for KV6, and $f_1/f_2 = 0.971$ for KV8), which indicate the excitation of non-radial modes (Breger 1979). In the case of KV7, we detected only one frequency of $f_1 = 24.308$ c/d with large power, which is the typical frequency for the δ Scuti-type stars. Although KV9 shows some scatter on the phase diagram, we detected one dominant frequency of $f_1 = 13.020$ c/d with large S/N ratio of 8.0. Thus we suggest that KV9 is a δ Scuti-type star candidate.

3.3. New eclipsing binaries

We discovered seven new eclipsing binaries, which show clear characteristics of W UMa-type binary except for KV12 (see Table 1 for the identification). In Figure 7, we show the phase diagrams for these newly discovered eclipsing binaries. We determined their orbital periods using the phase-match technique (Hoffmeister et al. 1985). KV11 shows the shallow secondary maximum (around orbital phase 0.75) and a hump just after the secondary eclipse, which is possibly due to the existence of surface inhomogeneity, i.e. effect of the spot. Although definite type of KV12 is ambiguous due to its incomplete light curve, it also appears to be an eclipsing binary. KV13 and KV15 show the most clear and typical W UMa-type light curves, with slightly different brightness of maxima probably due to the existence of a spot on the stellar surface. Although there are some scatters over the whole phase of light curves of KV14, KV16, and KV17, they also appear to be W UMa-type binaries. In Table 4, we summarize light curve parameters (period, epoch of minimum, and amplitude) of these eclipsing binaries.

4. Peculiar light variations of KV10

Among the new variable stars discovered from our observations, KV10 is the most interesting object with complex light variations. From our multiple frequency analysis (Kim & Lee 1996), we found that KV10 has two frequencies with similar amplitudes: $f_1$
= 22.796 c/d (high) with 32.9 mmag and \( f_2 = 2.396 \) c/d (low) with 24.2 mmag. Figure 8 displays the complex light variations of KV10. Upper panel shows original light variations. Lower panels are phase diagrams of residuals obtained from the subtraction of \( f_1 \) to the data, assuming two different periods of \( 1/f_2 = 0.417 \) day or two times of it.

There might be two possible interpretations for these peculiar light variations of KV10. First, KV10 can be a hybrid pulsator to be excited in both \( \gamma \) Doradus-type g-mode with a period of 0.417 day and \( \delta \) Scuti-type p-mode with a period of 0.044 day. This kind of hybrid pulsation has been known for two stars of HD 8801 (Henry & Fekel 2005) and HD 209295 (Handler et al. 2002). Second, KV10 may be a binary system with an orbital period of 0.835 day with ellipsoidal variations and one of the components in this binary system is a \( \delta \) Scuti-type pulsator. If the binary system has a semi-detached configuration, one of the components fills its Roche lobe and then makes ellipsoidal variations with its rotation. For example, from the photometric and spectroscopic observations of a triple system HD 207651, Henry et al. (2004) found two frequencies of 15.45 c/d resulted from \( \delta \) Scuti-type pulsation and 1.36 c/d from ellipsoidal variation. On the other hand, a few tens of \( \delta \) Scuti-type pulsating components in semi-detached eclipsing binary systems have been discovered (see the recent catalogue by Soydugan et al. 2006, and references therein).

Judging from the available near-infrared color indices from the 2MASS data (from the SIMBAD\(^1\)), \((J - H) = 0.448 \pm 0.135\) and \((J - K) = 0.451 \pm 0.157\), KV10 seems to be late G or early K type star (see Bessell & Brett 1988, Table II). This indicates that KV10 may not be an example of hybrid pulsator with A - F spectral type exhibiting both \( \delta \) Scuti-type and \( \gamma \) Doradus-type pulsations. Therefore, we prefer the second interpretation, i.e. KV10 is a semi-detached binary system with an orbital period of 0.835 day whose primary component is a \( \delta \) Scuti-type pulsator and secondary one is a late-type giant to fill its Roche lobe inducing ellipsoidal variations.

5. Cluster membership of the variable stars

The observed CMD of NGC 2099 is shown in Figure 9. The thick and thin solid lines represent adopted empirical zero-age main sequence (ZAMS) from Sung & Bessell (1999) and theoretical isochrone with \( \log t = 8.65 \) and \( Z = 0.019 \) (Girardi et al. 2000), respectively. The best fit of the ZAMS and isochrone to the observed CMD gives the interstellar reddening of \( E(B - V) = 0.21\) and the distance modulus of \( (V - M_V)_0 = 11.4\). These values are in good agreements with the previous results by Kalirai et al. (2001); \( E(B - V) = 0.21\) and

\(^1\)The SIMBAD database, operate at CDS, Strasbourg, France
\[(V - M_V)_0 = 11.55.\]

