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DISCOVERY OF NEW RR LYRAE STARS IN THE CENTER OF THE GLOBULAR CLUSTER M53

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ABSTRACT

We report the discovery of 17 new RR Lyrae variables in the central region ($r \leq 1'$) of the globular cluster M53. These candidates were identified by using the Welch & Stetson (1993) technique and confirmed by checking individual light curves in both B and V bands. The color-magnitude diagram of the horizontal-branch stars in the central region is compared with that for stars observed in the outer region by Rey et al. (1998). Including the new data from this study, we estimate the fraction of c type RR Lyrae variables, $n(c)/n(ab+c)$, to be 0.43 which agrees well with the values of other Oosterhoff group II clusters.

1. INTRODUCTION

The globular cluster M53 is the most ideal metal-poor Oosterhoff group II cluster for the observational investigation of the Sandage (1982) period-shift effect of RR Lyrae variables. It has (1) a large number of RR Lyrae stars ($\sim$ 40 RR Lyrae stars, Sawyer Hogg 1973), (2) little or no foreground reddening (Zinn 1985), and (3) the horizontal-branch (HB) morphology simliar to M15, but the blue tail phenomenon is not present (Rey et al. 1998). Although many RR Lyrae stars have been already identified in M53 (Rey et al. 1998), it is still important to search for more RR Lyrae stars not identified before, in order to obtain more improved period-temperature ($\log P$ - $\log T_{eff}$) relation of M53.

Until recently, most known variables in globular clusters have been found by photographic surveys. However, due to the limited dynamic ranges of photographic observations, complete photometry in the crowded central region could not be performed. For instance, only two RR Lyrae stars were previously reported within $r \sim 1'$ in M53 (Sawyer Hogg 1973). Recently, CCD observations enable us to carry out an effective photometric search for variable stars in the cluster centers. Rey *et al.* (1998) discovered eight new RR Lyrae variables in the outer region ($r > 1'$) of this cluster from their high quality CCD data. In this paper, using the same data set of Rey et al. (1998), we search for new RR Lyrae candidates in the central region ($r \leq 1'$) of the globular cluster M53.

2. OBSERVATIONS AND DATA REDUCTION

The observations were made by using the University of Hawaii 2.2 m telescope with the $f/10$ secondary and the Tektronix 2048 × 2048 pixel CCD, on 1995 March 30/31 and March 31/April 1. The CCD provides an image scale of $0''.22$ with a field size of $7'.5 \times 7'.5$. The cluster was covered out to a radius of $6'.6$ from the center, in a grid of four partially overlapping fields. Ten to eleven frames were taken in the B and V bandpasses for each field under excellent photometric conditions (FWHM = $0''.8 \sim 1''.2$). We used DAOPHOT II and ALLSTAR (Stetson 1987, 1992a) to perform stellar photometry. DAOMATCH/DAOMASTER (Stetson 1990, 1992b) routines were then used to match stars of all frames covering the same field and to derive the average instrumental magnitude and colors on the same photometric scale. The details of observations and reduction procedures are fully discussed in Rey et al. (1998).

3. DISCOVERY OF NEW RR LYRAE VARIABLE STARS

Candidates of new RR Lyrae stars were identified by using the Welch & Stetson (1993) technique. This technique looks for changes in brightness which is correlated in two wavelengths measured at nearly simultaneous epoch, and is strongly discriminant against "bad" data points. For the n epochs of photometry in the two bandpasses, the variability index (I_{WS}) of Welch & Stetson (1993) is defined by

$$I_{WS} = \sqrt{1/n(n-1)} \sum_{i=1}^{n} (\delta B_i \delta V_i) \tag{1}$$

where δB_i and δV_i are the normalized magnitude residuals for the individual bandpasses. For pulsating variable stars such as RR Lyrae variables, the residuals δB_i and δV_i are correlated, since an increase in surface temperature or radius result in brightness increases in both the b and v bandpasses. Therefore, large positive variability index implies true variability. This leads us to identify the true variability of pulsating stars by minimizing the possibility of misidentification. While there is possibility of spurious correlations arising from the observational conditions such as crowding effects, variations in seeings, or other purely observational effects (see Welch & Stetson 1993), we can expect negligible effect for our results since our data set is obtained under superb seeing condition during the observing run.

Figure 1 shows I_{WS} as a function of the mean V magnitude for HB stars within $1'$ from the center of M53. Seventeen stars clearly show large variability index (open circles in Figure 1), suggesting that they are RR Lyrae candidates. In order to confirm that they are indeed RR Lyrae stars, we construct light curves in both bandpasses, and they are shown in Figure 2. We plot the light curve of a non-variable HB star in Figure 3 to check the variability. Based on the shape and amplitude of the light curve, we conclude that they have the characteristics of RR Lyrae stars. In Table 1, we list the photometric characteristics of the 17 new RR Lyrae candidates discovered in this study. Column (1) is the identification number of RR Lyrae candidates. The identification number from the photometry of Rey et al. (1998, see their Table 2) is enclosed in the parentheses. Though the data set of the light curve is sparse, from the shape of light curve, we have classified the stars according to the Baily

