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A NEW SEARCH FOR VARIABLE STARS IN THE GLOBULAR CLUSTER NGC 6366[1]

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RESUMEN

A través de fotometría CCD de NGC 6366 se han descubierto nuevas estrellas variables. Se descubrieron: dos posibles Cefeidas Anómalas (o Cefeidas de Pob II), tres gigantes de largo período, una SX Phe y una binaria eclipsante. También se reporta una lista de 10 posibles variables. La curva de luz de la estrella RRab, V1, fue descompuesta en sus armónicos de Fourier y éstos se emplearon para estimar la metalicidad y la distancia de la estrella; [Fe/H] $= -0.87 \pm 0.14$ y $d = 3.2 \pm 0.1$ kpc. Se argumenta que la estrella V1 podría no ser miembro del cúmulo sino un objeto más distante. Si es así, se puede emplear V1 para calcular un límite superior para la distancia del cúmlo de 2.8 ± 0.1 kpc. La relación $P - L$ para estrellas tipo SX Phe y los modos de pulsación identificados en la SX Phe descubierta, V6, permiten una determinación independiente de la distancia $d = 2.7 \pm 0.1$ kpc. El caso de V1 es discutido en el marco de la relación M_V- [Fe/H] para estrellas RR Lyrae.

ABSTRACT

New CCD photometry of NGC 6366 has lead to the discovery of some variable stars. Two possible Anomalous Cepheids (or Pop II Cepheids), three long period variables, one SX Phe and one eclipsing binary have been found. Also a list of 10 candidate variables is reported. The light curve of the RRab star, V1, has been decomposed into its Fourier harmonics, and the Fourier parameters were used to estimate the star's metallicity and distance; [Fe/H] $= -0.87 \pm 0.14$ and $d = 3.2 \pm 0.1$ kpc. It is argued that V1 may not be a member of the cluster but rather a more distant object. If this is so, an upper limit for the distance to the cluster of 2.8 ± 0.1 kpc can be estimated. The $P - L$ relationship for SX Phe stars and the identified modes in the newly discovered SX Phe variable, V6, allow yet another independent determination of the distance to the cluster of $d = 2.7 \pm 0.1$ kpc. The M_V- [Fe/H] relationship for RR Lyrae stars is addressed and the case of V1 is discussed.

Key Words: **GLOBULAR CLUSTERS-NGC 6366, VARIABLE STARS - RR LYRAE, SX PHE**

1. INTRODUCTION

The importance of studying globular clusters is linked to the fact that they can provide insight into the structure and evolution of the Galaxy. Hence, the determination of their ages, chemical compositions, galactocentric distances and kinematics are of fundamental relevance. Numerous works in recent literature have been devoted to the estimation of the above mentioned quantities. Calculations of relative ages at a fixed metallicity provide an age scale with an uncertainty of ≤ 1 Gyr. This has allowed Harris et al. (1997) to estimate that the very metal-poor ([Fe/H] ~ -2.14) distant (~ 90 kpc) cluster NGC 2419 has similar age to the inner cluster M92, and conclude that the earliest stellar globular cluster formation began at about the same time everywhere in the Galaxy. By the same technique Stetson et al. (1999) found that some of the outer-halo clusters ($R_{GC} \geq 50$ kpc) (Palomar 3, Palomar 4 and Eridanus) are $\sim$1.5-2 Gyr younger than the inner-halo

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clusters, ($R_{GC} \leq 10$ kpc) of similar metallicity (M3 and M5). These author recognise however that the age difference can be less than ~ 1 Gyr if their [Fe/H] or [α/H] abundances are overestimated. Similarly Sarajedini (1997) concluded that the outer-halo cluster Palomar 14 is 3 to 4 Gyr younger than inner clusters of similar metallicity. It seems that most of the outer-halo globular clusters are 1.5-4 Gyr younger than the inner-halo clusters of similar [Fe/H], and that NGC 2419 may be an exception (VandenBerg 2000).

Based on their metallicities and kinematics, two populations of globular clusters have been distinguished; a halo population composed of metal poor clusters (i.e. [Fe/H] ≤ -0.8) which is slowly rotating ($V_{rot} = 20 \pm 29$ km/s with a large line-of-sight velocity dispersion of 127 ± 11 km/s; Zinn 1996), and a disk population composed of metal rich globular clusters (i.e. [Fe/H] ≥ -0.8) which is rapidly rotating ($V_{rot} = 157 \pm 26$ km/s with a small line-of-sight velocity dispersion of 66 ± 13 km/s; Zinn 1996) (see also Zinn 1985, Armandroff 1989; Zinn 1993; van den Bergh 1993). The metal-rich component may also include a bulge system ($R_{GC} \leq 3$ kpc) which according to Minniti (1995) formed after the halo. However, comparing the luminosity of the HB and the MS turn-off of the galactic bulge, the two metal-rich bulge globular clusters NGC 6528 and NGC 6553, and the inner Halo cluster NGC 104 (47 Tuc), allowed Ortolani et al. (1995) and Zoccali et al. (2003) to conclude that the bulge and the Halo are of the same age and that there are no traces in the bulge of an intermediate-age population. These authors recognise however that an age difference of $\sim$ 2-3 Gyr in either direction is possible.

The clusters of intermediate metallicity (~ -0.8 dex) are very important since they can be used to trace the border between halo and disk. In this context, NGC 6366 (R.A.(2000)= $17^h27^m44^s.3$, DEC(2000)= $-05°04'36''$; l=18.41°, b=+16.04°) is an interesting globular cluster since, on one hand, it is metal rich (with several [Fe/H] determinations that range between -0.65 and -0.99 Pike 1976, Johnson et al. 1982, Zinn & West 1984, DaCosta & Seitzer 1989, Da Costa & Armandroff 1995); and, on the other hand, it has a large heliocentric velocity of -123.2 ± 1.0 km/s, which associates the cluster with the slowly rotating halo cluster system (Da Costa & Seitzer 1989), and which would make NGC 6366 the most metal-rich member of this cluster population. Its Galactic position near to the Galactic disk contributes to its high reddening, with estimates ranging between $E(B-V) = 0.65$ and 0.80 (Harris 1976, Da Costa & Seitzer 1989, Harris 1993). Other Halo clusters with high metallicities ([Fe/H] ≥ -1.0) in the list of Armandroff (1989) are NGC 6171, NGC 6569 and NGC 6712. An analysis of their kinematics led Cudworth (1988) and Da Costa & Seitzer (1989) to conclude that NGC 6712 is a halo cluster, while the other two cannot be classified unambiguously. Thus, it is likely that NGC 6712 is the second most metal-rich ([Fe/H] = -1.01) cluster of the halo population.

Photometric studies of globular clusters are of special interest because they can be used to generate a color magnitude diagram (CMD) that provides insight into the cluster age and evolutionary stage. The CMD of NGC 6366 displays a clear turn off point, a well developed red giant branch, and a very incipient horizontal branch (HB) (Pike 1976; Harris 1993, Alonso et al. 1997). The appearance of the CMD has triggered an interest in the age determination of the cluster and highlighted its importance in the study of galactic dynamics.

A few estimates of the age of NGC 6366 can be found in the literature, and their dispersion confirms the difficulty of dating globular clusters. Alonso et al. (1997) found an age of 18^{+2}_{-3} Gyrs by comparing the CMD to the isochrones of Straniero & Chieffi (1991), and concluded that it is older by 4-6 Gyrs than other metal rich clusters. However, Rosenberg et al. (1999), using a homogeneous data base of 34 globular clusters and a differential approach relative to a group of coeval clusters of 13.2 Gyrs of age (Carretta et al. 2000), estimated an age of about 11.0 Gyrs and hence concluding that the cluster belongs to a group of clusters younger than the coeval group. Salaris & Weiss (2002), also applied a differential approach relative to a group of clusters whose ages are believed to be well determined (M15, M3, NGC 6171 and 47 Tuc) and made an age estimate of 9.4-9.6 $\pm$ 1.4 Gyr for NGC 6366, depending on the metallicity adopted, i.e. ~ 2 Gyr younger than the reference clusters. This result further supports the idea that the cluster is young and it belongs to a group of young clusters linked to the galactic disk.

The lack of a developed HB in the CMD of NGC 6366 is the cause of the lack of RR Lyrae stars in the cluster, and the existence of a solitary known RR Lyrae variable in the cluster is therefore not surprising. This variable star was detected and studied by Sawyer Hogg (1973), and subsequently by Pike (1976) and Harris (1993). The latter aimed his BV photometry with CCD observations to search for blue stragglers and variable stars. He reported 27 blue straggler candidates but found no variable stars. However, the photometry method used (PSF fitting directly to the images) does not allow precise measurements in crowded fields, limiting the possibility for detecting smaller amplitude variables (Harris 1993).

