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Variable stars in the globular cluster M53

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Abstract. We present the results of the search for variable stars in the central region of rather poorly studied globular cluster M53. We have obtained good quality light curves of the 23 previously known RR Lyrae stars in this cluster. Periods of four of them have been determined for the first time. One RR Lyrae variable till now classified as a Bailey type RRc, turned out to be type RRab. We have also confirmed the variability of ten RR Lyrae candidates discovered by Kravtsov (1990) and derived their periods. Moreover, we have found four new variables of this type in the core of the cluster. Altogether, the light curves have been obtained for 37 RR Lyrae stars. The total number of known RR Lyrae stars in M53 equals now to 59, 29 of them being of type RRab and remaining 30 of RRc. The mean period of all known RRab variables in M53 amounts to 0.65 ± 0.07 d, and the average period for RRc variables is equal to 0.36 ± 0.04 d. Mean V magnitudes and ranges of variations have been derived for 19 RR Lyrae stars. We also report the discovery of variations in six cluster bright giants. For these stars, however, our observations are not sufficient to state whether the variability is periodic or not.

Key words: stars: Population II – stars: variables: general – Galaxy: globular clusters: individual: M53

1. Introduction

The metal-poor ([Fe/H] = -2.04 according to Zinn 1985) globular cluster M53 (NGC 5024) is known to contain 45 RR Lyrae variables (Sawyer-Hogg 1973; Clement 1997). It is located relatively far from the Galactic plane in the Coma Berenices constellation. In consequence, its reddening is negligible and the contamination by field stars is low. The most recent photometric study of this cluster by Rey et al. (1998) indicates no significant difference in age between M53 and M92.

The newest version of the Catalogue of Variable Stars in Globular Clusters (CVSGC, Clement 1997) lists 47 variable stars in M53. Hereafter, referring to the specific variable we will use the numbering system of this catalogue.

The first 23 variables (v1 – v23) in M53 were discovered by Shapley (1920). Subsequently, Baade (1931) extended this list adding the next 17 ones (v24 – v40). All were supposed to be of the RR Lyrae type. Periods of most of them were determined by Grosse (1932). The latter investigation resulted also in finding two new variables (v41 and v42) and showing that v22 and v39 are constant in light. Grosse's (1932) periods of two RR Lyrae stars, v15 and v40, were proved to be erroneous by Oosterhoff (1940), who determined new values. The next four variables (v43 – v46) were discovered by van den Hoven van Genderen (1947). She confirmed the constancy of brightness of v22 and v39 and found the variability of v34 to be doubtful. One more RR Lyrae star (v47) was discovered by Margoni (1964). A search by Cuffey (1965, 1966) revealed another three variable stars (v48 – v50): one RR Lyrae star (v48) and two long-period red giant variables. Next, the cluster was observed and studied by Wachmann (1965, 1968), Margoni (1965, 1967), and Goranskij (1976). These papers are concerned mainly with the investigation of period changes of the cluster RR Lyrae variables.

After about 15 years, the core of M53 was observed by Kravtsov (1990). His work was restricted only to the comparison of photographic plates he took in the blink-comparator which resulted in the discovery of 11 new variables. Their brightness indicated that they are RR Lyrae stars. Kravtsov (1990) was not able, however, to derive periods for these stars. These variables are not included in the catalogue of Clement (1997).

The equatorial coordinates of all known variables in M53 were recently determined by Evstigneeva et al. (1997).

We have undertaken observations of M53 in order to study the period changes of its RR Lyrae variables. Preliminary results of this research were given by Kopacki (2000). Detailed analysis will be published elsewhere.

Below we present the results of our search for variable stars in the central region of the globular cluster M53 using the Image Subtraction Method of Alard & Lupton (1998). We also correct some ambiguities and mistakes in the identification and numbering of the already known variables. We show for the first time the light curves of RR Lyrae variables v18, v43, v44, and v46, which could not be determined earlier owing to the proximity to the cluster nucleus. In addition, the light curves of variable stars discovered by Kravtsov (1990) are shown here for the first time. The periods of these variables are also derived.