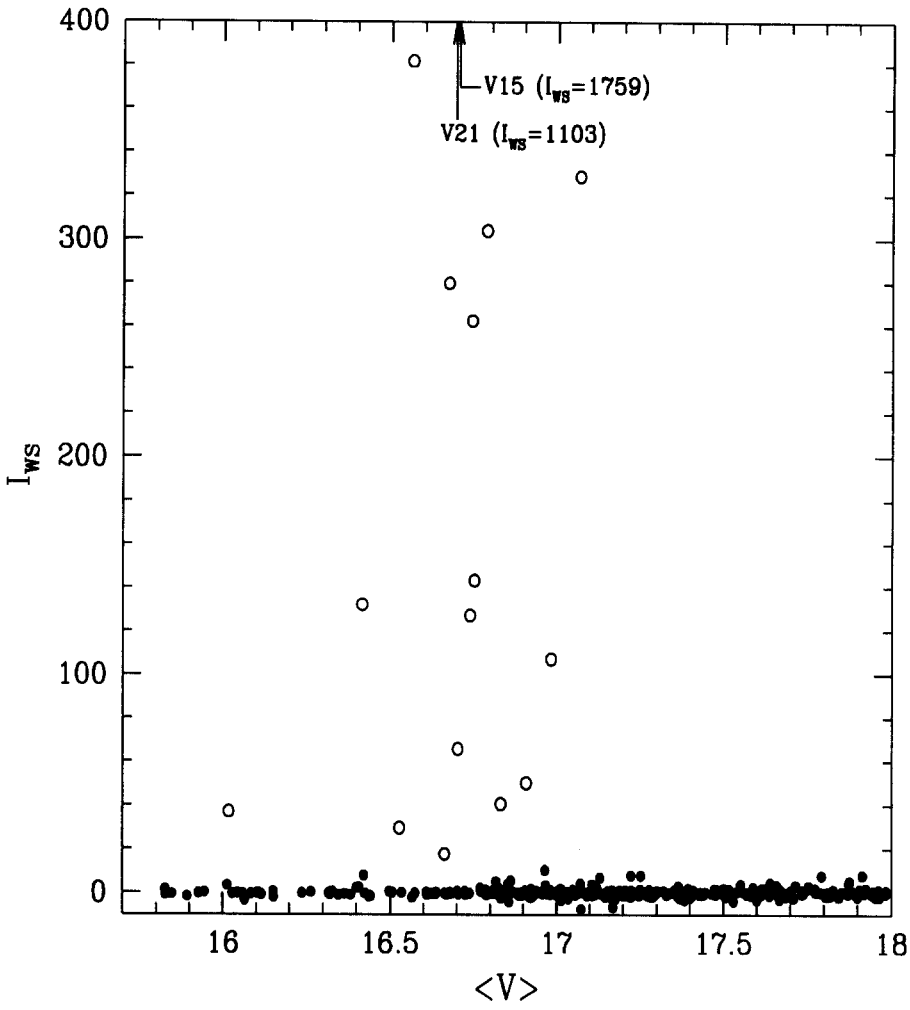


Figure 1. The variability index (I_{WS}) of Welch & Stetson (1993) plotted as a function of the mean V magnitude for horizontal-branch stars in the inner region ($r \leq 1'$) of M53. Open circles are for 17 new RR Lyrae candidates. Two stars (V15 and V21) with relatively large values of I_{WS} are marked with arrows.