Difference image analysis (DIA) is a powerful technique allowing accurate PSF photometry of CCD images, even in very crowded fields (Alard & Lupton 1998; Alard 2000; Bramich 2008). In the present study, we apply a new algorithm for difference image analysis (Bramich 2008) to a set of V and R images of NGC 6366 in order to search for new variable stars down to $V = 19.5$ mag. The paper is organized as follows: in section 2 we summarise the observations performed and describe the data reduction methodology. In section 3 we discuss our approach to searching for variable stars. In section 4 we report on the new variables found and discuss their nature. In section 5 we briefly discuss the Fourier decomposition of the light curve of the RR Lyrae star, V1, and its implications for the metallicity and distance of NGC 6366. In section 6 we present our conclusions.

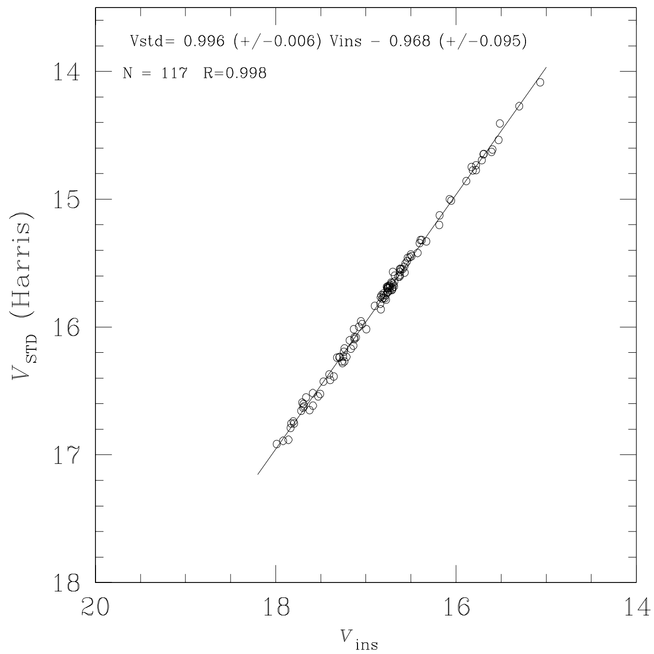

Fig. 1. The transformation relationship between the instrumental v and the standard V magnitudes.

2. OBSERVATIONS AND REDUCTIONS

The observations employed in the present work were performed, using the Johnson V and R filters, on May 5, 6 , 2006 and May 23, August 4, 5, September 4, 5, 2007. We used the 2.0m telescope of the Indian Astronomical Observatory (IAO) at Hanle, India, located at 4500m above sea level. The estimated seeing was ∼1 arcsec. The detector was a Thompson CCD of 2048 × 2048 pixels with a pixel scale of 0.17 arcsec/pix and a field of view of approximately 11. × 11. arcmin^2. Our data set consists of 61 images in the V and 61 images in the R filters.

Image data were calibrated via standard overscan, bias and flat-field correction procedures, and difference image analysis (DIA) was performed on the images with the aim of extracting high precision time-series photometry in the crowded field of NGC 6366. We used a pre-release version of the `DANDIA` software for the DIA (Bramich, in preparation), which employs a new algorithm for determining the convolution kernel matching a pair of images of the same field (Bramich 2008).

Briefly summarising the DIA procedure, we take the reference image for each filter as the best-seeing image. We then measure fluxes (referred to as reference fluxes) and positions for each PSF-like object (star) in the reference image by extracting a spatially variable (with polynomial degree 2) empirical PSF from the image and fitting this PSF to each detected object. Deblending of very close objects is attempted. Stars are matched between each image in the sequence and the reference image, and a linear transformation is derived which is used to register each image with the reference image using cubic O-MOMS resampling (Blu et al. 2001).

Each registered image is split into a 15 by 15 grid of subregions and a set of kernels, modelled as pixel arrays, are derived matching each image subregion to the corresponding subregion in the reference image. The kernel solution for each image pixel is determined by interpolating the grid of kernel models using bilinear interpolation, and the reference image, convolved with the appropriate kernel solution, is subtracted from each registered image to produce a sequence of difference images.

The differential fluxes for each star detected in the reference image are measured on each difference image as follows. The empirical PSF at the measured position of the star on the reference image is determined by shifting the empirical PSF model corresponding to the nearest pixel by the appropriate sub-pixel shift using cubic O-MOMS resampling. The empirical PSF model is then convolved with the kernel model corresponding to the star position and current difference image. Finally, it is optimally scaled to the difference image at the star position using pixel variances σ^2_{kij} for image k, pixel column i and pixel row j, taken from the following standard CCD noise model:

$$\sigma^2_{kij} = \frac{\sigma_0^2}{F_{ij}^2} + \frac{M_{kij}}{GF_{ij}} \quad (1)$$

where σ_0^2 is the CCD readout noise (ADU), F_{ij} is the master flat-field image, G is the CCD gain (e$^-$/ADU) and M_{kij} is the image model (see Bramich 2008).

Lightcurves for each star are constructed by calculating the total flux $f_{\rm tot}(t)$ in ADU/s at each time t from:

$$f_{\rm tot}(t) = f_{\rm ref} + \frac{f_{\rm diff}(t)}{p(t)}, \quad (2)$$

where $f_{\rm ref}$ is the reference flux (ADU/s), $f_{\rm diff}(t)$ is the differential flux (ADU/s) and $p(t)$ is the photometric scale factor (the integral of the kernel solution). Conversion to instrumental magnitudes is achieved using:

$$m(t) = 25.0 - 2.5\log(f_{\rm tot}(t)), \quad (3)$$

where $m(t)$ is the magnitude of the star at time t. Uncertainties are propagated in the correct analytical fashion.

2.1. *Transformation to the V standard system*

The instrumental v magnitudes were converted to the Johnson V standard system by using the stars in the field of the cluster listed in Table 2 of Harris (1993). Harris reports BV CCD magnitudes and colors tied to the photometric system of Landolt (1973; 1983) for 315 stars. We have explored the instrumental magnitudes of 160 of these stars contained in the field of our collection of images and reject those stars with a root-mean-square (RMS) scatter larger than 0.02 mag. In the end, we retained 117 stars which we use as local standards. Fig. 1 displays the relation between the instrumental and standard magnitude systems which has the fitted form $V = (0.996 \pm 0.006)\ v\ -\ (0.968 \pm 0.095)$. No significant color term was found.

The r observations were retained in the instrumental system since no standards with R photometry in the field of the cluster were found in the literature.

3. NEW VARIABLES IN NGC 6366

3.1. *Variable searching strategy*

All the V light curves of the 6172 stars measured in each of the 61 images available, were analyzed by the phase dispersion minimization approach (Burke et al. 1970; Dworetsky 1983). In this analysis the light curve is phased with the numerous test periods within a given range. For each period the dispersion parameter SQ is calculated. When SQ is at a minimum, the corresponding period is the best-fit period for that light curve. Bona fide variable stars should have a value of SQ below a threshold. Similar analysis of clusters with numerous variables have shown that all periodic variables are likely to have $SQ \leq 0.3$ (Arellano Ferro et al. 2004; 2006). Fig. 2 shows the distribution of SQ values for all stars measured in the images, with the threshold of $SQ = 0.3$ indicated. Before proceeding to explore the light curves of all stars with $SQ \leq 0.3$, the average magnitude and the standard deviation were calculated for each light curve. Fig. 3 shows the dispersions (log σ) as a function of the magnitude-weighted mean $(V)_m$. Stars with a large dispersion for a given mean magnitude are, in principle, good variable candidates. However, it is possible that a light curve has a large σ due to occasional bad measurements of the corresponding star in some images, in which case the

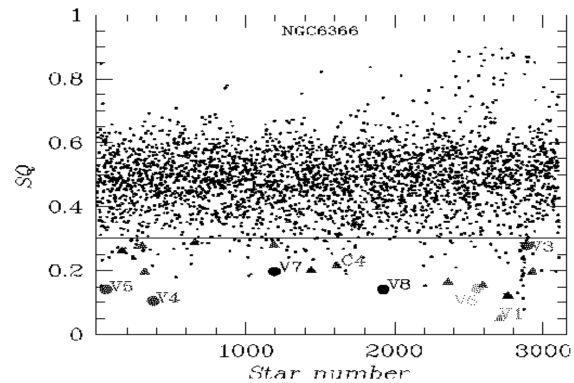

Fig. 2. SQ parameter distribution of all stars measured in the field of NGC 6366. Stars below the $SQ = 0.3$ line are likely to be variables. The confirmed variables are labelled. V1 is the known RRab star. Red symbols are confirmed (dots) and suspected (triangles) long period variables. Likewise, blue symbols indicate confirmed and suspected eclipsing binaries. [*See the electronic edition for a color version of this figure*]

variability is spurious. We have used the σ values to guide our search for variables in the list of stars with $SQ \leq 0.3$, and, for promising candidate variables, we checked the lightcurves by eye for outliers, and we inspected the difference images to check for possible contamination from nearby saturated stars and/or cosmetic defects on the CCD.

