CURious Variables Experiment (CURVE): Variable Stars in the metal-poor Globular Cluster M56

P. Pietrukowicz¹,², A. Olech¹, P. Kędzierski³, K. Zloczewski¹, M. Wisniewski¹, K. Mularczyk³

¹Nicolaus Copernicus Astronomical Center, ul. Bartycka 18, 00-716 Warsaw, Poland
e-mail: (pietruck,olech,kzlocz,mwisniew)@camk.edu.pl
²Departamento de Astronomía y Astrofísica, Pontificia Universidad Católica de Chile, Av. Vicuña MacKenna 4860, Casilla 306, Santiago 22, Chile
³Warsaw University Observatory, Al. Ujazdowskie 4, 00-478 Warsaw, Poland
e-mail: pkedzier,kmularcz@astrouw.edu.pl

ABSTRACT

We have surveyed a 6.5′ × 6.5′ field centered on the globular cluster M56 (NGC 6779) in search for variable stars. We have detected seven variables, among which two objects are new identifications. One of the new variables is an RR Lyrae star, the third such star in M56. Comparison of the new observations and old photometric data for an RV Tauri variable V6 indicates a likely period change in the star. Its slow and negative rate of $-0.005 ± 0.003$ d/yr would disagree with post-AGB evolution, however this could be a result of blue-loop evolution and/or random fluctuations of the period.

Hertzsprung-Russell (HR) and C-M diagrams – Stars: variables: BL Her, RV Tau, RR Lyr
– open clusters and associations: individual: M56 (NGC 6779)

1 Introduction

CURious Variables Experiment (CURVE) is a long-term project focused on observations of open clusters, globular clusters and cataclysmic variable stars in the northern hemisphere (Olech et al. 2003, Olech et al. 2007, Rutkowski et al. 2007). In stellar clusters we principally search for variable objects. However, our data also allows us to estimate basic parameters of observed clusters, such as distances and ages (Pietrukowicz et al. 2006).

The globular cluster M56 (NGC 6779) is located in a rather dense galactic field at $(l,b) = (62°.66, +8°.34)$. The most recent deep $BVRI$ photometry of the cluster was obtained by Hatzidimitriou et al. (2004) using 1.3-m telescope at Skinakas Observatory, in Crete. They estimate the distance modulus and the reddening for M56 of $(m-M)_V = 15.62 ± 0.26$ and $E(B-V) = 0.32 ± 0.02$, respectively. The authors also demonstrate that M56 is one of the most metal-poor ([Fe/H]$_{CG} = -2.00 ± 0.21$ on the scale proposed by Carretta and Gratton 1997) and one of the oldest globular clusters in the Galactic halo (13 Gyrs, using the age-index calibration of Salaris and Weiss 2002).

Despite the very early discovery of the first variable star in the globular cluster M56 (the object classified now as V3, Davis 1917) and excellent position for northern hemisphere observers of the cluster, identification of its variables has proceeded very slowly. Clement et al. (2001) lists only 12 variable stars in M56, but five of them are very likely field objects. In this contribution we present results of the search for variable stars in M56 based on new data and
with the use of image subtraction method, which works much better in crowded fields than classical photometry.

2 Observations and Data Reductions

Observations of the globular cluster M56 were made during 48 nights between July 5, 2002 and May 25, 2004 at the Ostrowik station of the Warsaw University Observatory. The data were collected using the 60-cm Cassegrain telescope equipped with a Tektronics TK512CB back-illuminated CCD camera. The scale of the camera was 0.′′76/pixel providing a 6.′5 × 6.′5 field of view. The full description of the telescope and camera was given by Udalski and Pych (1992).

We monitored the cluster in “white light”, which roughly corresponds to the Cousins R band (Udalski and Pych 1992). The exposure times were from 120 to 240 seconds. We analyzed 543 images with seeing better than 4.′′56 (< 6.0 pixels) and average background level lower than 3500. The best measured seeing reached 2.′′90. Table 1 lists the nights during which the data were obtained.