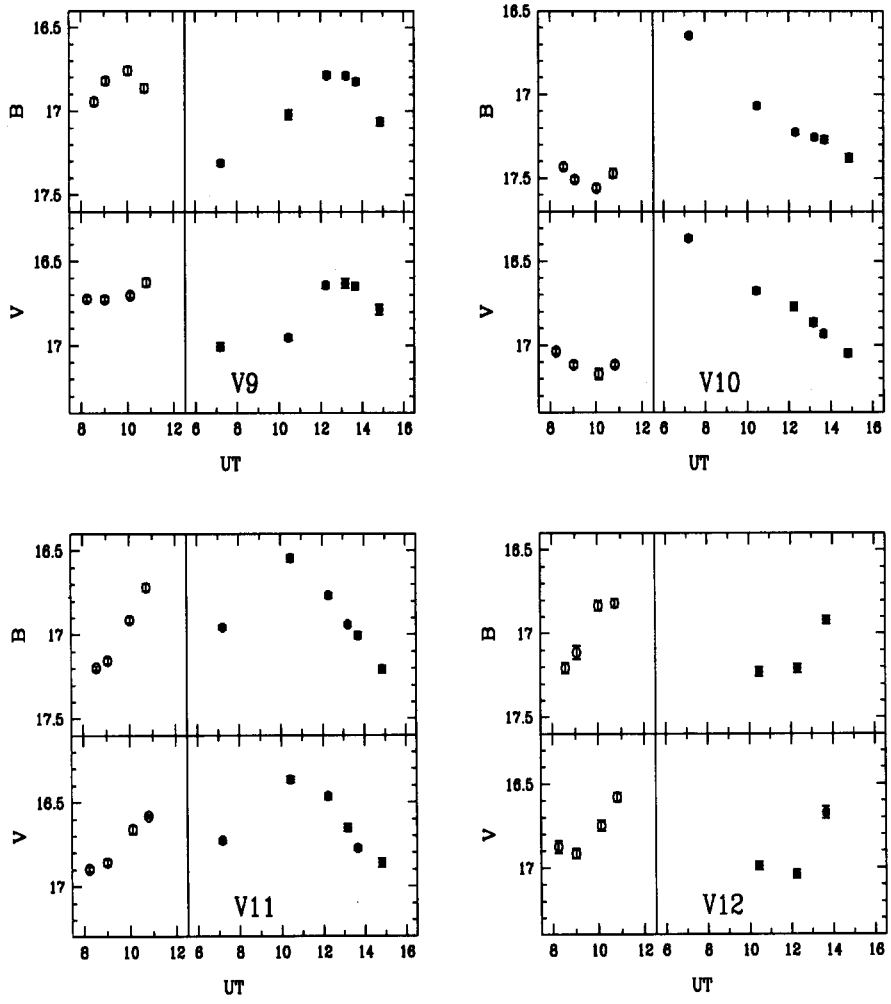


Figure 2. Individual light curves for 17 new RR Lyrae variables discovered in this study. The open and closed circles represent, respectively, data from two successive nights.

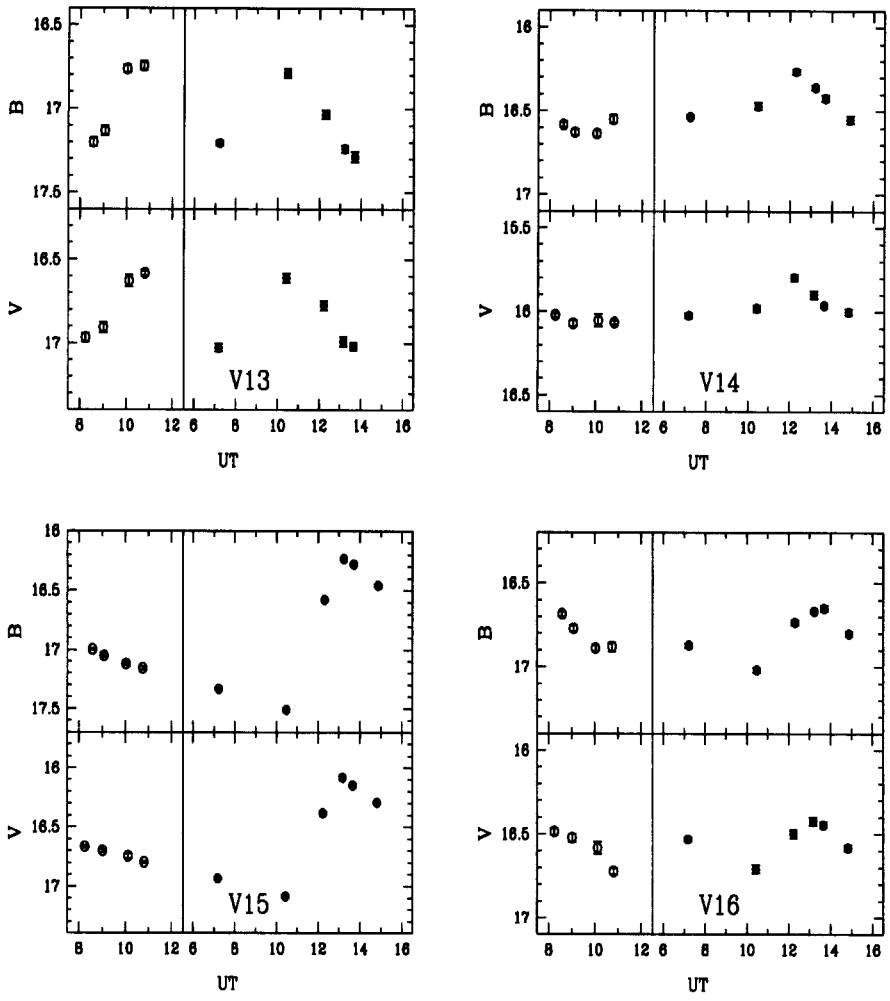
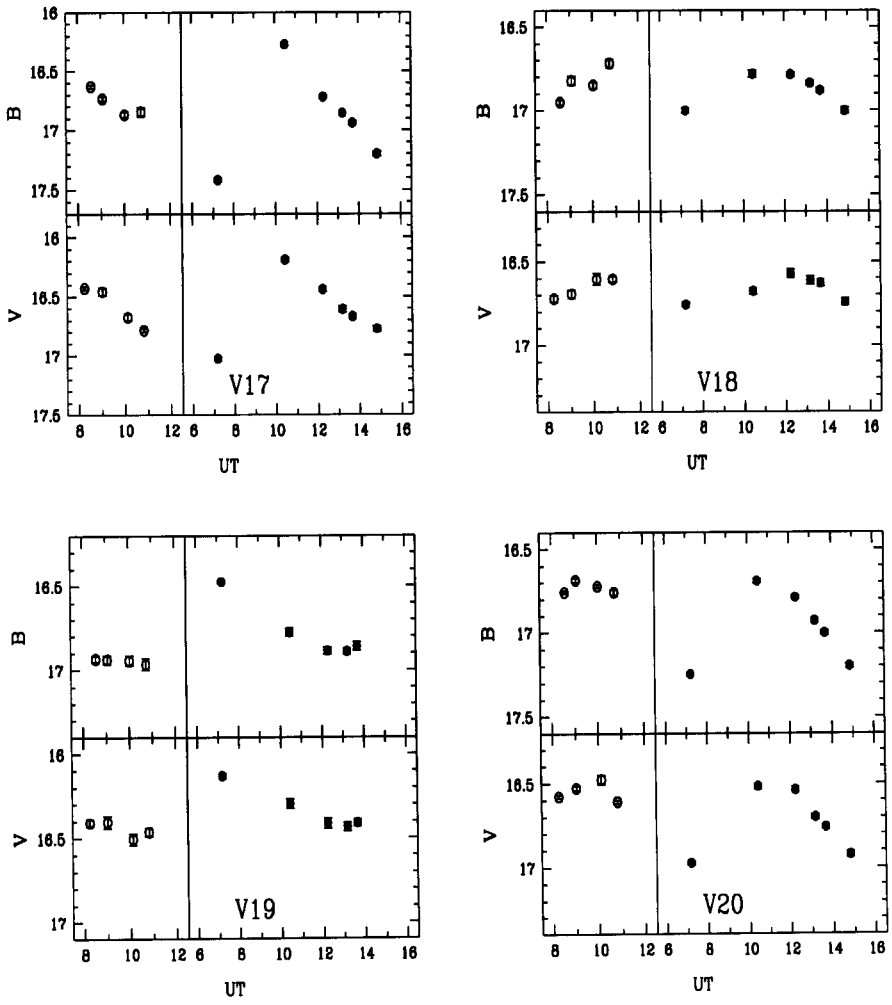


