ACTA ASTRONOMICA
Vol. **58** (2008) pp. 121–130

CURiuos Variables Experiment (CURVE): Variable Stars in the Metal-Poor Globular Cluster M56

P. Pietrukowicz[1,2], A. Olech[1], P. Kędzierski[3], K. Zloczewski[1], M. Wiśniewski[1] and K. Mularczyk[3]

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

Received June 9, 2008

ABSTRACT

We surveyed a $6\farcm5 \times 6\farcm5$ field centered on the globular cluster M56 (NGC 6779) in a search for variable stars detecting seven variables, among which two objects are new identifications. One of the new variables is an RR Lyrae star, the third star of that type 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.

Key words: *Hertzsprung-Russell (HR) and C–M diagrams – Stars: individual: 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 $(l,b) = (62\fdg66, +8\fdg34)$. 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 $(m-M)_V = 15.62 \pm 0.26$ mag and $E(B-V) = 0.32 \pm 0.02$ mag, respectively. The authors also demonstrate that M56 is one of the most metal-poor

($[\mathrm{Fe/H}]_{\mathrm{CG}} = -2.00 \pm 0.21$ 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 its excellent position for northern hemisphere observers, the identification of its variable stars proceeded very slowly. Clement *et al.* (2001) list 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 in crowded fields works much better 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 $0\farcs76$/pixel providing a $6\farcm5 \times 6\farcm5$ 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 $4\farcs56$ (< 6.0 pixels) and average background level lower than 3500. The best measured seeing reached $2\farcs90$. Table 1 lists the nights during which the data were obtained.

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

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 Schwarzenberg-Czerny 1989, 1996).

3. Detected Variable Stars

Search for variable stars in M56 led to the 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 ($\alpha_{2000} = 19^h16^m35\overset{s}{.}5$, $\delta_{2000} = +30°11'05''$, Harris 1996) are listed

Table 2

Coordinates of the variable stars detected in the field of M56

Name	RA(2000.0)	Dec(2000.0)	Distance from the center
V1	$19^h16^m39\overset{s}{.}33$	$-30°12'16\overset{''}{.}7$	$1\overset{'}{.}53$
V3	$19^h16^m37\overset{s}{.}82$	$-30°12'34\overset{''}{.}1$	$1\overset{'}{.}59$
V4	$19^h16^m27\overset{s}{.}46$	$-30°08'20\overset{''}{.}7$	$3\overset{'}{.}40$
V5	$19^h16^m36\overset{s}{.}58$	$-30°08'46\overset{''}{.}6$	$2\overset{'}{.}32$
V6	$19^h16^m35\overset{s}{.}79$	$-30°11'39\overset{''}{.}9$	$0\overset{'}{.}59$
V13	$19^h16^m38\overset{s}{.}72$	$-30°10'59\overset{''}{.}1$	$0\overset{'}{.}81$
V14	$19^h16^m29\overset{s}{.}83$	$-30°12'27\overset{''}{.}2$	$1\overset{'}{.}97$

in Table 2. Only two objects, V6 and V13, are located inside the cluster half-mass radius $r_h = 1\overset{'}{.}16$ (Harris 1996), but neither of them are located inside the core radius $r_c = 0\overset{'}{.}37$ (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

*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.

taken from Hatzidimitriou *et al.* (2004). Unfortunately, there is no photometric information on the three remaining objects: V4, V6 and V13.

Table 3

Photometric data on variable stars detected in M56

Name	B [mag]	$\langle R\rangle$ [mag]	ΔR [mag]	$B-\langle R\rangle$ [mag]	P [d]	Maximum in R-band JD-2450000	Type
V1	15.50	15.10	1.07	0.40	1.510116(8)	2784.46	BL Her
V3	14.65	12.08	0.78	2.57	72 ?	–	SR/Irr
V4	–	15.75	0.45	–	0.423723(4)	2462.50	RR Lyr
V5	14.73	12.13	0.57	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

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 $\langle R\rangle$ derived from our data. The magnitudes in the B-band were taken from Hatzidimitriou *et al.* (2004) where available. Note that for the three objects mentioned above there is no color information.