All images were de-biased, dark current subtracted and flat-fielded using the IRAF package. The photometry was extracted with the help of the Difference Image Analysis Package (DIAPL) written by Woźniak (2000) and recently modified by W. Pych. The package is an implementation of the method developed by Alard and Lupton (1998). A reference frame was constructed by combining 7 individual images taken during dark time on the night of May 24/25, 2003. Profile photometry for the reference frame was extracted with DAOPHOT/ALLSTAR (Stetson 1987). These measurements were used to transform the light curves from differential flux units into instrumental magnitudes, which later were transformed to the standard R-band magnitudes by adding a median offset of 0.549 mag, derived from data on 3894 stars presented by Hatzidimitriou et al. (2004). Finally, we performed period search and analysis with the TATRY code (see methods in Schwarzenberg-Czerny 1989, 1996).

Table 1: Dates of observations of M56

| Year | Month   | Nights                  |
|------|---------|-------------------------|
| 2002 | July    | 5/6, 6/7, 8/9, 9/10, 13/14 |
| 2002 | August  | 1/2, 10/11, 11/12, 13/14   |
| 2003 | May     | 24/25, 25/26             |
| 2003 | June    | 2/3, 24/25, 26/27, 30/31   |
| 2003 | August  | 17/18, 18/19, 20/21, 22/23, 24/25, 25/26, 27/28, 28/29, 29/30, 30/31, 31/1 |
| 2003 | September | 1/2, 2/3, 3/4, 5/6, 6/7, 7/8, 2/21 |
| 2003 | October | 3/4, 15/16, 18/19, 19/20   |
| 2003 | December| 7/8                    |
| 2004 | February| 19/20                   |
| 2004 | April   | 15/16, 19/20, 20/21, 22/23 |
| 2004 | May     | 10/11, 12/13, 14/15, 23/24, 24/25   |

*IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under a cooperative agreement with the National Science Foundation.
†The package is available at [http://users.camk.edu.pl/pych/DIAPL](http://users.camk.edu.pl/pych/DIAPL)
Table 2: Positions of detected variables in the field of M56

| Name | RA(2000.0) | Dec(2000.0) | Distance from the center |
|------|------------|-------------|-------------------------|
| V1   | 19\textsuperscript{h}16\textsuperscript{m}39\textsuperscript{s}33 | -30\textdegree12\arcmin16\arcsec7 | 1.53 |
| V3   | 19\textsuperscript{h}16\textsuperscript{m}37\textsuperscript{s}82 | -30\textdegree12\arcmin34\arcsec1 | 1.59 |
| V4   | 19\textsuperscript{h}16\textsuperscript{m}27\textsuperscript{.46} | -30\textdegree08\arcmin20\arcsec7 | 3.40 |
| V5   | 19\textsuperscript{h}16\textsuperscript{m}36\textsuperscript{s}58 | -30\textdegree08\arcmin46\arcsec6 | 2.32 |
| V6   | 19\textsuperscript{h}16\textsuperscript{m}35\textsuperscript{s}79 | -30\textdegree11\arcmin39\arcsec9 | 0.59 |
| V13  | 19\textsuperscript{h}16\textsuperscript{m}38\textsuperscript{s}72 | -30\textdegree10\arcmin59\arcsec1 | 0.81 |
| V14  | 19\textsuperscript{h}16\textsuperscript{m}29\textsuperscript{s}83 | -30\textdegree12\arcmin27\arcsec7 | 1.97 |

Table 3: Photometric data on detected variables in M56

| Name | B | \(<R>\) | \(\Delta R\) | B\(-<R>\) | P | Maximum Type | JD-2450000 |
|------|---|---------|---------|----------|---|--------------|-------------|
| V1   | 15.50 | 15.10 | 1.07 | 0.40 | 1.510116(8) | 2784.46 | BL Her |
| V3   | 14.65 | 12.08 | 2.57 | 72 ? | - | SR/Irr |
| V4   | - | 15.75 | 0.45 | - | 0.423723(4) | 2462.50 | RR Lyr |
| V5   | 14.73 | 12.13 | 2.60 | 145 ? | - | SR/Irr |
| V6   | - | 12.18 | 1.22 | - | 89.70(19) | 2498.34 | RV Tau |
| V13  | - | 13.61 | 0.13 | - | 38.96(3) | 2881.28 | puls? |
| V14  | 16.54 | 15.69 | 0.27 | 0.85 | 0.380795(5) | 2889.29 | RR Lyr |