TABLE 1

NEW VARIABLES IN NGC 6366.

Name	$(V)_m$	$(V-r)_m$	P (days)	Type
V3	14.29	−0.17	3.72379	AC?
V4	16.62	+0.01	—	LPV
V5	16.31	−0.02	—	LPV
V6	16.98	−0.30	0.08018	SX Phe[1]
V7	17.09	−0.01	0.475460	LPV
V8	18.70	+0.05	0.74291	E.B.

1. See Table 3.

TABLE 2

CANDIDATE VARIABLES IN NGC 6366.

Name	$(V)_m$	$(V-r)_m$	P (days)	type
C1	14.56	+0.20	—	LPV
C2	14.78	+0.10	—	LPV
C3	14.94	+0.11	—	LPV
C4	14.15	−0.20	—	AC?
C5	15.58	+0.01	—	LPV
C6	15.86	+0.29	—	LPV
C7	15.74	+0.02	—	LPV
C8	16.48	+0.14	1.14137	E.B. ?
C9	17.69	+0.03	0.86951	E.B. ?
C10	19.18	−0.24	0.43171	E.B. ?
C11	18.23	−0.12	0.57425	E.B. ?

The above procedure has allowed us to identify the group of variables and candidate variables that are listed in Tables 1 and 2, respectively. In these tables there are reported the magnitude-weighted mean magnitudes and colours $(V)_m$ and $(V-r)_m$, which are also used to plot the stars in Figs. 3 and 4. We note that of the previously known variables V1 and V2 in the cluster field, only V1 lies within the field of view of our observations.

For variables with periods under 1 day, the period found by the phase dispersion minimization method, produced a coherent light curve. In the case of long term variables, the sparse distribution of our observations (large gaps between observation dates) does not allow a period to be estimated. However, it is clear that these long term variables have seasonal variations well above the photometric error in the lightcurve measurements.

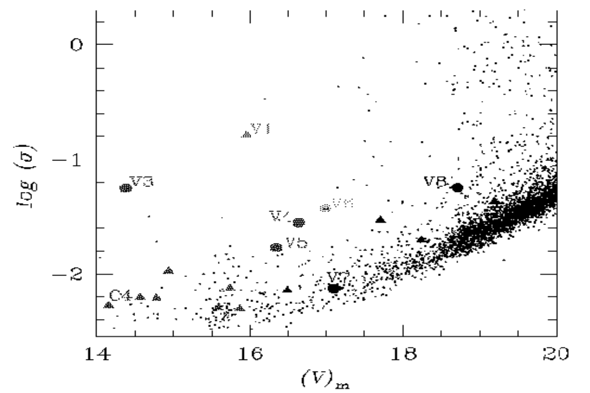

Fig. 3. Standard deviation as a function of the mean magnitude. Stars above the main cluster of points are good candidates variables. The confirmed variables are labelled as in Fig. 2. [*See the electronic edition for a color version of this figure*]

The CMD of the cluster is shown in Fig. 4 where the new confirmed and suspected variables are indicated. Individual stars are discussed in the following subsection.

We recall at this point that the intensity-weighted mean $< V >$ for variables reproduce better the magnitude for the equivalent static star than the magnitude-weighted mean $(V)_m$, that the difference $(V)_m - < V >$ increases with the amplitude and that for symmetric light curves $(V)_m =< V >$ (Bono et al. 1995). Of the variables discussed in this paper, V1 is the one with the largest amplitude (0.82 mag) and the most asymmetric light curve, and for this star $(V)_m - < V >\sim 0.1$. For the rest of the variables, the amplitudes are ≤ 0.1 mag and the variables in Table 1 display symmetric light curves. Similar arguments hold for the colour $(V-r)_m$. Thus,

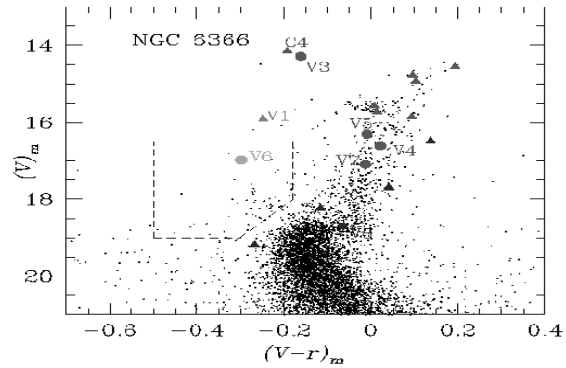

Fig. 4. CMD of NGC 6366 with the new confirmed and candidate variables indicated. The magnitudes and colours plotted are magnitude-weighted means over our entire collection of images. Symbols are as in Fig. 2. The *Blue Stragglers* region defined by Harris (1993) is enclosed by the dashed lines. [*See the electronic edition for a color version of this figure*]

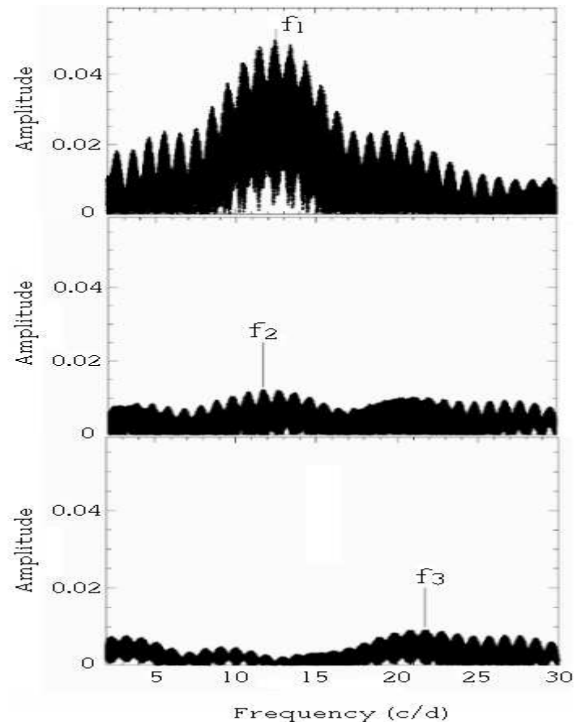

Fig. 5. Power spectrum of the SX Phe star, V6, showing the three active frequencies. The middle and bottom panels show the power spectra after the f_1 and f_2 frequencies have been respectively prewhitened.

we have chosen to plot $(V)_m$ and $(V-r)_m$ for all variables in Figs. 3 and 4, trusting that the differences with $< V >$ and $< V-r >$ are negligible, particularly when identifying the types of the newly detected variables.

3.2. *New variables*

V3. This star shows a variation with an amplitude of ∼0.13 mag and a period of 3.72379 ± 0.00001 days. Its position on the CMD, ~ 1.4 mag brighter than the RR Lyrae V1, suggest that this star might be an anomalous Cepheid (AC) or a Population II Cepheid (PC2). While ACs are common in dwarf spheroidal galaxies in the Local Group, they are rare in galactic globular clusters, only four are know; V19 in NGC 5466 and three in ω *Cen* (Clement et al. 2001). ACs are more massive than RR Lyrae stars, with masses ~ 1.8 to 4 $M_\odot$ (Caputo et al. 2004) and with periods between 0.5 and 3 days (Wallerstein & Cox 1984). These ranges of mass and period include the classical short-period Cepheids, which has led Dolphin et al. (2002) and Caputo et al. (2004) to suggest that rather than being a class of its own they are the natural extension to low metallicities of classical Cepheids. PC2s, on the other hand, are less massive than RR Lyrae stars and have periods between 1 and 25 days, but they are not expected in globular clusters without blue HB (Smith & Wehlau 1985). One exceptions seems to be the PC2 star in Palomar 3, a globular cluster with a red HB (Borissova, et al. 2000). This situation makes the PC2 classification also unlikely. A distinct difference between ACs and PC2s is the shape of their light curves. The former have smaller amplitudes and more symetric light curves (Sandage & Tammann 2006). Although the period found for V3 in this work is marginally larger than in other ACs, its amplitude is smaller and light curve is more symmetrical than in PC2s. May the AC or PC2 classifications be unlikely, one cannot initially ruled them out. Our observations are, however, too scanty to pin down the classification of this star and more observations are needed. It should be noted that, at this point, the possibility that V3 (and see below for C4) is not a member of NGC 6366 cannot be discarded.

