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Variable Star Status of Two Stars: V204 and I-I-39 in M3

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Abstract The star I-I-42 (=vZ1390), a cluster member in M3, located near the red edge of the instability strip of the horizontal branch, was discovered by Roberts and Sandage as a low amplitude variable, it was designated as V204 in the "second catalogue of variable stars in globular clusters", but its coordinates given in all versions of this catalogue are wrong since 1955. We argue that V204 is indeed a low amplitude HB variable star, located near to the red edge of the instability strip, with a period of $0.74785^{\rm d}$ and an amplitude of about 0.04 mag in V. We also find that the red cluster member star I-I-39 is a low amplitude variable with a period of $1.16^{\rm d}$ and amplitude of about 0.03 mag in V which might be pulsating at the second overtone.

Key words: globular cluster — stars: variables — stars: individual (V204 and I-I-39)

1 INTRODUCTION

The low amplitude variable star I-I-42 in M3 was discovered by Roberts & Sandage (1955) with a $P = 0.9170^{\rm d}$, $A_{\rm pg} = 0.14$, $A_{\rm pv} = 0.12$ and Bailey type = "?". Proper motion determination showed its cluster membership (Cudworth 1979). The parameters of this star given by Sandage (1959) are $P = 0.9163$, $V = 15.58$, $B - V = 0.42$, $U - B = -0.02$, $A_U = 0.22$, $A_B = 0.14$, $A_V = 0.12$ and Bailey type = "?". I-I-42 was compiled as V204 in the catalogue of variable stars in globular clusters (Sawyer1955), but was given an erroneous position. Although Cudworth (1979) pointed out the error, the latter has remained uncorrected in all the versions of the catalogue (Clement et al. 1998, 2001, 2007). Bakos et al. (2000) presented correct identification charts and astrometry of all the variables including V204 (see their finding chart fig.12). Adopting the center of M3 as: $\alpha_{2000} = 13^{\rm h}42^{\rm m}11.2^{\rm s}$; $\delta_{2000} = 28^\circ22'32''$, they gave for V204 $\Delta\alpha = 27.511^{\rm s}$; $\Delta\delta = 16.19''$, so the coordinates should be $\alpha_{2000} = 13^{\rm h}42^{\rm m}38.7^{\rm s}$; $\delta_{2000} = 28^\circ22'48.2''$ (in the CDS, the coordinates for vZ1390 are 13:42:38.87; 28:22:48.1 (2000)). Though in Clement et al. (2007) we find the statement "RAs, Decs and Types for this table are from Bakos et al." , but they still show "204 13:42:03.62 28:22:20.1 not var" in their table.

If the magnitude and colors measured by Sandage are correct, then V204 is located near the red edge of the instability strip. Kukarkin (1974) pointed out the importance of investigating the small amplitude variables in M3 at the red and blue boundaries of the instability strip. He was surprised at the indifference on the part of astronomers regarding this problem: since their discovery, no one has investigated their status.

Half a century later, V204 was measured with CCD photometry, but the results are puzzling. Corwin & Carney (2001) obtained B=16.490, $V = 15.693$ and $B - V = 0.797$, with the comment "nonvariable?" (see their table 4, the non-variable stars with variable ID in the catalogue). Benko et al. (2006) presented for V204, $V = 15.877$, $B = 15.948$ and $I = 15.042$ ($B - V = 0.071$). From the literature, V204 could be a constant star located far away from the instability strip. Note that all of above papers have referred to the paper of Barkos et al. (2000), so there should be no mis-identifications.

We have checked the variability of V204 and its position on the C-M diagram. It is shown that it is a low amplitude variable with a period of about $0.74785^{\rm d}$ and in V amplitude of about 0.04 mag, and is located near the red edge of the instability strip.

Meanwhile, we have found that the red cluster member star I-I-39 is a low amplitude variable with a period of about $1.16^{\rm d}$ and amplitude of about 0.03 mag in V. In this paper the photometric observations and reduction are described in Section 2, a discussion and the conclusions are given in Section 3.

2 OBSERVATIONS AND REDUCTION

The time series observations of M3 were obtained at the Cassegrain focus of the 2.16-m reflector plus BFOSC at Xinglong, National Astronomical Observatories, CAS, using the Loral 2048×2048 CCD detector (pixel size 15 μm at a scale of $0.301''$ pixel^{-1}) with a field size of about $10.3'\times10.3'$, on 2001 April 14–16 and 19.