Variable V1 is a BL Her-type 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 $(+3.3\pm0.2)$ d/Myr and the period $P_0 = 1.510019$ d at the epoch $t_0 = \mathrm{JD}\,2445252.316$. 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 period change, calculated as

$$\frac{\Delta P}{\Delta t} = \frac{P_1 - P_0}{t_1 - t_0} = (+4.4\pm0.4)\cdot 10^{-6}\ \frac{\mathrm{d}}{\mathrm{yr}}$$

where the values of P_1 and t_1 are taken from our data (Table 3), is consistent, at three sigma level, with the value given by Wehlau and Sawyer Hogg (1985). Our observations do not show the presence of either a dip shortly before maximum light or a bump on the descending branch in the light curve, as 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

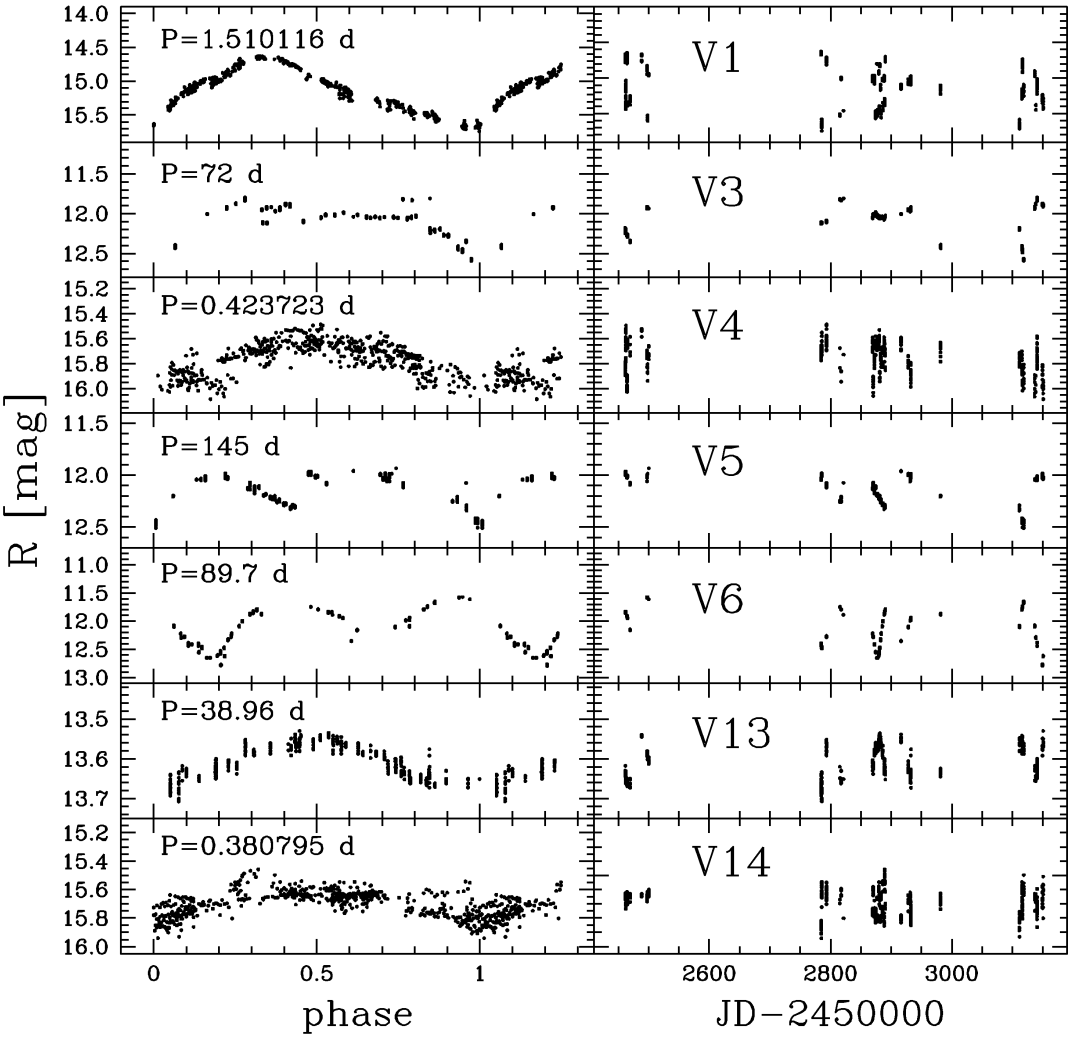

Fig. 1. Phased (*left column*) and time-domain (*right column*) light curves of seven variable stars detected in the field of the globular cluster M56.

variables, their membership being very probable in view of the proper motion measurements by Rishel *et al.* (1981). The periods of the variables given by Russeva (2000), namely 42.12 or 34.86 d for V3 and 31.33 d for V5, do not fit our data at all. From our data we find: 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 Lyr star and a very likely member of the cluster, although it is located almost $3r_h$ from the cluster center. Its sine-like light curve with an amplitude of about 0.45 mag and a period of 0.423723 d suggest it may be an RR Lyr star of 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