2. Observations and reductions

The CCD observations presented here were carried out at the Białków station of the Wrocław University Observatory with the same equipment as that described by Kopacki & Pigulski

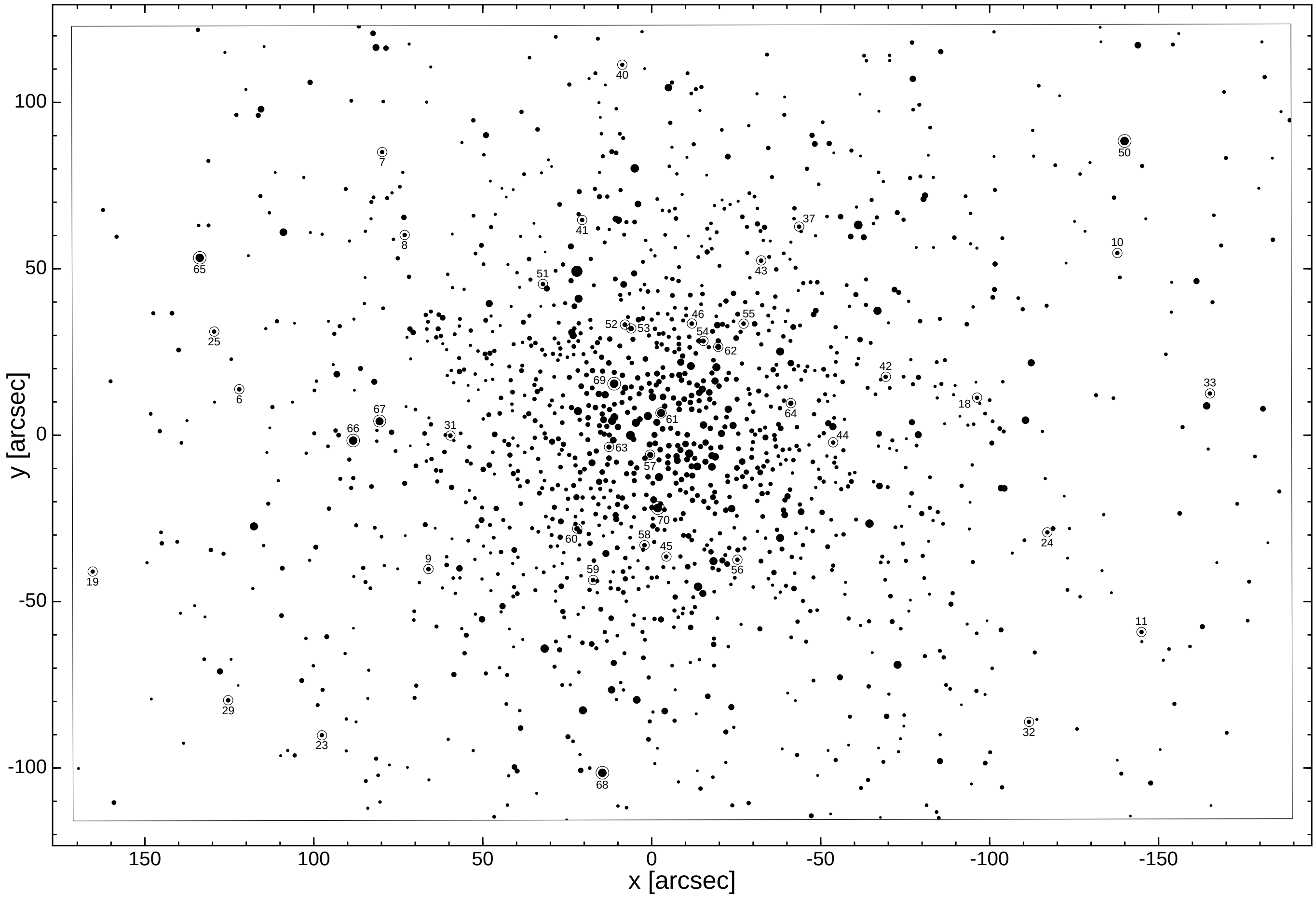

Fig. 1. The observed field of M53, covering an area of about 6×4 arcmin^2. All variable stars are enclosed in open circle and labeled with their numbers given in Tables 1 or 3. Positions (x, y) are in the reference frame of the CVSGC. North is up, east to the left.