V4 and V5. These stars display a long term

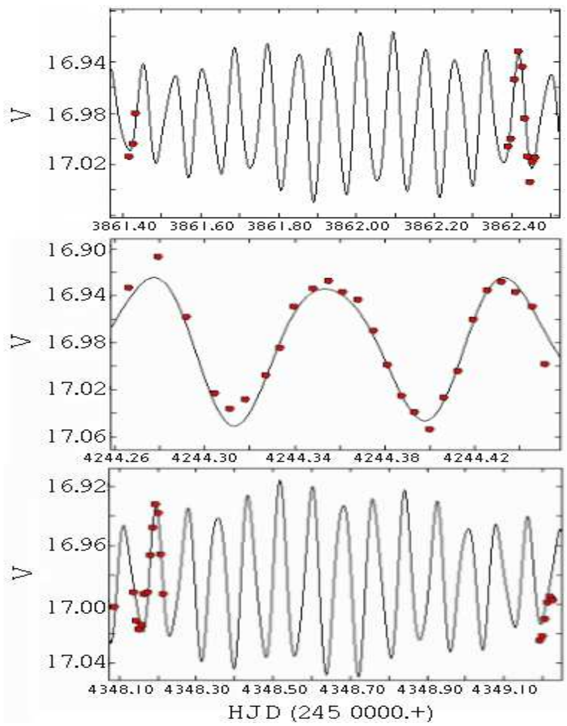

Fig. 6. Light curve of the SX Phe star V6, fitted by the superposition of the three active frequencies given in Table 3.

variation in V and r. They are long period variables sitting on the RGB.

V6. This is a multiperiodic short period variable of the SX Phe type. Three frequencies were identified. These are listed in Table 3 along with their corresponding amplitudes and mode identification. Fig. 5 shows the frequency spectra with the identification of the three modes. In Fig. 6 the light curve of the SX Phe star is shown, fitted with the combination of the three identified modes.

The amplitudes of the modes are comparable to those identified in SX Phe stars in other globular clusters, for instance in NGC 5466 (Jeon et al. 2004). Similar to SX Phe stars in NGC 5466, V6 falls on the *Blue Stragglers* region on the CMD defined for NGC 6366 by Harris (1993).

It is known that there is a Period-Luminosity ($P-L$) relationship for SX Phe stars (McNamara 1995) which is difficult to determine due to the common mixture of modes in these stars (McNamara 2001; Jeon et al. 2003). Linear $P-L$ relations independent of the metallicity can be found in the literature calculated in clusters of different metallicities, the slopes range between -3.25 and -1.62 (e.g. M53, -3.01, Jeon et al, 2003; NGC 5466, -3.25, Jeon et al, 2004; M55, -2.88 Pych et al. (2001); ω Cen, -1.62 McNamara 2000).

The calibration of Jeon et al. (2004) derived from the fundamental mode of seven SX Phe stars in NGC 5466 is of the form:

$$M_V = -3.25(\pm 0.46)\, logP - 1.30(\pm 0.06) \quad (\sigma = 0.04). \tag{4}$$

These authors have discussed the value of the slope of eq. 4 obtained from different clusters and have shown that the value -3.25 agrees within the uncertainties with the above empirical determinations and with the theoretical predictions (-3.04, Santolamazza et al. 2001; -3.05, Templeton et al. 2002).

Regarding the zero point of eq. 4, Jeon et al. (2004) adopted a true distance modulus of 16.0 for NGC 5466. It has been discussed by Arellano Ferro et al. (2008) that the true distance modulus of NGC 5466, in a scale where the true distance modulus for the LMC is 18.5 $\pm$0.1 (Freddman et al. 2001; van den Marel et al. 2002; Clementini et al 2003), is 16.01 $\pm$ 0.09. Therefore we can say that eq. 4 produces distances consistent with the above mentioned true distance modulus of the LMC. If we adopt eq. 4 for the SX Phe in NGC 6366, and $E(B-V) = 0.80$ (Harris 1993), we find a distance of 2.7 ± 0.1 kpc.

On the other hand, Nemec et al. (1994) proposed a $P-L$-[Fe/H] calibration for the fundamental mode of the form:

$$M_V = -2.56(\pm 0.54)\, logP + 0.36 + 0.32[\mathrm{Fe/H}]. \tag{5}$$

Which in turn, for an adopted value of [Fe/H] = -0.87, predicts a distance of 2.0 ± 0.5 kpc for the SX Phe in NGC 6366. This estimation of the distance to NGC 6366 would be the shortest known in the literature. We shall further discuss the distance to the cluster in section 4.2 in the light of the results derived for the RR Lyrae star V1.

V7. This star was found about 0.02 mag dimmer on the first two nights than in the rest of the run. We consider it to be a long term variable whose periodicity cannot be estimated with the present data. There is the possibility that this variation corresponds to an eclipse, but more observations are required to confirm or refute this hypothesis.

V8. This is an eclipsing binary with its eclipse clearly seen in the V and r light curves. The depth of the eclipse is about 0.15 mag. We have observed only a partial eclipse event and therefore the period cannot be accurately determined.

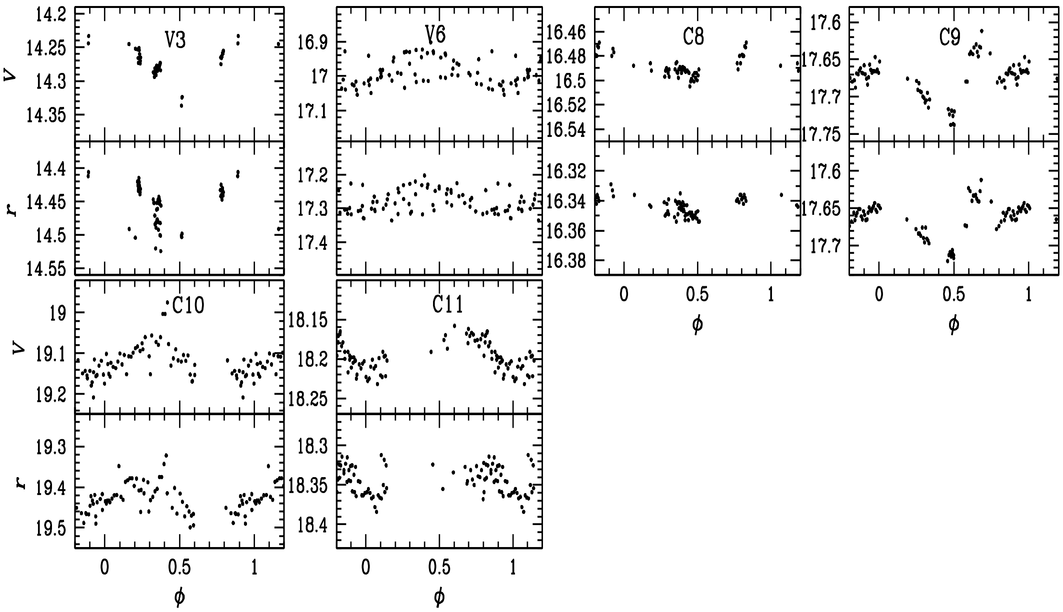

Fig. 7. Phased V and r light curves of short period confirmed and candidate variables.

3.3. *Candidate variables*

C1, C2, C3, C4, C5, C6 and C7. These are all possible long term variables with seasonal variations larger than 0.02 mag in both V and r filters. The distribution of our observations, designed to detect short variations over a few hours, does not facilitate further comment on their variable nature or an estimation of their characteristic times and/or periods. More observations would be required to estimate a period and/or the nature of variables. C4, judged by its position on the CMD, like V3, could possibly be an AC or a PC2. The limitations to accurately classify C4 at this point are like those discussed above for V3. Further observations are required to determine its amplitude, period, light curve shape, and membership in NGC 6366.

TABLE 3

ACTIVE MODES IN THE SX PHE TYPE STAR V6.