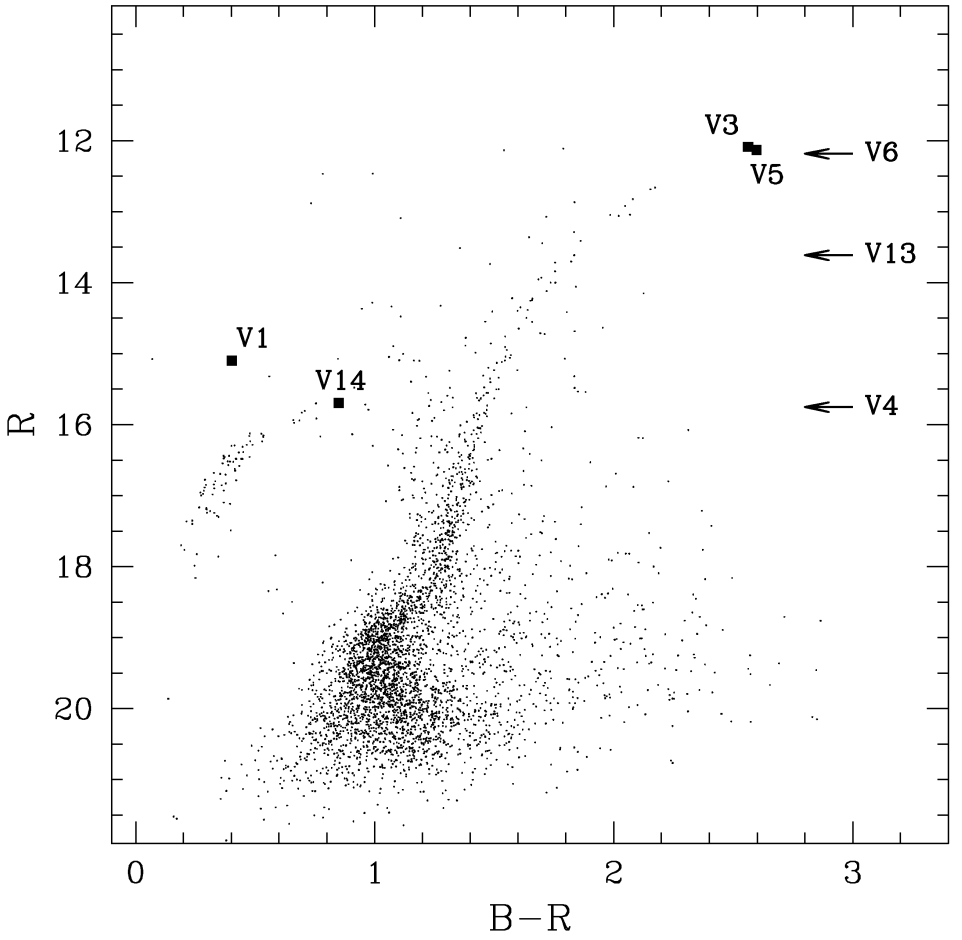

Fig. 2. $R/(B-R)$ color–magnitude diagram of M56. Locations for four detected variables are marked with squares. For three objects we only know the average R-band magnitudes (those are marked with arrows).

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 ± 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 archival data (see Table 4) published in Wehlau and Sawyer Hogg (1985) and we have found the period to decrease with a rate of -0.005 ± 0.003 d/yr.

Table 4

Times of maxima and derived periods of the RV Tau variable V6

E	Filter	$JD_{max} - 2400000.0$ [d]	P [d]	ΔP [d]
−268	*B*	28398.75	90.06	0.02
−114	*B*	42256.73	89.61	0.07
0	*R*	52498.34	89.70	0.19

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.