Figure 2. (continued)



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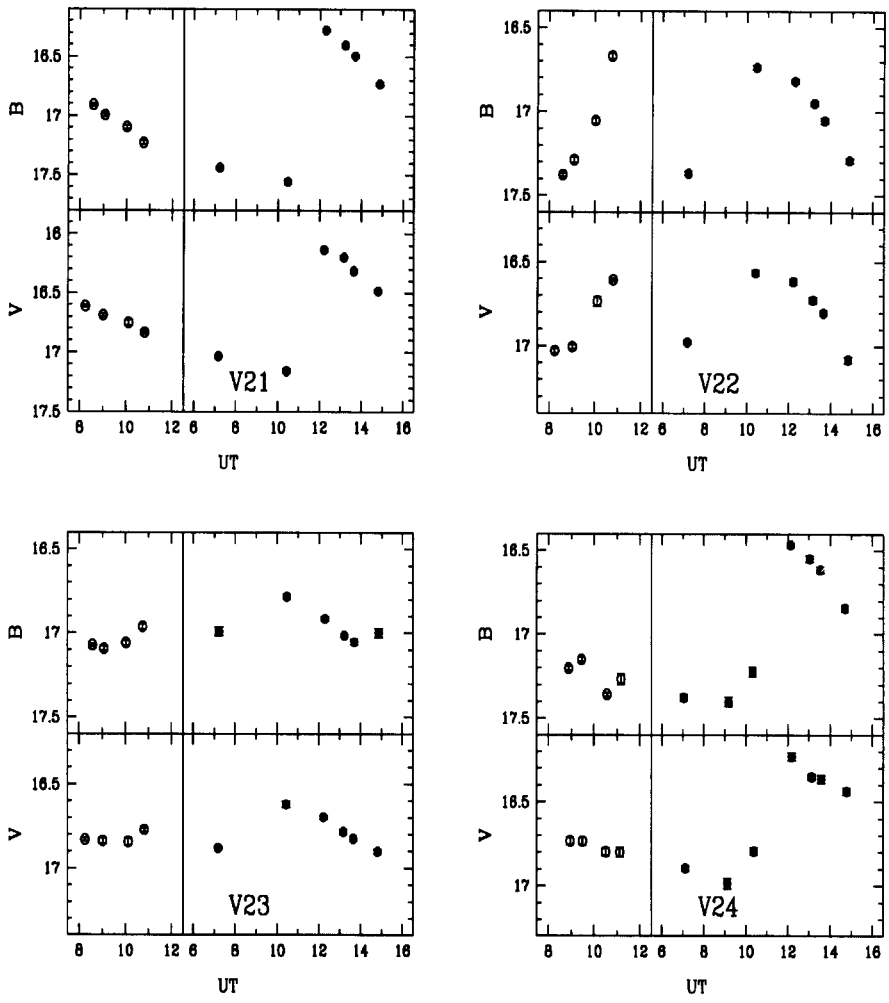