In Figure 9, we show the position of 24 variable stars. Among 224 stars within the \(\delta\) Scuti instability strip, only two (KV1 and KV2) \(\delta\) Scuti-type stars are detected. These two \(\delta\) Scuti-type stars have the lowest amplitudes of about \(\Delta V \sim 0.02\) mag among our newly discovered variables. The membership probability of KV1 based on the proper motion data by Zhao & Tian (1985) indicates 0.90, which confirms KV1 as a possible member star in the cluster. Assuming that most of the stars in the instability strip are cluster members, the fraction of variable stars in the instability strip is less than 1%. This incidence of variable stars in NGC 2099 is much lower than the case of field stars with about 30\% (Breger 1979; Wolff 1983) and of some open clusters comparable to that of field stars (Horan 1979; Frandsen et al. 1996). On the other hand, the low incidence of \(\delta\) Scuti-type stars in NGC 2099 is in line with the cases of other many open clusters (see Viskum et al. 1997). We should note that our detection of variable stars near the \(\delta\) Scuti instability strip are relied on the short exposure time data set with short time span, which are not enough to detect all multi-periodic small-amplitude \(\delta\) Scuti-type stars in this cluster.

Besides the KV1 and KV2, the other eight \(\delta\) Scuti-type stars are deviated from the location of instability strip. They are fainter than the stars in the instability strip, indicating that they are not likely to be member stars in this cluster. According to their locations on the CMD, one peculiar variable KV10 and one RRc-type star V5 also are much less likely the member stars. Based on the analysis of empirical period-luminosity relation, Kiss et al. (2001) also suggested that V5 and V6 are too faint to be bona-fide cluster member stars.

As for the membership of eclipsing binary stars, we only consider three (V1, V2, and V4) binaries as possible members of the cluster, since they are brighter (< 1 mag) than the main sequence for a given color, i.e. within the binary sequence. Another binaries fainter than the main-sequence should be field objects. However, two (KV12 and KV14) stars, which are slightly fainter than the main-sequence, can be marginal member stars considering their magnitude and color errors.

6. Conclusions

In the present study, we discovered nine \(\delta\) Scuti-type stars, seven eclipsing binaries, and one peculiar variable in the field of open cluster NGC 2099. We also confirmed the identifications of five previously known variables by Kiss et al. (2001). While a number of stars are found in the \(\delta\) Scuti instability strip of this cluster, we only detected two small amplitude \(\delta\) Scuti-type stars. The other eight \(\delta\) Scuti-type stars might be projected field
stars, according to their locations in the CMD deviated to the δ Scuti instability strip. This is supported by the serious field star contamination due to the proximity of this cluster to the Galactic plane. Among seven newly discovered eclipsing binaries in our observations, six stars are W UMa-type binaries while one binary star is not clearly classified due to its incomplete phase diagram.

KV10 shows peculiar light variations of δ Scuti-type short-periodic component combined with another long-periodic ones. The long-periodic variations can be interpreted by γ Doradus-type pulsations or ellipsoidal variations. Because the former interpretation could not match with the infrared color indices of KV10, we prefer the possibility of ellipsoidal variations. Further spectroscopic or more precise multi-band photometric observations are needed to define physical characteristics of this interesting object.

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Fig. 1.— Observed CCD field (22.2 × 22.2 arcmin²) of the open cluster NGC 2099. Identification of variable stars are also marked. North is up and east is to the left.
Fig. 2.— (Upper panels) Light variations of V1 and V2. We could not detect any fading for these two Algol-type eclipsing binaries discovered by Kiss et al. (2001). (Lower panels) Phase diagrams of five (V3 - V7) variables. Open circles and triangles are our V band data and $R_C$ band data of Kiss et al. (2001), respectively.
Fig. 3.— Power spectra of δ Scuti-type stars KV1 and KV2. A window spectrum is shown in the top panel.
Fig. 4.— Power spectra of five (KV3 - KV6, and KV8) δ Scuti-type stars. Window spectra are shown in the top left.
Fig. 5.— Light variations of five (KV3 - KV6, and KV8) δ Scuti-type stars discovered from our observations. Synthetic curves computed from our multiple frequency analysis are also superimposed.
Fig. 6.— Phase diagrams for two (KV1 and KV7) δ Scuti-type stars and two (KV2 and KV9) δ Scuti-type candidates. Large scatters of KV2 might be originated from double frequencies as shown in Figure 3.
Fig. 7.— Phase diagrams of newly discovered seven (KV11 - KV17) eclipsing binary stars.
Fig. 8.— Light variations of the peculiar variable KV10. (Upper panel) Original time-series data. The solid line is synthetic curve computed from our multiple frequency analysis with $f_1 = 22.796$ c/d and $f_2 = 2.396$ c/d. (Lower panels) Residuals obtained from the subtraction of $f_1$ to the data. We present two different-type light variations by assuming different periods, i.e. ellipsoidal variations with period of 0.835 day (left lower panel) and pulsating variable with a period of 0.417 day (right lower panel).
Fig. 9.— Positions of 24 variable stars in the color-magnitude diagram of NGC 2099. Different symbols indicate different type of variables; filled circles for δ Scuti-type pulsating stars, filled triangles for eclipsing binaries, asterisk for peculiar variable KV10, and filled square for V5 as RRc-type star. The thick and thin solid lines represent the adopted empirical zero-age main sequence from Sung & Bessell (1999) and theoretical isochrone from Girardi et al. (2000), respectively. Solid bars, nearly perpendicular to the ZAMS, represent δ Scuti instability strip (Breger 1979).
Table 1. Observational summary of 24 variable stars in the field of NGC 2099.