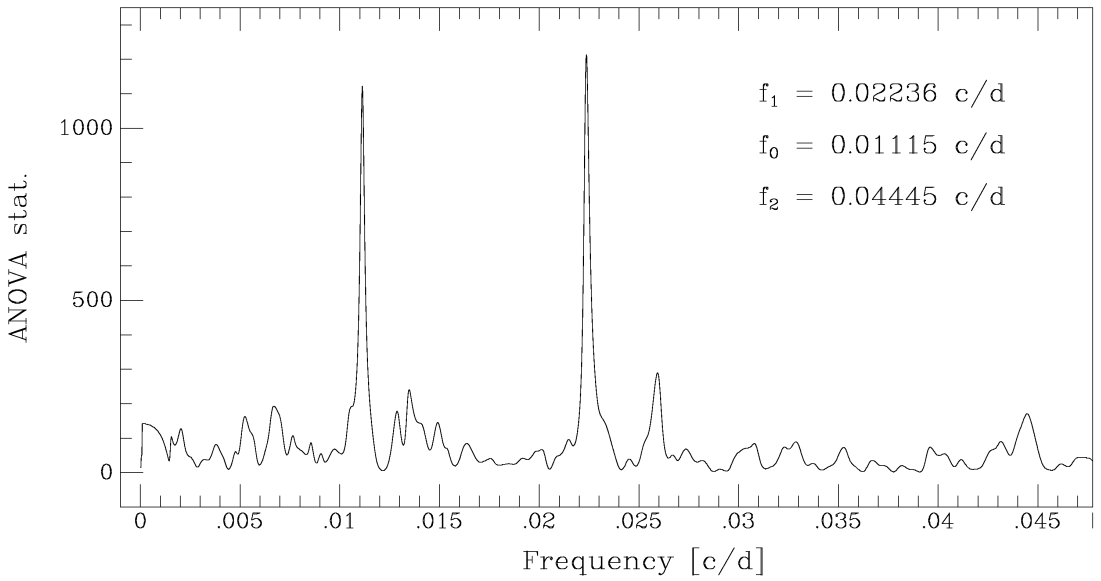

Fig. 3. The ANOVA power spectrum of the RV Tau star V6.

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 Lyr-type variable belonging to the cluster. If this interpretation is true then V14 would be the third RR Lyr known in the cluster, besides variable stars V4 and V12.

In this work we confirm the conclusion by Wehlau and Sawyer Hogg (1985) and also by Russeva (2000), that the object V2 is not variable. The analysis of our data does not indicate any variability of 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 M56. Unfortunately, this star is located outside the field of view of Hatzidimitriou *et al.* (2004) and cannot be placed on our color–magnitude diagram.