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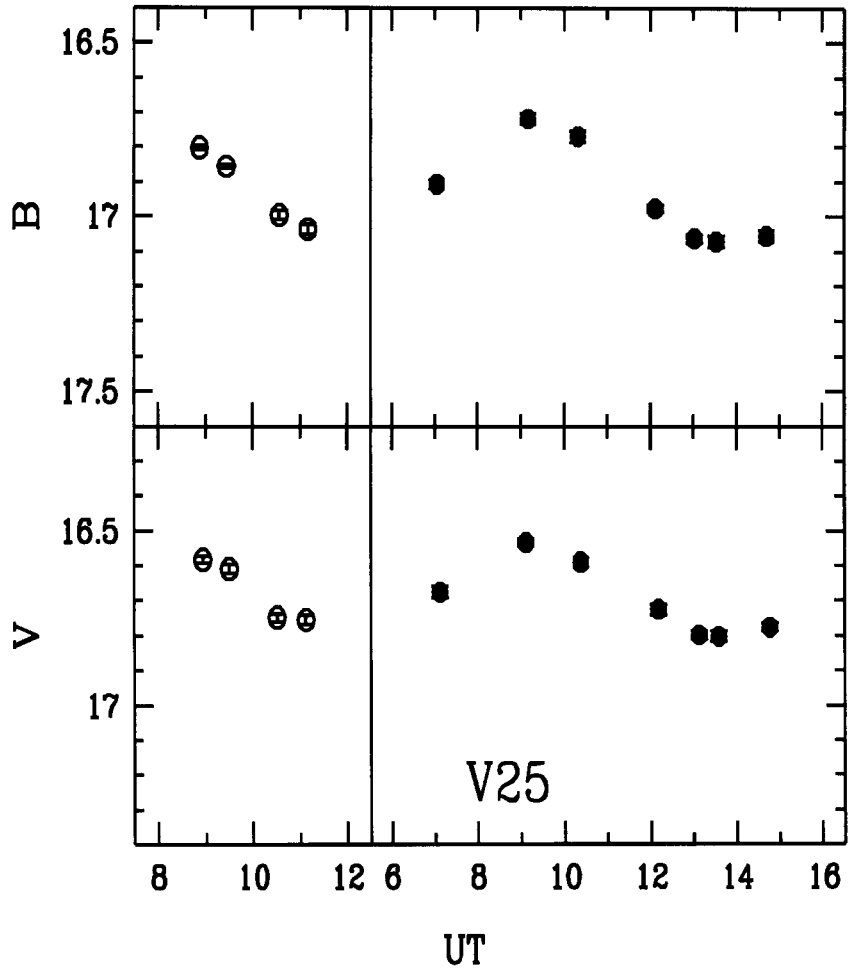

Figure 2. (continued)

types [column (7)]. The complete photometry of M53 RR Lyrae stars is now in progress and will provide a detailed survey of new RR Lyrae candidates. We identified a star (S48) which is listed as a RR Lyrae variable in the catalog of Sawyer Hogg (1973). However, it has a small I_{WS} value ($I_{WS} = -0.30$) and shows no prominent light variation (see Figure 4). This star is at a distance of $r = 0'.18$ from the center of M53, and may had been misidentified due to the poor quality of the photographic photometry over a very dense field (Rey 1999).

In Figure 5, we present the color-magnitude diagram (CMD) of HB stars in the central region ($r \leq 1'$) of M53. New RR Lyrae variables discovered in this study are plotted as open triangles. Note that the V magnitudes and $B - V$ colors for RR Lyrae stars presented in this study are only mean values measured from seven to ten frame pairs at random epochs. Therefore, they are not the true average values determined over their full light curves. Apparently, there are some stars within the RR Lyrae instability strip in the CMD, but show smaller values I_{WS} than the lower limit of newly discovered RR Lyrae stars. Careful examination of their light curves suggests that three of them show weak evidence of variability. They are plotted as crosses in Figure 5. The characteristics and light curves of these suspected RR Lyrae candidates are presented in Table 2 and Figure 7, respectively. Further observations for these stars are needed to determine whether they are indeed RR Lyrae stars or not.

The CMD of the HB stars in M53 including the outer region (data from Rey *et al.* 1998) is presented in Figure 7. Open circles are for 35 RR Lyrae stars in the outer region ($r > 1'$). It is known that Oosterhoff group II clusters have different proportions of *ab* to *c* type variables compared to the Oosterhoff group I clusters (see Lee *et al.* 1990). Including new RR Lyrae stars discovered in this study, we find $n(c)/n(ab+c) = 21/(28+21) = 0.43$, which is consistent with the mean value 0.44 of the Oosterhoff group II clusters (Smith 1995).

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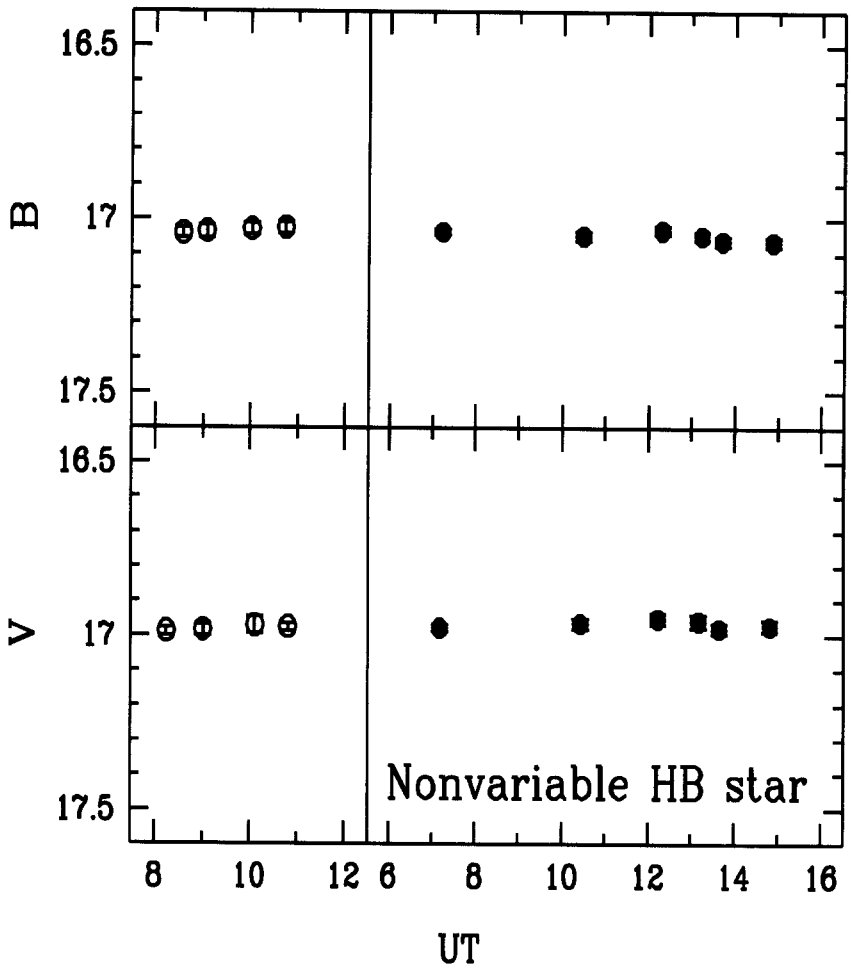