	Frequency (c/d)	Amplitude (mag)	mode	remark
f_1	12.4719	0.047	F	
f_2	11.6469	0.015	Nonradial	
f_3	21.7118	0.009	$2H$?	$f_1/f_3 = 0.574$

C8, C9, C10 and C11. On the other hand, these four stars display short period variations. Their periods, light curve shapes and position on the CMD suggest that these stars could be eclipsing binaries of the W UMa type.

The light curves of both the short and the long period variables, in V and r, are shown in Figs. 7 and 8. The similarities of the V and r light curve shapes is yet another test of consistency and serves to confirm the variable nature of the star. All the variables in the field of the cluster are identified in Fig. 10

4. THE RR LYRAE STAR V1

The only RR Lyrae known in NGC 6366 is V1. Our V light curve was compared with that of Harris (1993) and found it to be ∼0.02 mag fainter. Given the uncertainties in both photometries the agreement is reasonable. We shifted our data to the magnitude level of Harris (1993) light curve. After this we used the two data sets to perform a period search and found a period of 0.5131635 ± 0.0000002 days, which is in excelent agreement to the final period used by Harris (1993) of 0.5131634 days to fit Pike's (1976) data taken in 1974 and his own from 1990. This confirms that the period has remained constant from 1974 to 2007. The two data sets phased with the period 0.5131635 days and an epoch of 244 7751.48 are shown in Fig. 9. The full amplitude of the light curve is $A_V = 0.82$ mag.

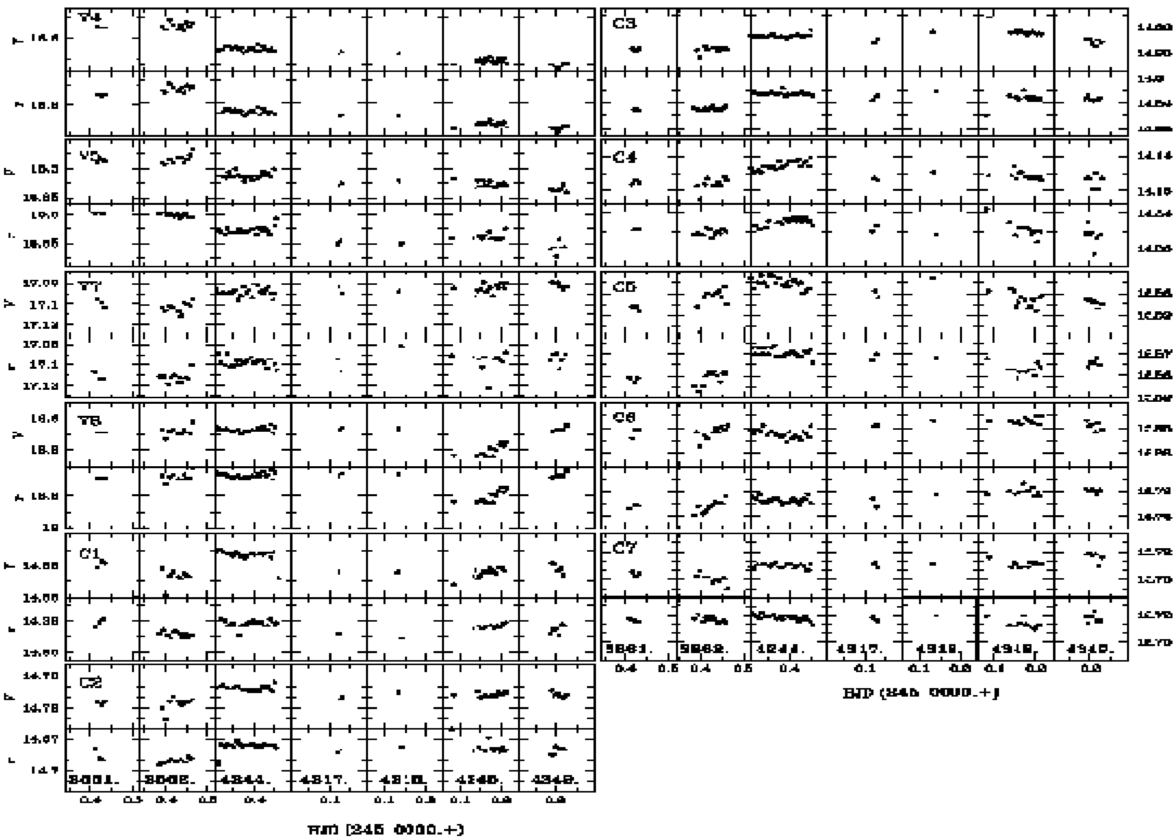

Fig. 8. V and r long term variations of confirmed and candidate variables. The horizontal axis is in julian day fraction. The integer number of each date is given inside the boxes at the bottom. The vertical scale is the same for the V and r light curves but it may be different from star to star.

The position of V1 on the DCM is about 0.3 mag fainter than the more densely populated red edge of the HB, as it has also been noted by Harris (1993). According to Harris, the location of the star near the cluster center and its magnitude on the HB make its membership in NGC 6366 very likely. While evolved RR Lyrae stars are expected to be brighter than the red HB, ZAHB models of Brocato et al. (1999) do show that for a mixing length parameter α of 1.0, the distribution of stellar masses allows red HBs brighter than blue HB tails. However this low value of α would also produce a very blue red HB (e.g. Fig. 3 of Brocato et al. 1999), which is not observed in globular clusters. Ferraro et al. (2006) have shown that α is not significantly dependent on the metallicity and that a value of 2.17 is unique for all globular clusters. This implies that RR Lyrae stars fainter than the red HB by as much as 0.3 mag cannot be

TABLE 4

FOURIER FIT PARAMETERS AND THEIR UNCERTAINTIES FOR THE V LIGHT CURVE OF THE RRAB STAR V1.

A_0	A_1	A_2	A_3	A_4	A_5	A_6
15.806	0.284	0.160	0.098	0.053	0.023	0.009
0.005	0.002	0.003	0.005	0.005	0.002	0.003
	ϕ_1	ϕ_2	ϕ_3	ϕ_4	ϕ_5	ϕ_6
	2.392	2.657	3.313	4.047	4.854	5.336
	0.020	0.034	0.043	0.080	0.157	0.296
	$\phi_{21}^{(c)}$	$\phi_{31}^{(c)}$	$\phi_{41}^{(c)}$			
	4.156	2.419	0.761			
	0.052	0.073	0.113			

produced by invoking a rather inefficient convection transport in red giants, i.e. $\alpha \sim 1.0$.

Another RR Lyrae in a metal rich cluster is V9 in 47 Tuc ([Fe/H]=−0.76; Harris 1996). This star, in contrast with V1 in NGC 6366, is much hotter and it is brighter than the red HB and has been interpreted by Carney et al. (1993) as highly evolved. Harris (1993) has shown that the RGB and the red HB fiducial sequences in 47 Tuc and NGC 6366 match very well. Since $\alpha \sim 2.7$ for 47 Tuc (Ferraro et al. 2006), in NGC 6366 α must have a similar value, which is yet another argument against the low value of α in NGC 6366 and hence against the possibility of the formation of an underluminous RR Lyrae. According to Carney et al. (1993) V9 has a much longer period for its blue amplitude A_B and when plotted on the log $P - A_B$ plane (Jones et al. 1992) there is indication that it is an evolved star. We do not have a B light curve for V1 but, if the V and B amplitude ratio is similar to that in V9, for $A_V = 0.82$ one can forsee $A_B \sim 0.97$ for V1. Since log $P = -0.2897$, it can be shown by plotting V1 in the log $P - A_B$ plane, that it is consistent with metal rich ([Fe/H] $\geq\sim -0.6$) field RR Lyraes (see Fig. 12 of Jones et al. 1992). Therefore, the fact that V1 is ~ 0.3 mag fainter than the red HB and the above given arguments against a low value of the mixing length parameter α in NGC 6366, seem to lead to the conclusion that V1 does not reside in the cluster but rather beyond. In the following sections the metallicity and distance to V1 will be estimated and compared with the generally accepted values for NGC 6366.