(1995). A $6' \times 4'$ field of view, centred approximately on the core of M53, was observed through V and $I_{\rm C}$ filters of the Johnson-Kron-Cousins $UBV(RI)_{\rm C}$ system.

The observations were carried out in two seasons: on 15 nights between 1998 May 1 and June 26, and on 23 nights between 1999 January 21 and July 3. Generally, the exposure times ranged from 300 to 600 s, but on some nights we observed also with shorter exposure times ($90 - 150$ s). Because we were mainly interested in the RR Lyrae stars, CCD frames taken with these short times were grouped and summed up to achieve higher signal-to-noise ratio.

In total, we collected 262 and 116 frames of the observed field of M53 in the $I_{\rm C}$ and V bands, respectively. On most nights the weather conditions were very good. On some nights, however, the sky brightness was rather high due to the bright Moon. The seeing changed in rather wide range, from 1.8 to 3.5 arcsec, with a typical value of 2.5 arcsec.

The pre-processing of the frames was performed in the usual way and consisted of subtracting the bias and dark frames and applying the flat-field correction. Instrumental magnitudes for all stars in the field were computed using the DAOPHOT profile-fitting software (Stetson 1987). All images were reduced in the same way as described by Jerzykiewicz et al. (1996). We identified 1540 stars in the field. The finding chart for the monitored field is shown in Fig. 1.

In order to search for variable stars in the core of the cluster we reduced our V-filter frames using also the Image Subtraction Method (ISM) package developed by Alard & Lupton (1998) and updated by Alard (2000). The power of this method in detecting variable stars in very crowded stellar field of the globular cluster M5 was already demonstrated by Olech et al. (1999).

In the ISM reductions it is essential to prepare an appropriate reference image which, after degrading to the seeing of the processed frame, will be subtracted from it. We constructed this image averaging 4 frames with the best seeing of $1.8 - 1.9$ arcsec after resampling them to the common pixel grid.

Next step consisted in astrometric transformation and resampling of all reduced frames into pixel grid of the reference image. This was accomplished by using the centroids of about 500 bright and unsaturated stars in processed image and reference image. The transformations of coordinates were performed with a first order polynomial.

All frames were then reduced with the ISM package of Alard & Lupton (1998). For each frame, we first found the kernel function which, convolved with the reference image, gave the best (in the sense of least squares) approximation of the processed frame. The convolved reference image was then subtracted from the processed frame and the resulting difference image contained only that part of the stars' brightness which was variable. Since the field we observed was relatively small, we used the approximation of the constant convolution kernel.

The sum or the average of the absolute values of all difference images defines the so called 'variability map' which contains the accumulated contribution of all variations with respect to the reference image. The list of the positions of suspected variables in the variablity map was build using the DAOPHOT package in a standard way. Then all frames were reduced once again with the ISM package to obtain profile photometry for the suspected variables.

3. Identification of the variables

As indicated above, the main source of the numbering schemes for variables in the globular clusters is CVSGC. In the case of M53, however, the catalogue contains a few errors. Evstigneeva et al. (1997) pointed out that the coordinates of two variables, v24 and v44, given in the catalogue are erroneous.

In the course of performing cross-identification of variables from the CVSGC with those detected in our CCD frames we noticed some obvious mistakes concerning v48, v49, and v50. It turned out that their coordinates in the catalogue of Clement (1997) are not given in arcsec (as for the other ones) but in arcmin. These errors caused these three stars to be placed in the very center of the cluster. Inspection of the map given by Cuffey (1965) confirmed our suspicion. It should be noted that these mistakes have been repeated in the work of Evstigneeva et al. (1997). Incidentally, v48 is the variable which is farthest from the cluster center.