Figure 3. The light curve for one arbitrary nonvariable HB star.

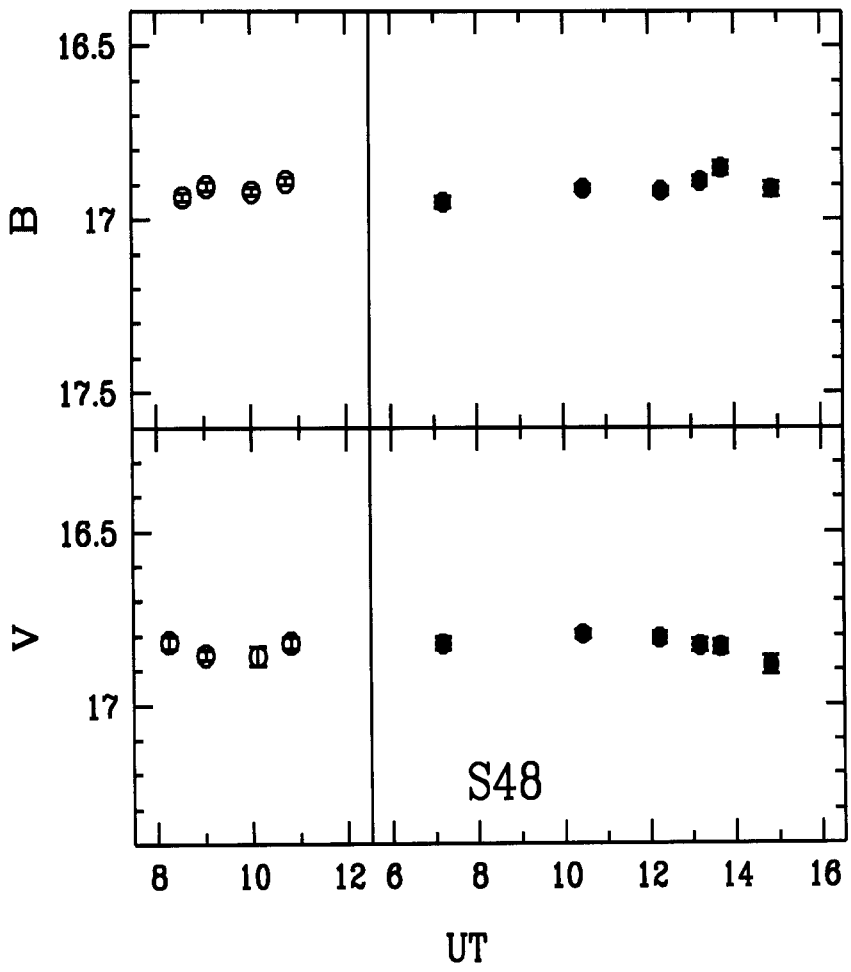

Figure 4. The light curve for S48, listed in the catalog of Sawyer Hogg (1973) as RR Lyrae star. This star may had been misidentified as a RR Lyrae variable in the previous investigation (see text).