| Star ID | RA.(J2000) | DEC.(J2000) | $<V>$ | $<B-V>$ | Type                  |
|---------|------------|-------------|-------|---------|-----------------------|
| V1      | 05:52:20.354 | +32:33:20.42 | 13.406 | 0.609   | EA candidate          |
| V2      | 05:52:16.540 | +32:28:15.65 | 14.653 | 0.688   | EA candidate          |
| V3      | 05:52:33.022 | +32:32:41.79 | 16.019 | 0.514   | EW                    |
| V4      | 05:52:53.272 | +32:33:01.33 | 15.946 | 0.851   | EW                    |
| V5      | 05:53:00.644 | +32:24:50.59 | 16.086 | 0.811   | RRc                   |
| V6      | 05:51:50.527 | +32:32:34.81 | 16.177 | 0.691   | $\delta$ Scuti       |
| V7      | 05:52:39.100 | +32:36:31.13 | 17.623 | 0.780   | EW                    |
| KV1     | 05:52:34.319 | +32:32:18.74 | 12.498 | 0.427   | $\delta$ Scuti       |
| KV2     | 05:52:14.906 | +32:24:40.96 | 13.298 | 0.370   | $\delta$ Scuti candidate |
| KV3     | 05:52:00.494 | +32:36:48.21 | 14.762 | 0.531   | $\delta$ Scuti       |
| KV4     | 05:53:10.442 | +32:33:47.30 | 15.419 | 0.390   | $\delta$ Scuti       |
| KV5     | 05:52:03.382 | +32:35:13.72 | 16.039 | 0.699   | $\delta$ Scuti       |
| KV6     | 05:52:44.697 | +32:30:16.52 | 16.762 | 0.368   | $\delta$ Scuti       |
| KV7     | 05:52:07.883 | +32:26:38.87 | 16.780 | 0.490   | $\delta$ Scuti       |
| KV8     | 05:52:11.171 | +32:25:15.81 | 17.074 | 0.700   | $\delta$ Scuti       |
| KV9     | 05:53:07.445 | +32:30:58.36 | 17.865 | 0.807   | $\delta$ Scuti candidate |
| KV10    | 05:52:43.518 | +32:34:30.33 | 17.325 | 0.743   | $\delta$ Scuti+ellipsoid? |
| KV11    | 05:52:10.999 | +32:41:45.20 | 14.561 | 0.450   | EW                    |
| KV12    | 05:51:29.340 | +32:24:18.06 | 16.406 | 0.824   | E                     |
| KV13    | 05:52:47.297 | +32:39:35.49 | 17.648 | 0.813   | EW                    |
| KV14    | 05:52:40.708 | +32:24:24.35 | 18.053 | 1.078   | EW                    |
| KV15    | 05:53:03.506 | +32:32:14.05 | 18.540 | 0.910   | EW                    |
| KV16    | 05:52:43.889 | +32:28:52.22 | 20.433 | 0.865   | EW                    |
| KV17    | 05:51:34.433 | +32:29:06.06 | 20.751 | 0.630   | EW                    |

Note. — Star IDs of V are for the variables discovered by Kiss et al. (2001) and those of KV are for the newly discovered variables by our observations.
Table 2. Variable stars identified by Kiss et al. (2001).

| Star ID | ΔV (mag) | Period (d) | Epoch (H.J.D) | ΔR_c (mag) | Period (d) | Epoch (H.J.D) |
|---------|----------|------------|---------------|------------|------------|---------------|
| V1      | …        | …          | …             | 0.24       | …          | …             |
| V2      | …        | …          | …             | 0.23       | …          | 2451540.5180  |
| V3      | 0.33     | 0.4224     | 2453014.660   | 0.31       | 0.4224     | 2451575.5083  |
| V4      | 0.32     | 0.5582     | 2453014.665   | 0.33       | 0.5585     | 2451576.7260† |
| V5      | 0.42     | 0.2787     | 2453014.634   | 0.32       | 0.2800     | 2451576.5000  |
| V6      | 0.52     | 0.1098     | 2453014.787   | 0.45       | 0.1098     | 2451540.5367  |
| V7      | 0.49     | 0.3578     | 2453014.792   | 0.55       | 0.3579     | 2451574.2620  |