A total of 73 V and a few B frames were obtained with exposure times varying from 200 to 600 seconds depending on the atmospheric transparency, the seeing was between $1.4''$ and $6.6''$ (FWHM). The observation log is shown in Table 1. Twilight sky exposures were combined to obtain the flat field. After the bias was subtracted and the flat field removed, the DAOPHOT (Stetson 1987) in IRAF (routine allstar) was used to measure the stars. Period98 (Sperl 1998) was used to analyse all the unevenly sampled data.

Table 1 Observation Log

Date	Telescope	Number of useful frames	Seeing ($''$)
2001 April 14	2.16-m + BFOSC	18	1.4 to 1.9
2001 April 15	2.16-m + BFOSC	16	1.7 to 3.5
2001 April 16	2.16-m + BFOSC	18	2.1 to 2.5
2001 April 19	2.16-m + BFOSC	21	4.5 to 6.6

2.1 Positions on the C-M Diagram

All the stars (except the crowded core area) on the CCD frames d1021 (V) and d1022 (B) were measured to obtain the C-M diagram shown in Figure 1, with the member stars V204, I-I-40 and I-I-39 marked. A small $1.5'$ by $1.5'$ region around V204 cut from the frame d1021 is shown in Figure 2.

In Figure 1, V and $B-V$ are the instrumental values: no attempt was made to transform them into standard Johnson B and V system, because the BFOSC CCD data obtained in April of 2001 are not suitable for such work. The reasons are: (a) The Inhomogeneity in the spectral transmission of the coated glass filters of BFOSC (Yao & Huang 2001). (b) The strong influence of scattered light from the 2.16-m on the flat field (Yao & Lin 1997; Yao et al. 2005). (c) The special optics of BFOSC and the weakness of the used CCD controller (the degree of nonlinearity and the FWHM of the star change from one position to the next on the CCD), the psf varies from pixel to pixel and no one of the six analytic functions in DAOPHOT can fit it perfectly (Yao et al. 2004, 2006).

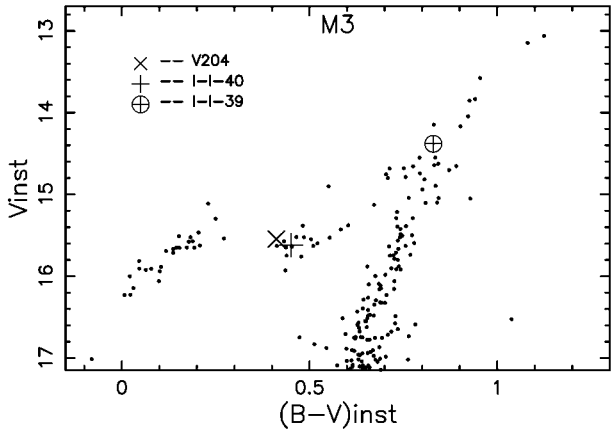

Fig. 1 C-M diagram of M3, with instrumental V and $B-V$.

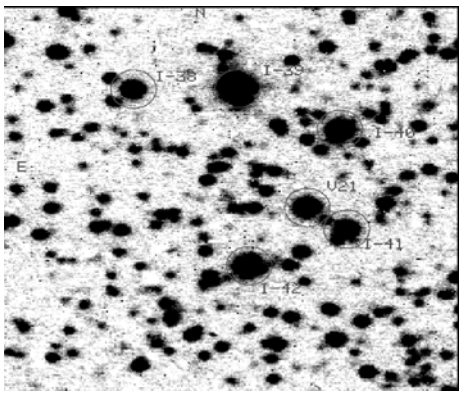

Fig. 2 Identification chart for V204 and I-I-39 (I-42 = I-I-42 = V204, I-39 = I-I-39, for simplicity).

Nevertheless, Figure 1 shows the relative positions on the C-M diagram, well. The relevant measurements in the literature and in this paper are as follows:

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Red edge of the instability strip
  (B-V) = 0.39              (Johnson & Sandage 1956, photographic photometry)
  (B-V) = 0.420             (Sandage, 1969, photoelectric photometry)
  (B-V)inst = 0.43   (this paper)
V204 = I-I-42
  V = 15.58, B-V = 0.44, U-B = 0.02     (Sandage 1969, photoelectric)
  V = 15.58, B-V = 0.42                 (Sandage 1990, mean values)
           (B-V)inst = 0.41             (this paper)
I-I-40
  V = 15.68, B-V = 0.39, U-B = 0.00     (Sandage 1969, photoelectric)
           (B-V)inst = 0.45             (this paper)
I-I-39
  V = 14.44, B-V = 0.91, U-B = 0.37     (Johnson & Sandage 1956, photographic)
           (B-V)inst = 0.83             (this paper)
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Sandage (1969) made his photoelectric photometry with the 200-inch reflector. Although a small diaphragm ($7.6''$ in diameter) was used, corresponding to 25.2 pixels on the BFOSC CCD frame, he was still able to include some faint neighboring stars in his diaphragm. There is an effect of the relative brightness. The $B-V$ of I-I-40 measured by Sandage is bluer than that of the red edge and V204, so it would be located inside the instability strip, but in fact its $B-V$ is larger so it could be located beyond the red edge. In our CCD photometry, the $B-V$ of V204 is always bluer than that of I-I-40.