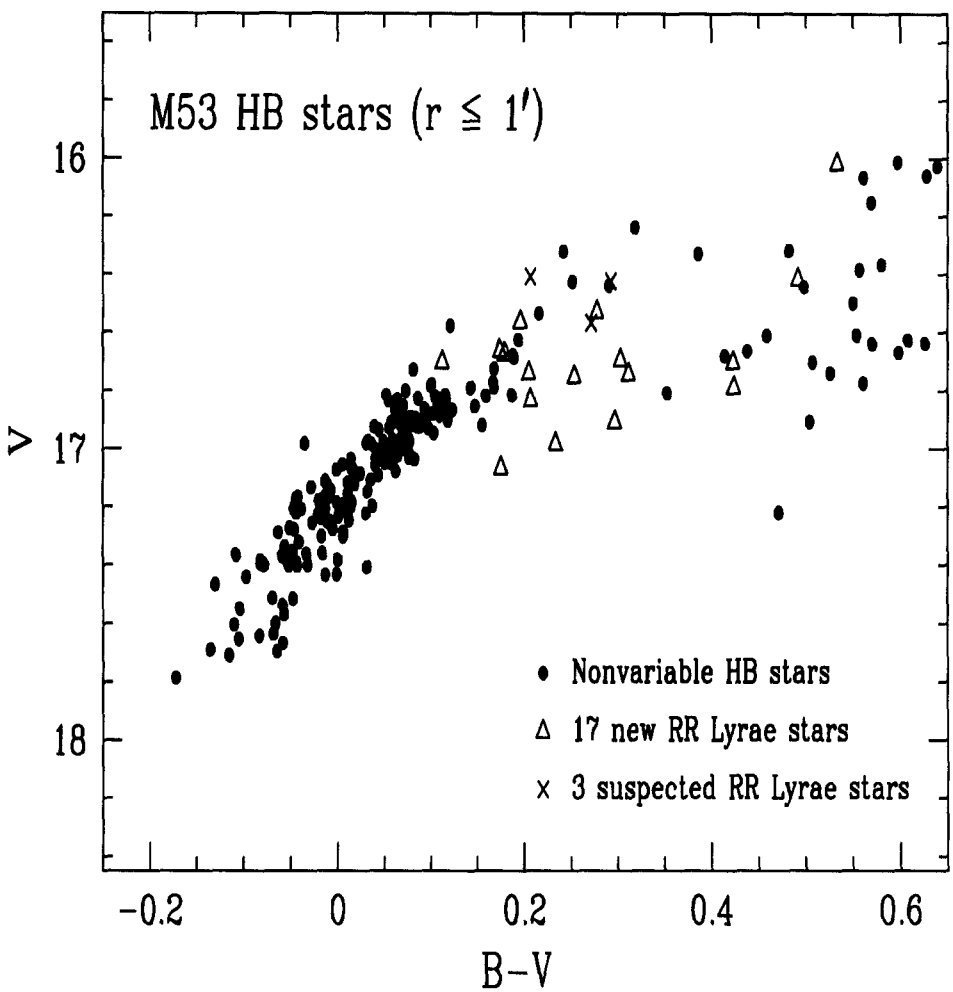

Figure 5. Color-magnitude diagram of the HB stars in the inner region ($r \leq 1'$) of M53.

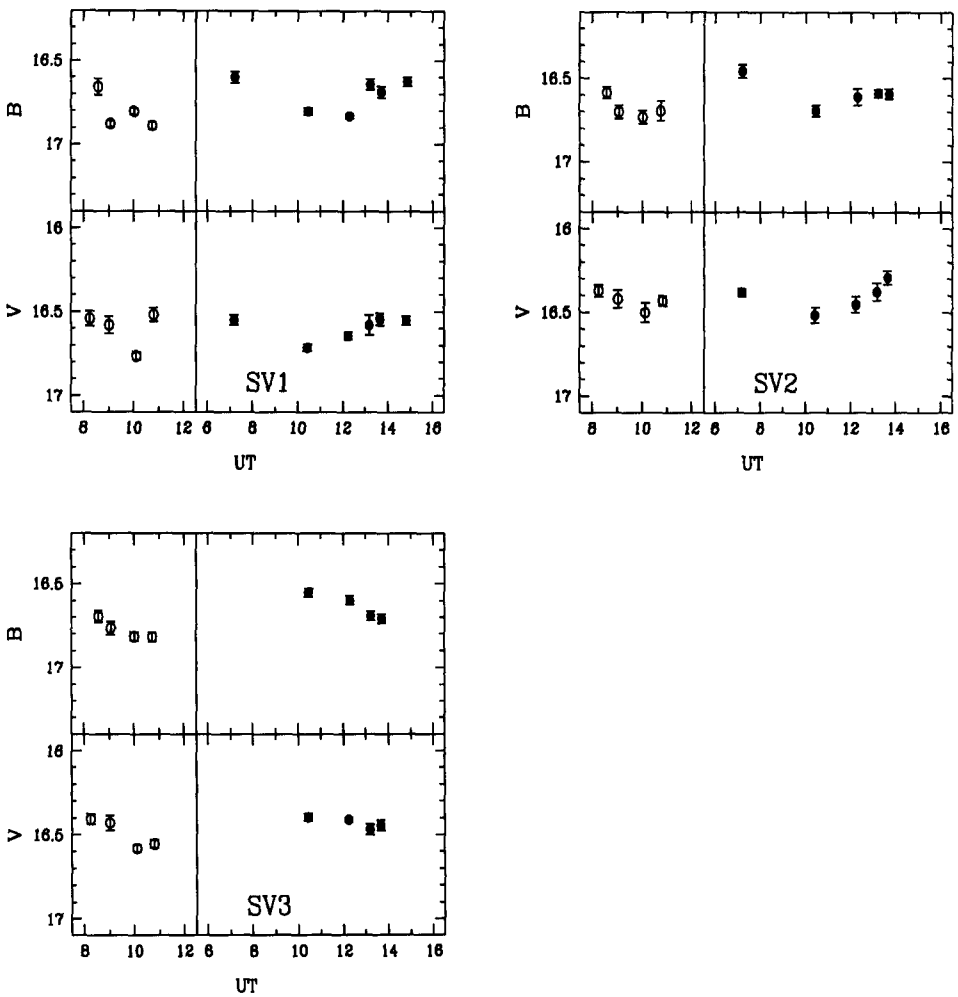

Figure 6. Individual light curves for 3 suspected RR Lyrae candidates.