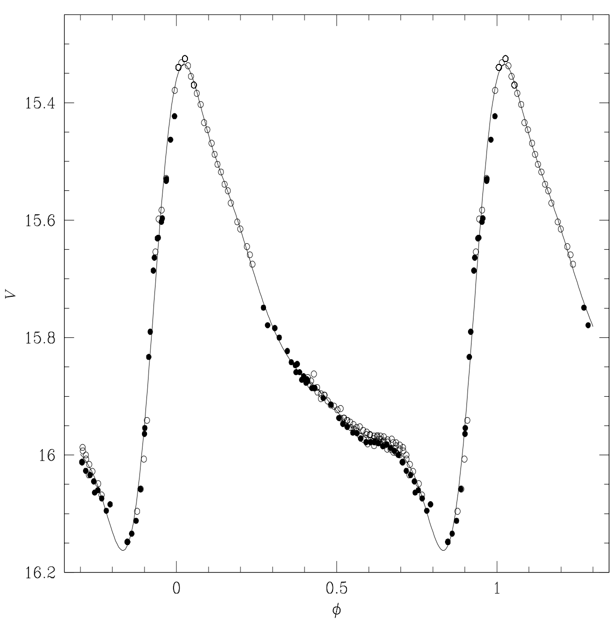

Fig. 9. Light curve of the RRab star V1. Dots are from the present work. Open circles are the observations of Harris (1993). The data are phased with a period of 0.5131635 days and an epoch of 244 7751.48. See text for discussion.

4.1. *Fourier Decomposition of* V1

The mathematical representation of the light curve of V1 is of the form:

$$m(t) = A_o \ + \ \sum_{k=1}^{N} A_k \ cos \ (\frac{2\pi}{P} \ k \ (t-E) \ + \ \phi_k), \tag{6}$$

where $m(t)$ are magnitudes at time t, P the period

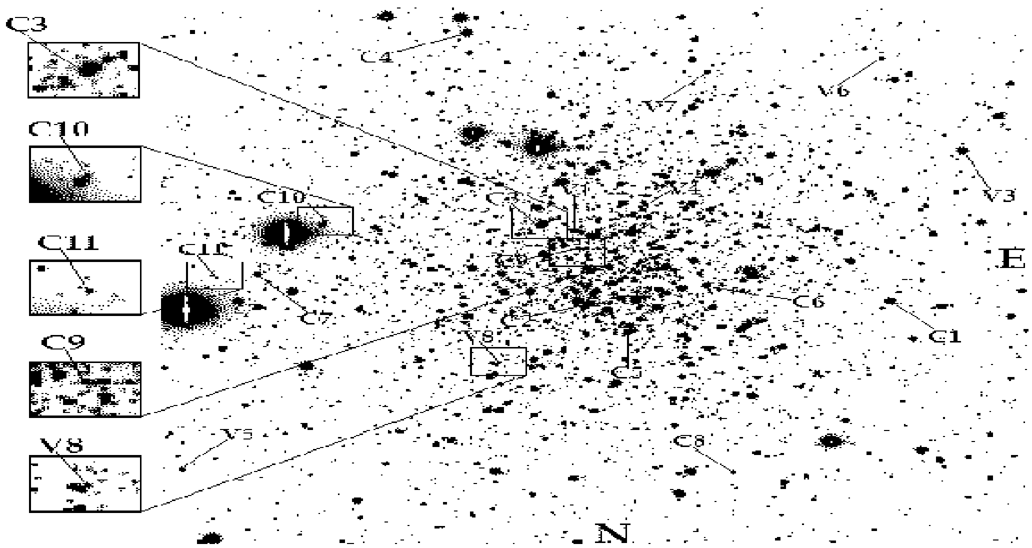

Fig. 10. Field of NGC 6366 with the new and candidate variables indicated. V1 is the known RRab star. Other names are as in Tables 1 and 2. A few stars with ambiguous identification are expanded in the left. The image is taken at the 2.0-m HCT of the IAO and it is approximately 10 × 10 arcmin^2.

and E the epoch. A linear minimization routine is used to fit the data with the Fourier series model, deriving the best fit values of E and of the amplitudes A_k and phases ϕ_k of the sinusoidal components.

From the amplitudes and phases of the harmonics in eq. 4, the Fourier parameters, defined as $\phi_{ij} = j\phi_i - i\phi_j$, and $R_{ij} = A_i/A_j$, were calculated. The solid curve in Fig. 9 is the combination of 6 harmonics with amplitudes and phases A_k and ϕ_k as listed in Table 4. The cosine $\phi_{21}^{(c)}$, $\phi_{31}^{(c)}$ and $\phi_{41}^{(c)}$ are also listed.

4.2. *On the metallicity and distance of V1 and NGC 6366*

Calibrations of the iron abundance and absolute magnitude in terms of the Fourier parameters for RRab stars have been offered by Jurcsik & Kovács (1996) and Kovács & Walker (2001) respectively. These calibrations are of the form;

$$[\mathrm{Fe/H}]_\mathrm{J} = -5.038 \;-\; 5.394\;P \;+\; 1.345\;\phi_{31}^{(s)}, \quad (7)$$

and

$$M_V(K) = \;-1.876\,log\;P\;-1.158\;A_1\;+0.821\;A_3 + K. \quad (8)$$

The standard deviations in the above equations are 0.14 dex and 0.04 mag respectively. In eq. 7, the phase $\phi_{31}^{(s)}$ is calculated from a sine series. To convert the cosine series based $\phi_{jk}^{(c)}$ into the sine series $\phi_{jk}^{(s)}$, one can use $\phi_{jk}^{(s)} = \phi_{jk}^{(c)} - (j-k)\frac{\pi}{2}$.

The metallicity $[\mathrm{Fe/H}]_\mathrm{J}$ from eq. 7 can be converted to the metallicity scale of Zinn & West (1984) (ZW) via $[\mathrm{Fe/H}]_\mathrm{J} = 1.43\;[\mathrm{Fe/H}]_\mathrm{ZW} + 0.88$ (Jurcsik 1995). We used the period 0.5131635 days and the value of $\phi_{31}^{(c)}$ in Table 4 duly transformed into $\phi_{31}^{(s)}$, to calculate $[\mathrm{Fe/H}]_\mathrm{J} = -0.36$ which translates into $[\mathrm{Fe/H}]_\mathrm{ZW} = -0.87$.

The zero point of eq. 8, K=0.43, has been calculated by Kinman (2002) using the prototype star RR Lyrae as calibrator, adopting for RR Lyrae the absolute magnitude $M_V = 0.61 \pm 0.10$ mag, as derived by Benedict et al. (2002) using the star parallax measured by the HST. Kinman (2002) finds his result to be consistent with the coefficients of the M_V-[Fe/H] relationship given by Chaboyer (1999) and Cacciari (2003). All these results are consistent with the distance modulus of the LMC of 18.5 ± 0.1 (Freedman et al. 2001; van den Marel et al. 2002; Clementini et al. 2003). The referee has led us to the recent paper by Catelan & Cortés (2008) where these authors argue that the prototype RR Lyr has an overluminosity due to evolution of 0.064 ± 0.013 mag relative to HB RR Lyrae stars of similar metallicity. This would have to be taken into account if RR Lyr is used as a calibrator of the constant K in eq. 7. While Catelan & Cortés (2008) determined $M_V = 0.600 \pm 0.126$ for RR Lyr, i.e. very similar to the value quoted above from Benedict et al. (2002), following Kinman's (2002) steps we find a new value of $K = 0.487$. Cortés & Catelan (2008) have shown how the oveluminosity is also a function of the metallicity and have calibrated their equations in terms of the Strömgren color $c_{\rm o}$. Since we do not have $c_{\rm o}$ data for V1 in NGC 6366, the metallicity effect cannot be quantified but we note that changing the value of K between 0.43 and 0.487 produces a minor change in the derived distance to V1 from 3.24 to 3.16 kpc respectively. For the sake of homogeneity and better comparison with previous results (e.g. Arellano Ferro et al. 2008), in what follows we have adopted $K = 0.43$.

Eqs. 7 and 8 can be applied to light curves with a *compatibility condition parameter* $D_m \leq 3$. For the definition of D_m see the works of Jurcsik & Kovács (1996) and Kovács & Kanbur (1998). For the 6 harmonic light curve fit represented in Fig. 9 we find D_m=3.2, i.e. only marginally larger that the prescribed limit. If this criterion is applied to the 6 harmonic fit exclusively performed on Harris (1993) data, which has a better phase coverage, we find D_m=0.7. For consistency, the Fourier coefficients and physical parameters reported in Tables 4 and 5 respectively, correspond to the calculated by fitting the data of Harris (1993) exclusively. It should be pointed however, that if the fit to both data sets had been used, the derived physical parameter would change well within the quoted uncertainties.

The results for the iron abundance and luminosity for the RRab star, V1, are summarized in Table 5 together with the distance d, and the true distance modulus μ_o.