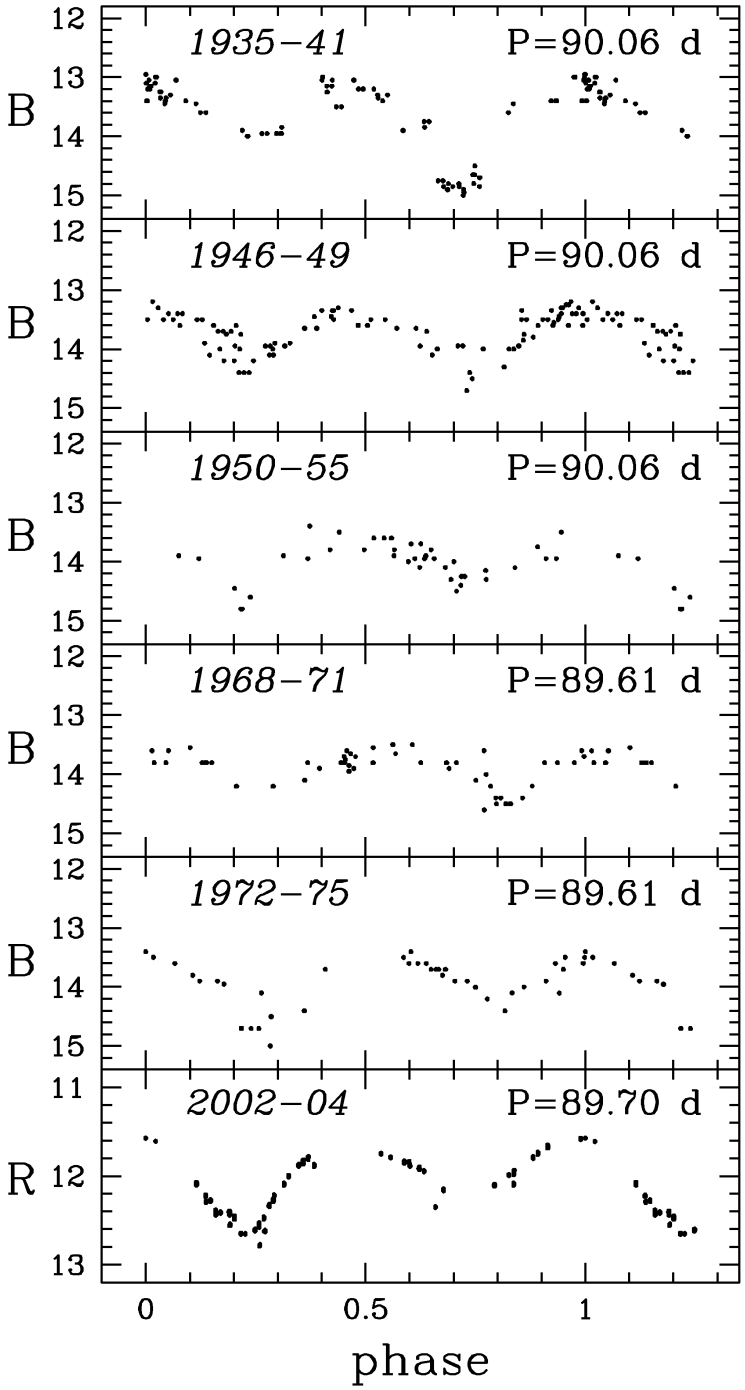

Fig. 4. Light curves of the RV Tau star V6 in different epochs from the years 1935–2004. Note the presence of alternating primary and secondary minima.