We have no intensity-averaged color for V204, but the amplitude of V204 in V is small, so the amplitude of its $B-V$ must be smaller, and the observation date of d1021 and d1022 corresponding to the phase $\approx$0.25 on the light curve, we estimate that the deviation from the mean color is less than 0.01 mag. Therefore, it should be safe to infer that V204 is located near to the red edge of the instability strip and may be within the strip. Its $B-V$ can never be 0.797, nor 0.071.

2.2 Period Searching and Light Curves

In the small region shown in Figure 2, the psf is approximately constant, so differential photometry is feasible. There are only six bright stars in Figure 2. I-I-38 and I-I-41 are not suitable as comparison stars because their neighboring stars are not faint enough. Then, the only comparison star left is I-I-40. The known RR Lyrae star V21 has a period of $0.5157336^{\rm d}$. Comparing the light curves of V21 – I-I-40 (Fig. 3) with that by V21 – V204 (Fig. 4) and by V21 – I-I-39 (Fig. 5), systematic deviations among different nights on the light curves between phase 0.1 and 0.5 in Figures 4 and 5 can be found, but not in Figure 3.

If we suppose that I-I-40 is constant, then variability is confirmed for V204 and I-I-39, and their preliminary periods are found: V204 has a period of $0.74785^{\rm d}$ and a peak to peak amplitude of $\approx$0.04 mag

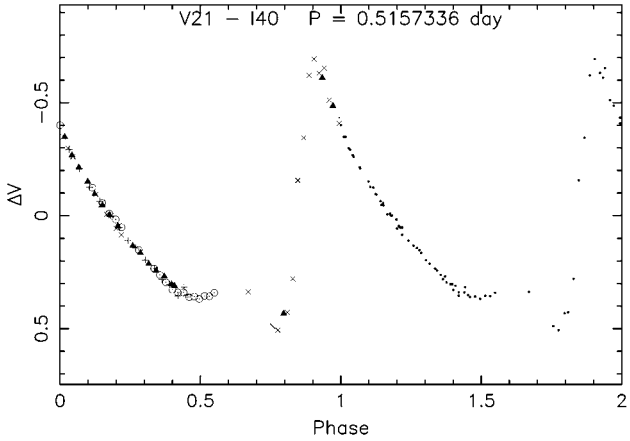

Fig. 3 Folded differential light curve of V21–I-I-40 (I40 = I-I-40). Different symbols are used for different nights between phase 0.0–1.0 and the same symbol between 1.0 and 2.0. The same symbols are used in Figs. 3–8.

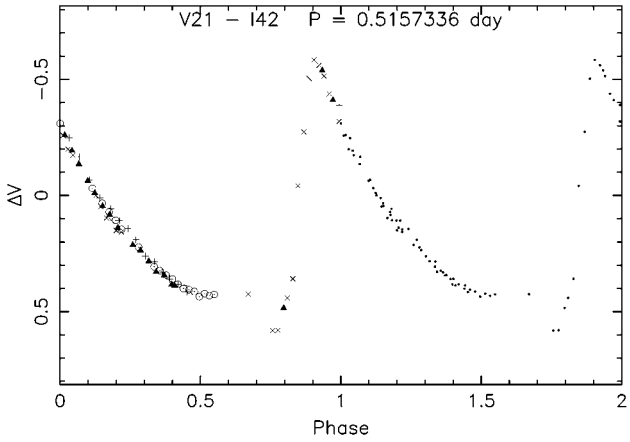

Fig. 4 Folded differential light curve of V21–V204 (I42 = V204).

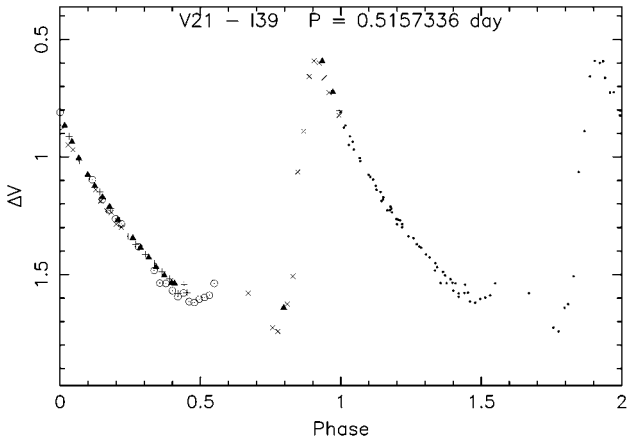

Fig. 5 Folded differential light curve of V21–I-I-39 (I39 = I-I-39).