One of the suspected variables of Kravtsov (1990), his variable no. 6, is identical with v44. Using the numbering convention of the CVSGC we labeled Kravtsov's variables v51 through v60, omitting this duplicated variable, v51 being his variable no. 1, and v56, his no. 7.

Rey et al. (1998) announced the discovery of 8 new RR Lyrae stars in M53, but careful investigation showed that all they are already known variables. Their 'new' variable no. 1 is v40, no. 2 is v42, no. 3 is v37, no. 4 is v28, no. 5 is v24, no. 6 is v18, no. 7 is v42, and no. 8 is v33.

Table 1. Corrected positions (x, y) relative to the cluster center, Bailey types, and periods (P) of the RR Lyrae variables in the observed field. Coordinates are given in the reference frame of the CVSGC. Periods of v18, v43, v44, and v46, Kravtsov's variables (v51 − v60), and four new RR Lyrae stars (v61 − v64) were derived for the first time, and periods of v23, v31, v32, v40, and v41 were redetermined. All remaining periods are from the CVSGC.

Variable	Type	x [″]	y [″]	P [d]
v6	ab	122.1	13.9	0.6640142
v7	ab	79.9	85.1	0.5448460
v8	ab	73.2	60.1	0.6155072
v9	ab	66.1	−40.2	0.6003482
v10	ab	−137.7	54.7	0.6082530
v11	ab	−144.9	−59.4	0.6299424
v18	c	−96.3	11.2	0.33611
v19	c	164.9	−40.8	0.3909871
v23	c	97.5	−90.1	0.36579
v24	ab	−117.1	−29.2	0.7631901
v25	ab	129.8	31.1	0.7051473
v29	ab	125.3	−79.6	0.8232550
v31	ab	59.6	−0.1	0.70572
v32	c	−111.7	−86.3	0.39041
v33	ab	−165.5	12.5	0.624585
v37	ab	−43.5	62.7	0.717611
v40	c	8.8	111.5	0.31466
v41	ab	20.7	64.7	0.61455
v42	ab	−69.2	17.7	0.713694
v43	ab	−32.2	52.6	0.71205
v44	c	−53.6	−2.1	0.27276
v45	ab	−4.3	−36.5	0.654966
v46	ab	−11.8	33.7	0.70363
v51	c	31.7	44.7	0.35519
v52	c	7.7	33.1	0.37414
v53	c	6.6	31.6	0.38911
v54	c	−15.2	28.3	0.31512
v55	c	−27.4	33.5	0.30677
v56	c	−25.4	−37.5	0.32895
v57	ab	2.0	−5.6	0.56831
v58	c	2.1	−33.0	0.35499
v59	c	17.0	−43.8	0.30393
v60	ab	22.1	−27.9	0.64475
v61	c	−2.5	6.9	0.37951
v62	c	−19.6	26.4	0.35992
v63	c	12.9	−3.5	0.31044
v64	c	−41.0	9.6	0.31955

4. Results

In the observed field we detected 37 RR Lyrae stars. Periods of four out of the 23 variables of this type listed in the CVSGC (v18, v43, v44, and v46) were determined for the first time. In the case of v23, v31, v32, v40, and v41 it was necessary to redetermine the periods. Variable v31 classified until now as a Bailey type RRc, turned out to be of the RRab type. It should be noted that all new periods were derived using only the observations presented in this work. The V-filter light curves of 23 previously known RR Lyrae stars we observed are plotted in Fig. 2.

We confirm the variability of all ten variables discovered by Kravtsov (1990). All show brightness variations typical for RR Lyrae stars (see Fig. 3). Two of them are RRab stars and the remaining eight are of the RRc type. Moreover, we found four new RRc variables in the core of the cluster. Extending the numbering scheme of the CVSGC for M53, we designate these four new variables v61 through v64. We show their V-filter light curves in Fig. 4. Periods of Kravtsov's RR Lyrae stars and the four new ones were determined using simple Fourier periodogram and are given in Table 1. As expected, no variations were detected for v22, v34, and v39.