3 Detected variables

Searches for variable stars in M56 led to detection of seven objects. Besides five known variables, two objects, V13 and V14, are new identifications. The equatorial coordinates of all objects, as well as their angular distances from the cluster center \((\alpha_{2000} = 19\textsuperscript{h}16\textsuperscript{m}35\textsuperscript{s}5, \delta_{2000} = +30\textdegree11\arcmin05\arcsec, \text{Harris 1996})\) are listed in Table 2. Only two of the variables, namely V6 and V13, are located inside the cluster half-mass radius \(r_h = 1.16\) (Harris 1996), but neither of them are located inside the core radius \(r_c = 0.37\) (Harris 1996). Table 3 gives photometric data on the variables. The \(B\)-band magnitudes for four of the variables, namely V1, V3, V5 and V14, were taken from Hatzidimitriou et al. (2004). Unfortunately, there is no photometric information on the three remaining objects: V4, V6 and V13.

In Fig. 1 we present phased as well as time-domain light curves of the seven detected variables. Fig. 2 shows \(R/B-R\) color-magnitude diagram of M56 based on the data from Hatzidimitriou et al. (2004). For all detected variables we adopted the average magnitudes \(<R>\) derived from our data. The magnitudes in the \(B\) band were taken from Hatzidimitriou et al. (2004) if they were available. Note that for the three objects mentioned above there is no color information.

Variable V1 is a BL Her star whose cluster membership was proved by a radial velocity study by Harris et al. (1983) and a relative proper motion study by Rishel et al. (1981). Based on photographic \(B\) and \(V\) data obtained in the years 1935–1984 Wehlau and Sawyer Hogg (1985) constructed an \(O-C\) diagram. They estimated a secular period change rate in this star of \((+3.3 \pm 0.2)\) d/Myr and the period \(P_0 = 1.510019\) d at the epoch \(t_0 = \text{JD2445252.316}\). The different band used in our observations does not allow us to add another point in that diagram; however we confirm positive period change in the object. The rate of
Fig. 1. Phased (left column) and time-domain (right column) light curves of seven variable stars detected in the field of the globular cluster M56.

period change calculated as

$$\frac{\Delta P}{\Delta t} = \frac{P_1 - P_0}{t_1 - t_0} = (+4.4 \pm 0.4) \text{ d/10}^{-6}\text{yr}$$

where the values of $P_1$ and $t_1$ come from our data (Table 3), is consistent, at three sigma level, with that given by Wehlau and Sawyer Hogg (1985). Our observations do not show the presence of neither a dip shortly before maximum light nor a bump on the descending branch in the light curve, noticed by them. Their remark could be a result of a small number of data points per period (only 24 in the $V$-band).

Objects V3 and V5 occupy the same region on the color-magnitude diagram of the cluster, the tip of the red giant branch. They are semiregular or irregular variables for which relative proper motions measured by Rishel et al. (1981) indicate their membership. The periods of the variables given by Russeva (2000), namely 42.12 or 34.86 days for V3 and 31.33 days for V5, does not fit our data at all. We have found other periods in our data: 72 and 145 days for V3 and V5, respectively, but the objects require more continuous observations to study their behavior.

Variable V4 is an RR Lyrae variable and a very likely member of the cluster, though it is located almost $3r_h$ from the cluster center. Its sine-like light curve
Fig. 2. $R/B - R$ color-magnitude diagram of M56. Locations for four detected variables are marked with squares. For three objects we only know the average $R$-band magnitudes (those are marked with arrows).

with an amplitude of about 0.45 mag and a period of 0.423723 d suggest it may be RR Lyrae type “c”.

Another variable object, V6, is an RV Tau star which belongs to the cluster (Webbink 1981). There are only six known such variables in Galactic globular clusters (Zsoldos 1998). RV Tau stars are pulsating supergiants of the formal period $P_0$ in the range of 30-150 days, having spectral types F-G in maximum light and K-M in minimum light. Their light curves are characterized by the presence of alternating deep and shallow minima and the amplitude ratio $A_0/A_1$ of about 1, where $A_0$ and $A_1$ are the amplitudes of the formal period and its first harmonic, respectively.