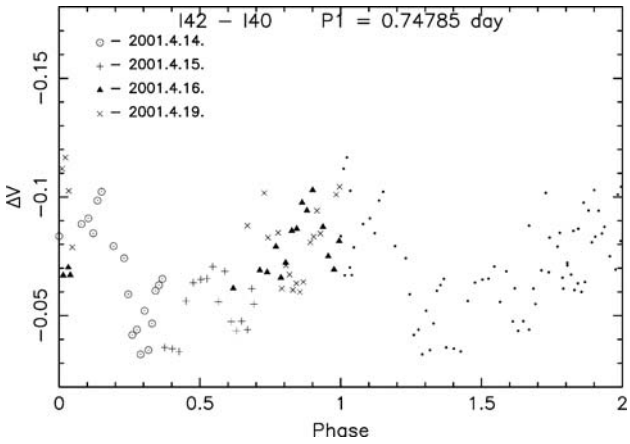

Fig. 6 Folded light curve with P_1 of V204 (I42 = V204, I40 =I-I-40).

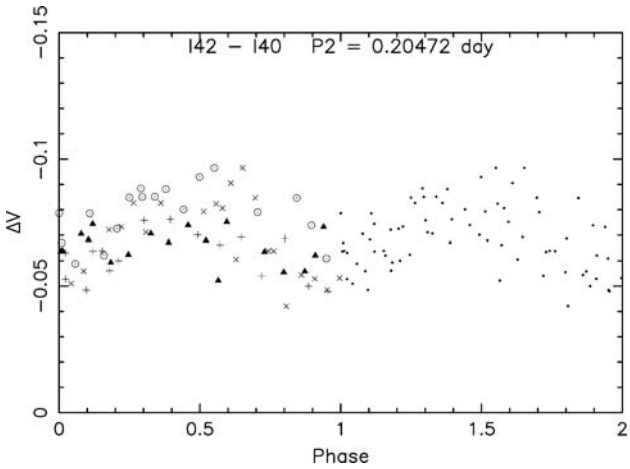

Fig. 7 Folded light curve with P_2 of V204.

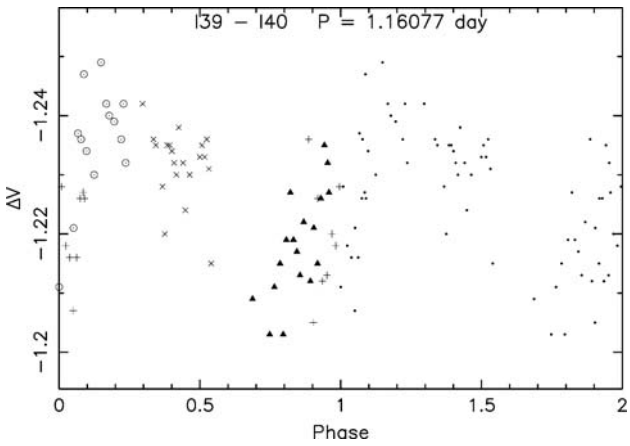

Fig. 8 Folded light curve of I-I-39 (I39 = I-I-39).

in V. There is a second period $P2 = 0.20472^{\rm d}$, but, it may belong to I-I-40. Further better photometry is required to examine this question.

The red star I-I-39 has a period of about $1.16077^{\rm d}$ and amplitude of 0.03 mag in V. The folded light curves are shown in Figures 6, 7 and 8.

3 DISCUSSION AND CONCLUSIONS

1. V204 is not a constant star, but it may be that the period is shorter and the amplitude is lower than that measured by Roberts & Sandage (1955).
2. Further better observations should be carried out in order to improve the period measurement.
3. At the accuracy of our measurement, it is difficult to decide whether I-I-39 is an RGB or an AGB star. In the literature the distance modulus for M3 is $(m - M)_V = 14.8 - 15.2$, so if we take for I-I-39, $E_{(B-V)} = 0.01$, $(m - M)_V = 15.0$ and $V = 14.44$, then its $M_V = -0.59$. According to Xiong's estimation (2006a,b), I-I-39 will be pulsating at the second overtone.
4. Needless to say, the results in this paper should be checked by independent observations. A reflector plus CCD camera with a scale better than $0.3''$ pixel^{-1} is preferred in order to operate psf analyse and to eliminate the influence of faint neighbor stars more precisely.

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