Positions relative to the cluster center according to Sawyer-Hogg (1973), Bailey types, and adopted periods of the observed

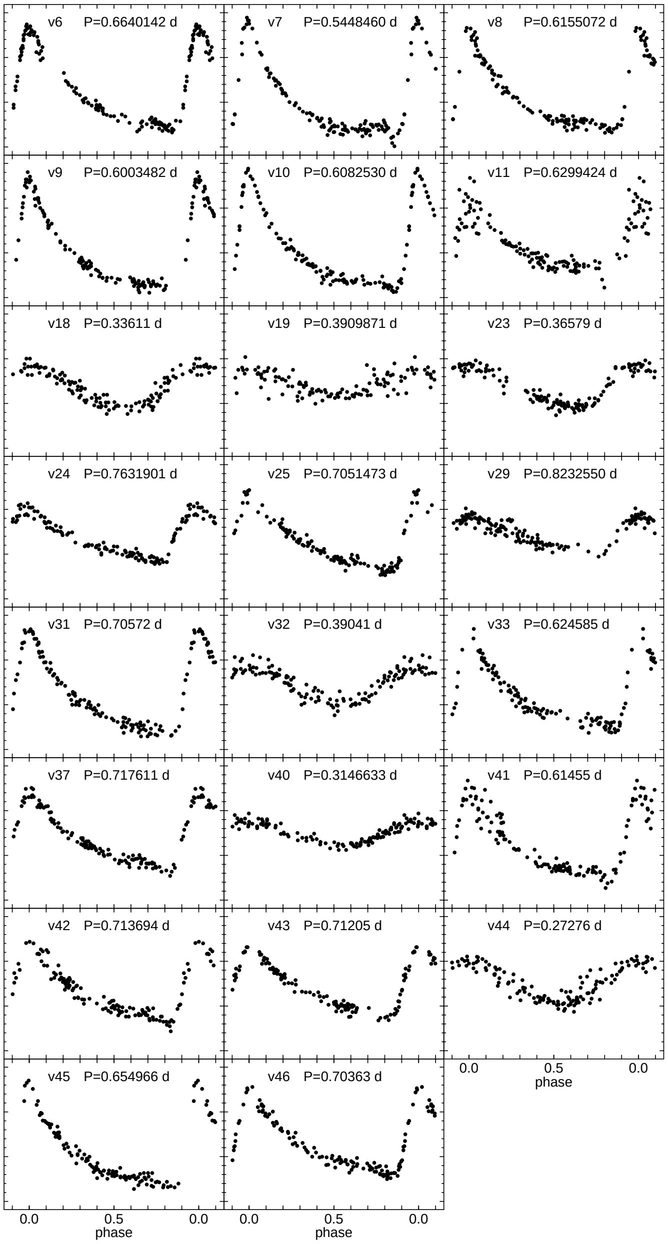

Fig. 2. V-filter light curves of the observed RR Lyrae stars listed in the CVSGC. Variables are arranged according to their numbers in that catalogue. The separation between long ordinate ticks corresponds to 500 arbitrary flux units.