The variable V6 fulfills the classification criteria very well. Fig. 3 illustrates the power spectrum of the object, calculated with the help of ANOVA statistics (Schwarzenberg-Czerny 1996). The two highest peaks at $f_0 = 0.01115$ c/d and $f_1 = 0.02236$ c/d correspond to the formal period and its harmonic, respectively. In Fig. 4 we show phased light curves of the variable taken from different epochs from the years 1935–2004. The presence of alternating minima is obvious. The new data indicate the formal period of V6 to be $89.70 \pm 0.19$ days, slightly shorter than the period published in previous studies (90.0 days, Sawyer 1949, Wehlau and Sawyer Hogg 1985) and which was believed to be stable. We reanalyzed
Table 4: Times of maxima and derived periods of the RV Tau variable V6

| E Filter | JD\(_{\text{max}}\) − 2400000.0 | \(P\) | \(\Delta P\) |
|----------|-------------------------------|------|---------|
| -268 B   | 28398.75                      | 90.06| 0.02    |
| -114 B   | 42256.73                      | 89.61| 0.07    |
| 0 R      | 52498.34                      | 89.70| 0.19    |

We have found the period to decrease with a rate of \(-0.005 \pm 0.003\) d/yr.

Figure 3: The ANOVA power spectrum of the RV Tau star V6.

Variables V13 and V14 are new identifications. The first object is located inside the half-mass radius of the globular cluster, but we cannot confirm its membership status. Unfortunately, there is no color information on this star. If V13 belongs to M56 it could be an AGB pulsating star.

Variable V14 is the second faintest of the seven detected variables. It has \(R = 15.69\) mag on average, an amplitude \(\Delta R = 0.27\) mag, and a period of 0.380795 d. These numbers and location of the star on the color-magnitude diagram are consistent with classifying V14 as an RR Lyrae-type variable belonging to the cluster. If this interpretation is true then V14 would be the third RR Lyrae known in the cluster, after variables V4 and V12.

In this work we confirm, followed by Wehlau and Sawyer Hogg (1985) and also Russeva (2000), that the object V2 is not variable. The analysis of our data has not indicated any variability for the red giant star Kustner 204 suggested by Russeva (2000). Variables V6-V12 are located outside our field of view, but according to Wehlau and Sawyer Hogg (1985) only V12, an RRab star of a period of 0.90608 d, is a member of the globular cluster M56. Unfortunately, this star is located outside the field of view of Hatzidimitriou et al. (2004), making it impossible to place on our color-magnitude diagram.

4 Discussion and Summary

We have presented the results of a search for variable stars in the globular cluster M56. Besides five already known variables we have identified two new objects: V13 and V14. The object V13 has a period of 38.96 days and probably is a
Fig. 4. Light curves of the RV Tau star V6 in different epochs from the years 1935–2004. Note the presence of alternating primary and secondary minima.

The variable V14 is very likely an RR Lyrae star which belongs to the cluster, the third such object in M56, after V4 and V12. The number of RR Lyrae stars in this metal-poor globular cluster seems to be very small, but there are known clusters with similar characteristics. For example, in M30 of metallicity $[\text{Fe/H}]_{CG} = -2.17 \pm 0.08$ (Carretta 2003) there have been found only 5 such variables (Clement et al. 2001, Pietrukowicz and Kaluzny 2004); in NGC 6397 of metallicity $[\text{Fe/H}]_{CG} = -2.03 \pm 0.05$ (Gratton et al. 2003) there is no known RR Lyrae star at all (Kaluzny et al. 2006).

For previously known variables in M56 we have confirmed positive period changes in BL Her variable V1 and semi-regular nature of V3 and V5. For variable V6, the RV Tau star, we have found, for the first time, very likely period change in this star. The negative period change rate of $-0.005 \pm 0.003$ d/yr seems to be in contradiction to the evolutionary status of RV Tau stars as post-AGB objects, but not with blue-loop evolution. Numerous studies of period changes in RV Tau (e.g., Percy et al. 1997, Percy and Coffey 2005) also show that $O - C$ diagrams are dominated by random cycle-to-cycle period fluctuations of typically 0.005 to 0.02 of a period. The fluctuations may mask real evolutionary period changes. Moreover, the interpretation of the diagrams depends on the specific interval involved.