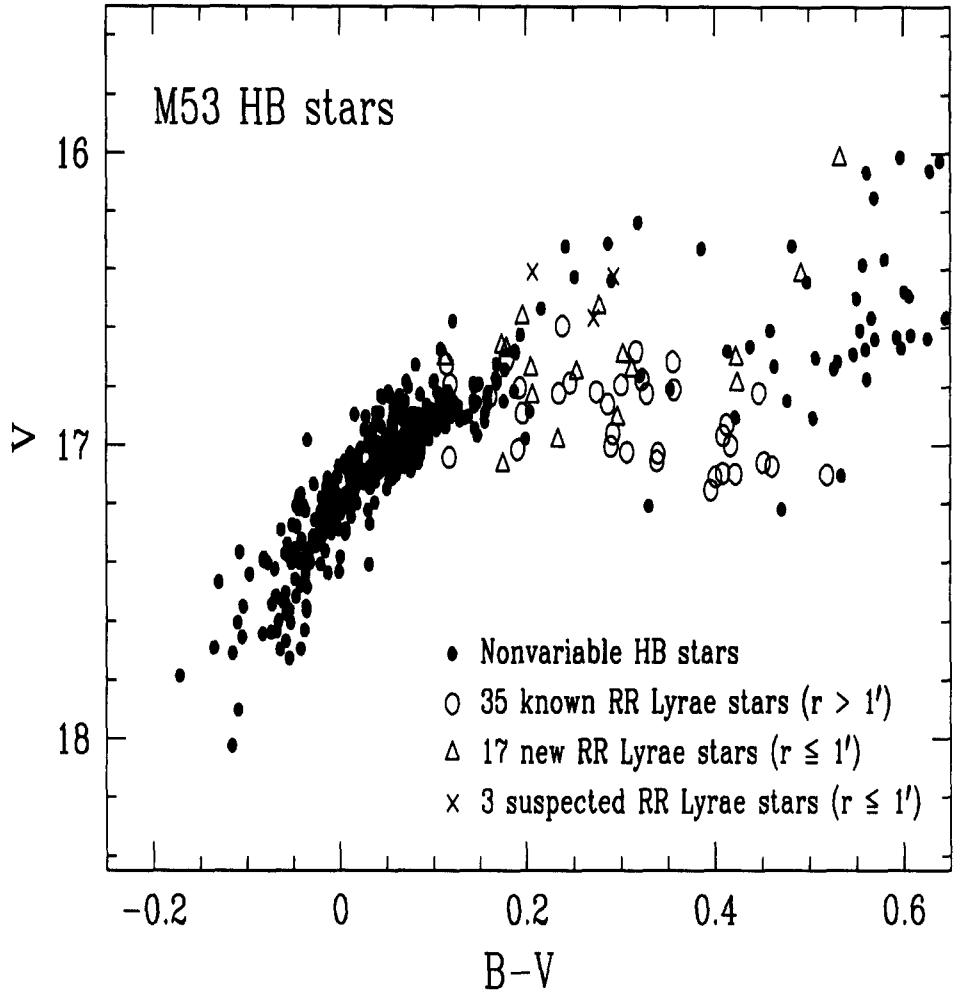

Figure 7. Color-magnitude diagram of the HB stars in M53 including outer region ($r > 1'$). Open circles denote 35 RR Lyrae stars in the outer region (Rey et al. 1998).

Table 1. New RR Lyrae stars discovered in the central region of M53.

Star	r (′)[a]	V[a]	$(B-V)$[a]	I_{WS}	N[b]	Type
V9(483)	0.50	16.702	0.112	65.74	10	c
V10(859)	0.56	17.068	0.175	328.72	10	ab
V11(503)	0.72	16.739	0.205	128.09	10	c
V12(654)	0.47	16.908	0.297	50.05	7	c(?)
V13(732)	0.52	16.983	0.234	107.10	9	c
V14(253)	0.76	16.018	0.533	36.93	10	c
V15(486)	0.93	16.703	0.423	1759.25	10	ab
V16(418)	0.19	16.528	0.278	29.54	10	c
V17(468)	0.16	16.674	0.179	279.75	10	ab
V18(462)	0.26	16.663	0.174	17.57	10	c
V19(368)	0.60	16.416	0.492	131.97	9	ab(?)
V20(429)	0.61	16.564	0.196	381.74	10	c
V21(480)	0.68	16.693	0.303	1102.54	10	ab
V22(501)	0.84	16.744	0.312	262.41	10	c(?)
V23(570)	0.82	16.832	0.207	40.49	10	c
V24(535)	0.94	16.788	0.424	303.85	10	ab
V25(510)	0.93	16.752	0.254	143.15	10	c

[a] From Rey et al. (1998)
[b] Number of frames detected

Table 2. Suspected RR Lyrae candidates in the inner region of M53.

Star	r(′)[a]	V[a]	$(B-V)$[a]	I_{WS}	N
SV1(436)	0.30	16.556	0.272	-2.15	10
SV2(366)	0.09	16.408	0.207	2.35	9
SV3(371)	0.54	16.422	0.293	7.80	8

[a] From Rey et al. (1998)