4. Discussion and Summary

We presented the results of a search for variable stars in the globular cluster M56. In addition to the five already known variable stars we identified two new objects: V13 and V14. The object V13 has a period of 38.96 d and probably is a pulsating AGB star. V14 is very likely an RR Lyr star belonging to the cluster; the third such object in M56, besides V4 and V12. The number of RR Lyr 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 $[\mathrm{Fe/H}]_{CG} = -2.17 \pm 0.08$ (Carretta 2003), there have been found only five RR Lyr stars (Clement *et al.* 2001, Pietrukowicz and Kaluzny 2004); in NGC 6397, of metallicity $[\mathrm{Fe/H}]_{CG} = -2.03 \pm 0.05$ (Gratton *et al.* 2003), there is no known RR Lyr star at all (Kaluzny *et al.* 2006).

For previously known variables in M56 we confirmed positive period changes in BL Her variable star V1 and semi-regular nature of V3 and V5. For variable V6, the RV Tau star, we found, for the first time, very likely period change. The negative period change rate of -0.005 ± 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 stars (*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, typically of the order of 0.005 to 0.02 of a period. These fluctuations may mask the real evolutionary period changes.

Results presented here improved our knowledge on variable stars in the globular cluster M56, but future searches with bigger telescopes (1 or 2-m class) located in sites with better seeing conditions are obviously needed.

Acknowledgements. 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 MNiSW 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, *ApJ*, **503**, 325.
Carretta, E., and Gratton, R.G. 1997, *A&AS*, **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., and Sawyer Hogg, H. 2001, *AJ*, **122**, 2587.
Davis, H. 1917, *PASP*, **29**, 210.
Gratton, R.G., Bragaglia, A., Carretta, E., Clementini, G., Desidera, S., Grundahl, F., and Lucatello, S. 2003, *A&A*, **408**, 529.
Harris, H.C., Nemec, J.M., and Hesser, J.E. 1983, *PASP*, **95**, 256.
Harris, W.E. 1996, *AJ*, **112**, 1487.

Hatzidimitriou, D., Antoniou, V., Papadakis, I., Kaltsa, M., Papadaki, C., Papamastorakis, I., and Croke, B.F.W. 2004, *MNRAS*, **348**, 1157.
Kaluzny, J., Thompson, I.B., Krzeminski, W., and Schwarzenberg-Czerny, A. 2006, *MNRAS*, **365**, 548.
Olech, A., Kędzierski, P, Zloczewski, K., Mularczyk, K., and Wiśniewski, M. 2003, *A&A*, **411**, 483.
Olech, A., Rutkowski, A., and Schwarzenberg-Czerny, A. 2007, *Acta Astron.*, **57**, 331.
Percy, J.R., Bezuhly, M., Milanowski, M., and Zsoldos, E. 1997, *PASP*, **109**, 264.
Percy, J.R., and Coffey, J. 2005, *JAAVSO*, **33**, 193.
Pietrukowicz, P., and Kaluzny, J. 2004, *Acta Astron.*, **54**, 19.
Pietrukowicz, P., Olech, A., Wiśniewski, M., Kędzierski, P., Mularczyk, K., Zloczewski, K., Starczewski, S., and Szaruga, K. 2006, *Acta Astron.*, **56**, 267.
Rishel, B.E., Sanders, W.L., and Schroder, R. 1981, *A&AS*, **45**, 443.
Russeva, T. 2000, *IBVS*, **4846**, 1.
Rutkowski, A., Olech, A., Mularczyk, K., Boyd, D., Koff, R., and Wiśniewski, M. 2007, *Acta Astron.*, **57**, 267.
Salaris, M., and Weiss, A. 2002, *A&A*, **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, *ApJ*, **460**, L107.
Stetson, P.B. 1987, *PASP*, **99**, 191.
Udalski, A., and Pych, W. 1992, *Acta Astron.*, **42**, 285.
Webbink, R.F. 1981, *ApJS*, **45**, 259.
Wehlau, A., and Sawyer Hogg, H. 1985, *AJ*, **90**, 12.
Woźniak, P.R. 2000, *Acta Astron.*, **50**, 421.
Zsoldos, E. 1998, *Acta Astron.*, **48**, 775.