The results presented here have improved our knowledge on variable stars.
in the globular cluster M56, but future searches will require a bigger telescope (a 1-m or 2-m class telescope) at an observatory located in a place with better seeing conditions.

**Acknowledgments.** The authors would like to thank Dr. W. Pych for providing some useful software which was used in the analysis. PP and AO acknowledge support from the Domestic Grant for Young Scientists of the Foundation for Polish Science and Polish MNiI grant N203 301 335, respectively. Telescope operation was supported by the BW grant to Warsaw University Observatory.

**REFERENCES**

Alard, C., and Lupton, R.H. 1998, *Astrophys. J.*, 503, 325.
Carretta, E., and Gratton, R.G. 1997, *Astron. Astrophys. Suppl. Ser.*, 121, 95.
Carretta, E. 2003, *Memorie della Societa Astron. Italiana Sup.*, 3, 90.
Clement, C.M., Muzzin, A., Dufton, Q., Ponnampalam, T., Wang, J., Burford, J., Richardson, A., Rosebery, T., Rowe, J., Sawyer Hogg, H. 2001, *Astron. J.*, 122, 2587.
Davis, H. 1917, *P.A.S.P.*, 29, 210.
Gratton, R.G., Bragaglia, A., Carretta, E., Clementini, G., Desidera, S., Grundahl, F., Lucatello, S. 2003, *Astron. Astrophys.*, 408, 529.
Harris, H.C., Nemec, J.M., and Hesser, J.E. 1983, *P.A.S.P.*, 95, 256.
Harris, W.E. 1996, *Astron. J.*, 112, 1487.
Hatzidimitriou, D., Antoniou, V., Papadakis, I., Kaltsa, M., Papadaki, C., Papamastorakis, I., Croke, B.F.W. 2004, *MNRAS*, 348, 1157.
Kaluzny, J., Thompson, I.B., Krzeminski, W., Schwarzenberg-Czerny, A. 2006, *MNRAS*, 365, 548.
Olech, A., Kędzierski, P, Złoczewski, K., Mularczyk, K., Wiśniewski, M. 2003, *Astron. Astrophys.*, 411, 483.
Olech, A., Rutkowski, A., and Schwarzenberg-Czerny, A. 2007, *Acta Astron.*, 57, 331.
Percy, J.R., Beuzit, M., Milanowski, M., Zsoldos, E. 1997, *P.A.S.P.*, 109, 264.
Percy, J.R., and Coffey, J. 2005, *JAAVS*, 33, 193.
Pietrukowicz, P., and Kaluzny, J. 2004, *Acta Astron.*, 54, 19.
Pietrukowicz, P., Olech, A., Wiśniewski, M., Kędzierski, P., Mularczyk, K., Złoczewski, K., Starczewski, S., Szaruga, K. 2006, *Acta Astron.*, 56, 267.
Rishel, B.E., Sanders, W.L., and Schroder, R. 1981, *Astron. Astrophys. Suppl. Ser.*, 45, 443.
Russeva, T. 2000, *IBVS*, 4846, 1.
Rutkowski, A., Olech, A., Mularczyk, K., Boyd, D., Koff, R., Wiśniewski, M. 2007, *Acta Astron.*, 57, 267.
Salaris, M., and Weiss, A. 2002, *Astron. Astrophys.*, 388, 492.
Sawyer, H.B. 1949, *Journal of the Royal Astron. Soc. of Canada*, 43, 38.
Schwarzenberg-Czerny, A. 1989, *MNRAS*, 241, 153.
Schwarzenberg-Czerny, A. 1996, *Astrophys. J.*, 460, L107.
Stetson, P.B. 1987, *P.A.S.P.*, 99, 191.
Udalski, A., and Pych, W. 1992, *Acta Astron.*, 42, 285.
Wehlau, A., and Sawyer Hogg, H. 1985, *Astron. J.*, 90, 12.
Woźniak, P.R. 2000, *Acta Astron.*, 50, 421.
Zsoldos, E. 1998, *Acta Astron.*, 48, 775.