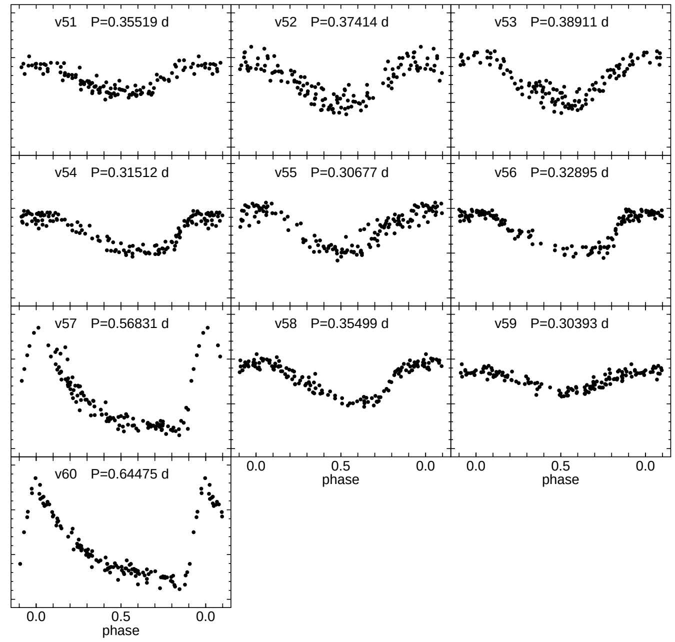

Fig. 3. V-filter light curves of ten RR Lyrae stars discovered by Kravtsov (1990). Ordinate is expressed in the same units as in Fig. 2.

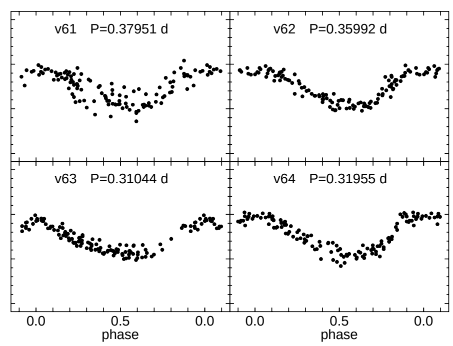

Fig. 4. V-filter light curves of four new RR Lyrae stars. Ordinate is expressed in the same units as in Fig. 2.

RR Lyrae variables are given in Table 1. Coordinates are given in the reference frame of the CVSGC, but were redetermined using positions of 22 known RR Lyrae stars. All variables that we observed are also indicated in Fig. 1.

Using photometric data of Rey et al. (1998) we were able to transform our instrumental V magnitudes of the RR Lyrae stars to the standard ones. Mean magnitudes, $\langle V \rangle$, and ranges of variability, ΔV, of these variables, given in Table 2, were derived according to the formulae

$$\langle V \rangle = \oint f_V(\phi)\, d\phi, \quad \Delta V = \max_{\phi}\{f_V(\phi)\} - \min_{\phi}\{f_V(\phi)\},$$

where f_V is a smooth curve obtained from the Fourier decomposition of the phased light curve of a given variable; ϕ is the phase of the pulsation period. Since a reliable DAOPHOT profile photometry could be obtained only for the stars located well outside the cluster core, we list in Table 2 only those variables whose distance from the cluster centre is greater than about 1 arcmin. The mean V magnitude of the horizontal branch estimated using mean magnitudes of 19 RR Lyrae stars listed in Table 2 is equal to 16.81 ± 0.01 mag.

The total number of known RR Lyrae stars in M53 is now equal to 59, 29 of them being of the RRab type and remaining 30 of RRc. The fraction of the RRab stars has been revised from about 60 per cent to 50 per cent, a value somewhat more typical for the Oosterhoff's (1944) type II globular cluster. The mean period of RRab variables (taking into account also those which we did not observe) amounts to 0.65 ± 0.07 d, and the average period for RRc variables is equal to 0.36 ± 0.04 d.

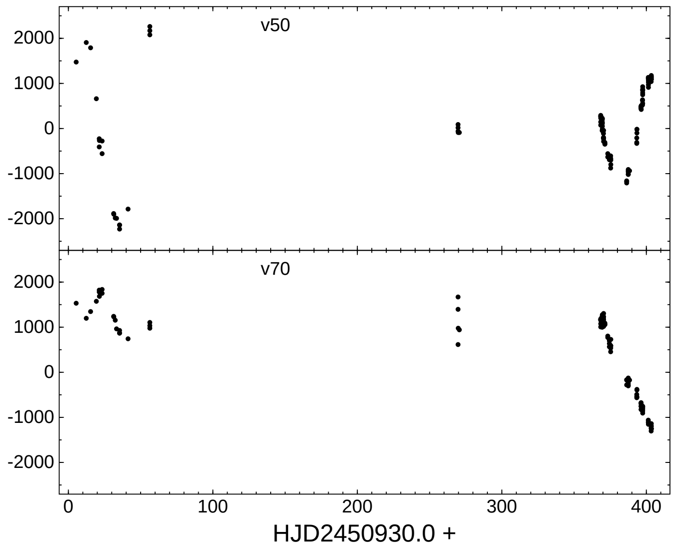

Fig. 5. V-filter light curves of the two variable red giants, v50 and v70. Ordinate is expressed in the same units as in Fig. 2.