†Epoch shifted +0.5 phase from Kiss et al. (2001)'s result which made a mis-identification of primary minimum due to the incomplete phase diagram.
Table 3. Results of multiple frequency analysis for new pulsating variable stars.

| Star ID | Frequency (c/d) | $A_j^\dagger$ (mmag) | $\Phi_j^\dagger$ | S/N$^\dagger$ |
|---------|----------------|----------------------|-----------------|-------------|
| KV1     | $f_1 = 8.368$  | 11.3±.6              | 3.14±.06        | 8.5         |
|         | $f_2 = 10.478$ | 7.7±.7               | −1.03±.10       | 6.2         |
| KV2     | $f_1 = 11.006$ | 4.5±.7               | 2.10±.16        | 4.9         |
| KV3     | $f_1 = 12.750$ | 16.1±.6              | −0.33±.03       | 9.1         |
|         | $f_2 = 10.261$ | 10.9±.6              | −1.17±.05       | 8.8         |
|         | $f_3 = 10.824$ | 10.3±.6              | 2.19±.06        | 9.7         |
|         | $f_4 = 7.937$  | 6.6±.6               | 1.21±.09        | 7.6         |
|         | $f_5 = 9.580$  | 4.7±.6               | −0.95±.13       | 4.9         |
| KV4     | $f_1 = 8.426$  | 52.1±.5              | 0.54±.01        | 34.2        |
|         | $f_2 (= 2f_4) = 16.261$ | 12.0±.5 | 4.70±.04 | 11.2        |
|         | $f_3 (\sim f_1 + f_4) = 16.478$ | 8.3±.5 | −0.76±.06 | 7.7         |
|         | $f_4 = 8.129$  | 4.4±.5               | 0.05±.11        | 4.8         |
|         | $f_5 = 13.572$ | 3.9±.5               | 3.93±.12        | 4.3         |
|         | $f_6 = 15.856$ | 4.1±.5               | 2.81±.12        | 4.9         |
| KV5     | $f_1 = 12.719$ | 10.9±.5              | 0.32±.05        | 8.5         |
|         | $f_2 = 7.889$  | 9.6±.5               | 4.59±.05        | 7.7         |
|         | $f_3 = 12.991$ | 8.1±.5               | 2.31±.06        | 8.6         |
|         | $f_4 = 14.450$ | 5.1±.5               | −0.02±.10       | 6.2         |
|         | $f_5 = 11.018$ | 4.2±.5               | 1.59±.12        | 5.4         |
|         | $f_6 = 9.511$  | 3.3±.5               | 0.98±.15        | 4.2         |
| KV6     | $f_1 = 10.037$ | 15.0±.6              | 3.05±.04        | 11.8        |
|         | $f_2 = 10.470$ | 8.7±.6               | −0.79±.06       | 8.2         |
|         | $f_3 = 17.138$ | 5.2±.6               | 4.68±.11        | 5.8         |
|         | $f_4 = 14.034$ | 5.0±.6               | 1.69±.11        | 5.7         |
| KV7     | $f_1 = 24.308$ | 22.9±.6              | 1.06±.03        | 24.3        |
| KV8     | $f_1 = 15.173$ | 11.0±.8              | 1.40±.07        | 8.3         |
|         | $f_2 = 15.623$ | 11.2±.8              | 2.31±.07        | 8.9         |
|         | $f_3 = 16.227$ | 5.1±.8               | 1.86±.15        | 4.3         |
| KV9     | $f_1 = 13.020$ | 16.1±1.4             | 3.91±.09        | 8.0         |
\[ V = V_0 + \sum_j A_j \cos\{2\pi f_j (t - t_0) + \Phi_j\}, \quad t_0 = H.J.D.2453000.0 \]

\[ \frac{\text{S/N}}{} = \left( \frac{\text{power for each frequency}}{\text{mean power after prewhitening for all frequencies}} \right)^{1/2} \]
Table 4. Parameters of new eclipsing binaries.

| Star ID | Period(d) | Epoch(H.J.D)   | ΔV(mag) |
|---------|-----------|----------------|---------|
| KV11    | 1.887     | 2453014.410    | 0.15    |
| KV12    | 0.984     | 2453014.470    | 0.13    |
| KV13    | 0.289     | 2453014.774    | 0.19    |
| KV14    | 0.335     | 2453029.635    | 0.21    |
| KV15    | 0.355     | 2453014.270    | 0.23    |
| KV16    | 0.295     | 2453013.815    | 0.70    |
| KV17    | 0.224     | 2453014.830    | 0.75    |