TABLE 5

IRON ABUNDANCE, LUMINOSITY AND DISTANCE ESTIMATES OF THE RRAB STAR V1 FROM THE FOURIER LIGHT CURVE DECOMPOSITION.

$[\mathrm{Fe/H}]_{\mathrm{ZW}}$	-0.87 ± 0.14	μ_o	12.55 ± 0.04
$M_V(K)$	0.68 ± 0.04	$d(kpc)$	3.2 ± 0.1
$\log(L/L_\odot)$	1.623 ± 0.013	$E(B-V)$	0.80[1]

1. Adopted from the value of Harris (1993) for NGC 6366.

The value of $[\mathrm{Fe/H}]_{\mathrm{ZW}} = -0.87 \pm 0.14$ found above for V1 can be compared with previous estimations from different approaches for NGC 6366; Da Costa & Seitzer (1989) found [Fe/H]$= -0.85 \pm 0.10$ using the strength of the Ca II triplet at $\lambda\lambda$ 8498, 8542, 8662Å as a metallicity indicator in four giant stars in the cluster. Rutledge et al. (1997), also using the Ca II triplet, and transforming the metallicity to the scales of ZW and of Carretta & Gratton (1997) (CG), found $[\mathrm{Fe/H}]_{\mathrm{ZW}} = -0.58 \pm 0.14$ and $[\mathrm{Fe/H}]_{\mathrm{CG}} = -0.73 \pm 0.05$, respectively.

The value of $M_V(K) = 0.68 \pm 0.04$ for V1 and the adoption of $E(B-V) = 0.80$ and $R = 3.2$, lead to the distance $d(\mathrm{V1}) = 3.2 \pm 0.1$ kpc. If, as discussed in section 4, V1 is beyond NGC 6366 such that the star appears ~ 0.3 mag fainter than the cluster's red HB, we can still estimate the distance to the cluster by shifting V1 0.3 mag to roughly the ZAHB, and then find $d(\mathrm{NGC6366}) = 2.8 \pm 0.1$ kpc. Since V1 may also be evolved above the ZAHB, this distance estimate to NGC 6366 should be considered an upper limit.

On the other hand, referring to section 3.2, the distance $d(\mathrm{V6}) = 2.7 \pm 0.1$ kpc was obtained from the SX Phe variable star V6 by considering the $P-L$ relation for SX Phe stars (Jeon et al. 2004). Alternativelly the $P-L$-[Fe/H] calibration of Nemec et al. (1994) for the fundamental mode in SX Phe stars produced a distance of $d(\mathrm{V6}) = 2.0 \pm 0.5$ kpc. Other determinations of the distance include 3.0 kpc with $E(B-V) = 0.80$ (Harris 1993) and 2.8 kpc with $E(B-V) = 0.70 \pm 0.04$ mag (Alonso et al. 1997). These results seem to disfavor the use of the $P-L$-[Fe/H] calibration proposed by Nemec et al. (1994) for a cluster as metal rich as NGC 6366.

4.3. *On the M_V- [Fe/H] relationship for RR Lyrae stars*

The relation between M_V and [Fe/H] for RR Lyrae stars has been traditionally represented in a linear fashion as $M_V = \alpha$ [Fe/H] + β and numerous calibrations by different techniques exist in the literature. Recent and very complete summaries on the calibration of this equation can be found in the works of Chaboyer (1999), Cacciari & Clementini (2003) and Sandage & Tammann (2006). Most recent theoretical HB models do predict however a non linear relation between M_V and [Fe/H], and again, thorough revisions of the results obtained since 1990 are given by Cacciari & Clementini (2003) and Sandage & Tammann (2006).

Recently Arellano Ferro et al. (2008) obtained a M_V-[Fe/H] relationship for clusters whose parameters have been estimated by the Fourier decomposition of their RR Lyrae stars. These authors have converted the Fourier metallicities and absolute magnitudes to the ZW metallicity scale and to a distance scale where the LMC distance modulus is 18.5 ± 0.1 mag respectively. The relationship found by these authors; $M_V = +(0.18 \pm 0.03)[\mathrm{Fe/H}] + (0.85 \pm 0.05)$, is reproduced in Fig. 11, where the point corresponding to V1 has been added using the results in Table 5. The error bars on V1 are from the dispersions of eqs. 7 and 8. The position of V1 corresponds well with a linear extrapolation to the metal rich domain of the above linear M_V-[Fe/H] relationship. The solid line in Fig. 11 is from Arellano Ferro et al. (2008) (V1 not included in the fit) and it implies $M_V(RR)$=0.58±0.05 mag for [Fe/H]=−1.5, in excellent agreement with independent calibrations of Chaboyer (1999) (0.58±0.12) and Cacciari & Clementini (2003) (0.59±0.03).

We have also included in Fig. 11 the cluster distribution calculated by Caputo et al. (2000) for [α/Fe] = 0.3 and which has often been used as an empirical evidence of the non-linearity of the M_V-[Fe/H] relationship (triangles). In fact Caputo and co-workers have suggested two linear fits for the metallicity domains separated at [Fe/H]=−1.5. Since Caputo et al. metallicities are given in the Carretta & Gratton (1997) metallicity scale, to fairly compare with the Fourier results we have converted their metallicities into the ZW metallicity scale (see Carretta & Gratton 1997). There are also included two extreme and rather emblematic predicted calibrations for the ZAHB; by Cassisi et al. (1999) (upper segmented line) and by VandenBerg et al. (2000) for [α/Fe] = 0.3 (lower segmented line). Since during their HB evolution the stars spend most of their time at 0.1-0.2 mag brighter than the ZAHB (Cacciari & Clementini 2003), to take into account evolutionary effects and to better compare with the empirical results, the $M_V(ZAHB)$-[Fe/H] theoretical relations must be shifted to convert them into $M_V(RR)$-[Fe/H]. Such a shift is a function of [Fe/H] and the difficulties in quantifying it have been amply discussed in the review by Gallart et al. (2005) (see their Fig. 9). We have adopted the Cassisi & Salaris (1997) relation between $M_V(ZAHB)$-$M_V(RR)$ and [Fe/H] to transform the predicted $M_V(ZAHB)$-[Fe/H] relationship from the ZAHB models of VandenBerg et al. (2000) into its corresponding evolved $M_V(RR)$-[Fe/H] relationship (dashed blue line in Fig. 11). This evolved $M_V(RR)$-[Fe/H] relationship is the one that should be compared with the empirical results obtained from RR Lyrae stars through the Fourier approach.

Given their internal accuracies and dispersions, the results from the Fourier solutions coincide with the independent determinations from Caputo et al. (2000), rather satisfactorily, particularly for the low metallicity domain. Also, and very significantly, the Fourier results agree, within the uncertainties, with the theoretical prediction from VandenBerg et al.'s (2000) ZAHB models and the evolutive effects and their dependence on the metallicity calculated by Cassisi & Salaris (1997). While it is true that the Fourier results seem to suggest a linear distribution, enhanced by the appearance of V1 after the results in the present paper, it would be very interesting to incorporate RR Lyrae stars in metal-rich clusters, such as NGC 6388 ([Fe/H]=−0.60) and NGC 6441 ([Fe/H]=−0.53), to the sample of Fourier analyzed systems to study the behaviour of the $M_V(RR)$-[Fe/H] relationship in the high metallicity range. The light curves of some RRab and RRc stars in NGC 6388 and NGC 6441 have been Fourier-decomposed by Pritzl et al. (2002, 2001) respectively. The metallicity values found by Pritzl and collaborators for the RRab stars in these clusters, already transformed to the ZW metallicity scale are: $[\mathrm{Fe/H}]^{6388}_{\mathrm{ZW}} = -1.4 \pm 0.16$, $[\mathrm{Fe/H}]^{6441}_{\mathrm{ZW}} = -1.3 \pm 0.13$, $M_V^{6388} = 0.66 \pm 0.14$ and $M_V^{6441} = 0.68 \pm 0.03$. For the RRc stars they found $M_V^{6388} = 0.82 \pm 0.06$ and $M_V^{6441} = 0.79 \pm 0.03$. We have complemented the RRc star by estimating [Fe/H] by means of the calibration of Morgan et al. (2007) and adopting the Fourier parameters published by Pritzl and collaborators, the results are $[\mathrm{Fe/H}]^{6388}_{\mathrm{ZW}} = -0.74 \pm -0.23$ and $[\mathrm{Fe/H}]^{6441}_{\mathrm{ZW}} = -0.80 \pm 0.24$. The uncertainties are the standard deviations of the mean. These results are plotted and labeled following the symbol