Table 2. Average V magnitudes ($\langle V\rangle$) and ranges of variability (ΔV) for 19 RR Lyrae stars located well outside the cluster core.

Variable	Type	$\langle V\rangle$ [mag]	ΔV [mag]
v6	ab	16.77	1.03
v7	ab	16.86	1.24
v8	ab	16.86	1.07
v9	ab	16.81	1.17
v10	ab	16.86	1.24
v11	ab	16.86	0.67
v18	c	16.82	0.53
v19	c	16.83	0.41
v23	c	16.80	0.48
v24	ab	16.79	0.65
v25	ab	16.74	0.82
v29	ab	16.75	0.40
v32	c	16.84	0.51
v33	ab	16.80	1.05
v37	ab	16.75	0.84
v40	c	16.93	0.31
v41	ab	16.77	0.85
v42	ab	16.74	0.92
v44	c	16.78	0.47

Out of the two previously known variables in M53 which are not of the RR Lyrae type, we observed only the red giant v50. Cuffey (1966) determined a period of 55.4 d for this variable. The star is obviously variable in our CCD frames (see Fig. 5). We derived a period of about 49 d for it, but due to the insufficient number of data this value should be treated as a tentative one.

Almost all bright giants in the observed field show some degree of variablity. In most cases, however, it is hard to state whether this is periodic or irregular variability. The most pronounced variations are visible for six red giants which we designated v65 through v70. Positions of these new variables, computed in the same way as for RR Lyrae stars, are given in Table 3.

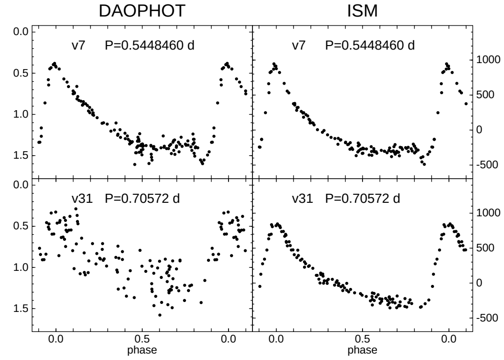

Fig. 6. Comparison of the DAOPHOT differential photometry with the ISM photometry for two RR Lyrae stars. v7 is an isolated star situated outside the cluster core, whereas v31 is blended with several other stars and is much closer to the cluster centre than v7. Ordinate of the left hand side panels is expressed in mag, that of the right hand side panels, in arbitrary flux units.

Table 3. Positions (x, y) relative to the cluster center of the red variables in the observed field. Except for v50, all stars given here are new discoveries. Coordinates are given in the reference frame of the CVSGC.

Variable	x [$''$]	y [$''$]
v50	-139.9	88.4
v65	133.9	53.3
v66	88.5	-1.6
v67	80.7	4.2
v68	14.6	-101.6
v69	11.3	15.4
v70	-1.8	-21.9

Since the brightness changes of these red variables, all located in the tip of the cluster red giant branch, are very similiar to each other, we show in Fig. 5 the light curves only for v50 and v70.

The light curves of all the variables are available in electronic form from CDS in Strasbourg via anonymous ftp to 130.79.128.5.

In Fig. 6, the DAOPHOT and the ISM photometry for two RRab stars, v7 and v31, are compared. In the case of an isolated variable, v7, situated outside the cluster core, the difference is not very large. On the other hand, for v31, located in a more crowded area and closer to the center of the cluster, the quality of the ISM light curve is much better than that of the DAOPHOT one. The ability of the ISM in finding variables in heavily crowded fields can be clearly seen.

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