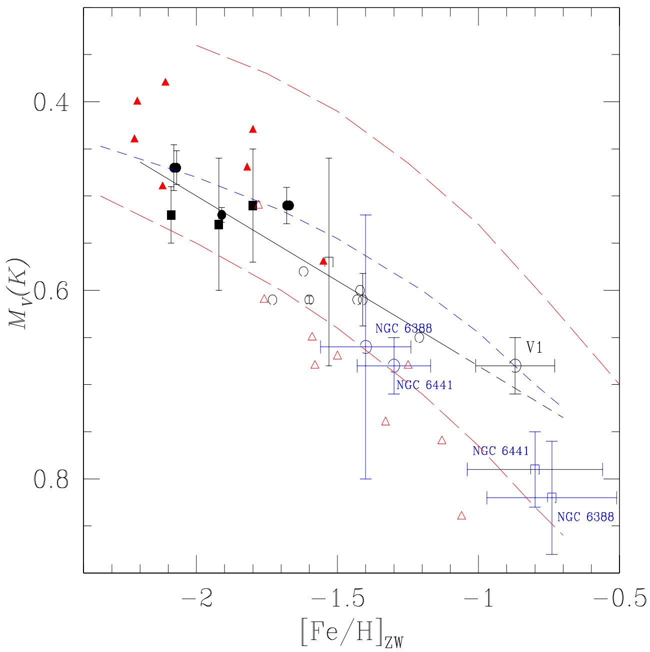

Fig. 11. The M_V-[Fe/H] relationship from the RR Lyrae Fourier light curve decomposition for a family of globular clusters taken from Arellano Ferro et al. (2008). Circles represent the results from the RRab stars while squares are from the RRc stars. NGC 6366 from the present work is labelled and its error bars correspond to dispersions of eqs. 7 and 8. The best fit line has the form $M_V = +(0.18 \pm 0.03)$[Fe/H] + (0.85 ± 0.05). The cluster distribution of Caputo et al. (2000) are also included (triangles). The two metal-rich clusters NGC 6388 and NGC 6441 are included for completness in the high [Fe/H] domain. Two predicted calibrations from the ZAHB models from Cassisi et al. (1999) (top) and VandenBerg et al. (2000) (bottom) are shown as segmented lines. The blue dashed line corresponds to the VandenBerg et al. (2000) ZAHB after the evolution and its dependence on metallicity are considered. Open symbols are used for OoI type clusters and filled symbols for OoII type clusters. See text in section 4.3 for detailed discussion. [*See the electronic edition for a color version of this figure*]

conventions on Fig. 11. The points corresponding to NGC 6388 and NGC 6441 might lean toward favouring a non-linear $M_V(RR)$-[Fe/H] relationship, leaving V1 at an odd position. However a few words of caution are necessary. Pritzl et al. (2001, 2002) noted already the low values of [Fe/H] for the RRab stars estimated from the Fourier approach when compared with the values by Armandroff & Zinn (1988) from the Ca II IR triplet. Pritzl et al. have discussed the possibility of metallicity spread in NGC 6388. It is known that RR Lyraes in these two clusters have unusually long periods, which has originated the suggestion that they are of the OoII type, and it is uncertain whether the Jurcsik-Kovács calibrations are valid in such case. For the M_V values of RRc stars, Pritzl et al. (2001, 2002) have used the Jurcsik (1998) calibration M_V(P,A_1, ϕ_{31}) but one can use alternativelly the Kovács (1998) calibration M_V(P,A_4, ϕ_{21}). The zero point of the later calibration has been disputed by Cacciari et al. (2005) who have suggested that, for M3, the zero point should be decreased by 0.2 ± 0.02. This exercise produced distances for metal poor clusters (e.g. M3 and NGC 5466) which are consistent with the luminosities of RR Lyrae in the LMC and a distance modulus of LMC of 18.5 ± 0.1 (e.g. Cacciari et al 2005; Arellano Ferro et al. 2008). The zero point of these calibrations might be metallicity dependent and it is not clear what the offset should be for metal richer clusters like NGC 6388 and NGC 6441. Given these considerations, the RRc points for NGC 6388 and NGC 6441 on Fig. 11 might need to be shifted to brighter magnitudes by as much as 0.2 mag. Thus, the Fourier results on these two metal rich clusters cannot be given too much weight in determining the shape of the $M_V(RR)$-[Fe/H] relationship in the high metallicity range.

The amplitude and period of V1, $A_V = 0.82$ and log $P = -0.29$, place the star on the $A_V - logP$ plane among the field metal-rich ([Fe/H] ≥ -0.8) RR Lyraes, and not among the RR Lyraes of the metal rich cluster NGC 6388 ([Fe/H]=-0.6; Armandroff & Zinn 1988) which have unusually large periods for a given amplitude (see for instance Fig. 9 of Pritzl et al. 2002). On the plane P$_{\rm ab}$-[Fe/H] the young and the old galactic cluster populations show the Oosterhoff dichotomy (see Fig. 5 of Catelan 2005) and likewise, the V1 is positioned as an extension of the OoI group. If V1 was a member of NGC 6366, on the basis of the above comparisons, it would seem reasonable to consider NGC 6366 of the OoI type. However, since V1 is likely a non-member of the cluster, no Oo type can formally be assigned to NGC 6366.

5. CONCLUSIONS

The use of difference imaging has enabled us to perform precision photometry in the globular cluster NGC 6366 and thereby lead to the detection of confirmed and possible new variables. The difference imaging technique used employs a new algorithm for determining the convolution kernel as a pixel grid. Among the new variables that we have found, we have identified one SX Phe star with at least three active modes, two possible AC's (or P2C's), one eclipsing binary and three long period red variables. We have also detected possible variations in a group of long term variables and short period eclipsing binaries likely to be of the W UMa type.

Despite the position of V1 very near the center of NGC 6366, the membership of V1 in the cluster is doubted mainly because the star is ~ 0.3 mag fainter than the red HB in the CMD, and because an inneficient convection transport in the red giants in NGC 6366 cannot be invoked as a possible cause for a real underluminosity of V1. Therefore, the metallicity and distance estimated for V1 from the Fourier technique, cannot be considered as representative of the cluster. We note however that the metallicity found for V1, $[Fe/H]_{ZW} = -0.87 \pm 0.14$, is very similar to values ascribed to NGC 6366 by independent spectroscopic estimates for giant stars in the cluster, (e.g $[Fe/H]_{ZW} = -0.85 \pm 0.10$, Da Costa & Seitzer 1989; $[Fe/H]_{ZW} = -0.58 \pm 0.14$, Rutledge et al. 1997).

The distance to V1 was estimated as $d(\mathrm{V1}) = 3.2 \pm 0.1$ kpc. If V1 is shifted 0.3 mag to the ZAHB, and considering that V1 might be evolved above the ZAHB, an upper limit for the distance to the cluster of $d(\mathrm{NGC\ 6366}) = 2.8 \pm 0.1$ kpc can also be estimated. An independent determination of the distance to NGC 6366 from the $P - L$ relationship for SX Phe stars and the pulsation modes identified in the SX Phe star V6 found in the cluster, gives the distance $d(\mathrm{V6}) = 2.7 \pm 0.1$ kpc, which is consistent with the upper limit determined from V1.

The position of V1 on the M_V-[Fe/H] plane suggests a linear extrapolation to the metal-rich domain. Inclusion of RR Lyrae stars in the metal rich clusters NGC 6388 and NGC 6441 seem to suppot the non-linear behavior of the M_V-[Fe/H] relationship, however it must be stressed that those RR Lyraes have unusual long periods for their amplitudes and then, the Fourier decomposition calibrations to determine their [Fe/H] and M_V values may not be applicable.

The $M_V(RR)$-[Fe/H] relationship derived from the Fourier results compares well, within the uncertainties, with the clusters distribution from the analysis of Caputo et al. (2000) and with the $M_V(ZAHB)$-[Fe/H] relationship prediction from ZAHB models of VandenBerg et al. (2000) once evolution from the ZAHB is considered. The excellent agreement of the position of V1 with this theoretical prediction further supports the idea that V1 is an evolved object from the ZAHB and that its apparent underluminosity in the CMD is due to its non-membership in NGC 6366. This interpretation has to compete with the otherwise straight one that, based on the similarity of the metallicities of the V1 and of the cluster and sitting V1 so close to the center of the cluster, V1 is very likely a member of the cluster. In this later case the observed underluminosity of V1 relative to the red HB is yet to be understood.

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