CIENCIA 15(3), 393 - 400, 2007
Maracaibo, Venezuela

Physical parameters of RR Lyrae stars in M15*

G. García Lugo[1], H. Arellano Ferro[2] y Patricia Rosenzweig[3]**

[1]*Grupo de Astrofísica Teórica, Facultad de Ciencias, Universidad de Los Andes, Mérida, Venezuela and Facultad de Humanidades y Educación. Departamento de Pedagogía y Didáctica. Universidad de Los Andes, Mérida, Venezuela.* [2]*Instituto de Astronomía. Universidad Nacional Autónoma de México.* [3]*Grupo de Astrofísica Teórica, Facultad de Ciencias, Universidad de Los Andes, Mérida, Venezuela.*

Recibido: 30-11-05 Ac eptado: 10-04-06

Abstract

The V, R light curves for 33 RR Lyrae stars in M15 were used to calculate their physical parameters. The Blazhko effect, previously reported in V12, was not detected. The values for the iron content and distance of the cluster are: [Fe/H]= -1.98 ± 0.24 and d = 8.67 ± 0.41 kpc, respectively. The mean values of the physical parameters, determined for the RR Lyrae, stars place the cluster precisely into the sequences Oosterhoff type – metallicity and metallicity – effective temperature, valid for globular clusters. Evidences of evolution from the ZAHB are found for the RRc but not for the RRab stars.

Key words: Blazhko effect; Globular Clusters-M15; Variable Stars-RR Lyrae.

Parámetos físicos de estrellas RR Lyrae en M15

Resumen

Las curvas de luz *V*, *R* de 33 estrellas RR Lyrae en M15 se han utilizado para calcular sus parámetros físicos. El efecto Balzhko, reportado previamente para V12 no ha sido detectado. Los valores determinados para el contenido de hierro y la distancia del cúmulo son: [Fe/H]= -1,98 ± 0,24 y d = 8,67 ± 0,41 kpc, respectivamente. Los valores medios de los parámetros físicos de las estrellas RR Lyrae colocan al cúmulo correctamente en las secuencias tipo de Oosterhoff – metalicidad y metalicidad – temperatura efectiva, válidas para cúmulos globulares. Se han encontrado evidencias de evolución, desde la Rama Horizontal de Edad Cero, de las estrellas RRc pero no de las RRab.

Palabras clave: Cúmulos globulares-M1; efecto Blazhko; estrellas variables-RR Lyrae.

* Trabajo presentado en el V Congreso de la Sociedad Venezolana de Física, Universidad del Zulia. Nucleo Punto Fijo - Edo. Falcón, Venezuela, Noviembre 2005.

** Autor para la correspondencia. E-mail: gygarcia@ula.ve

Introduction

M15 (NGC7078) is one of the most luminous and dense clusters in the Milky Way. Numerous photometric studies of the cluster have originated, since the pioneering work of Brown (1), until the most recent CCD study of RR Lyrae in the cluster, by Silbermann & Smith (2). More than 150 variables are listed in the catalogue of Clement (3) and approximately 100 them are RR Lyrae. M15 is one of the globular clusters with a very low metal content, the nany determinations of its metallicity range between $-2.15 \leq [Fe/H] \leq -1.76$ (4).

During the last decade, the light curve Fourier decomposition technique, to estimate physical parameters of RR Lyrae stars (5-7) has been applied to some globular clusters with a large range of metallicities (8, 9). The results of the metallicity, stellar mass, effective temperature, and luminosity, obtained from this homogeneous approach, clearly show trends that offer insights on the origin of the Oosterhoff dichotomy (9, 10).

The Fourier light curve decomposition technique has not been applied for RR Lyrae in M15. With the aim to include M15 in the list of clusters, for which this technique has been applied to estimate fundamental physical parameters, we have obtained further *VR* CCD photometry of two selected fields of the cluster, and have Fourier decomposed the light curves of 33 RR Lyrae.

Observational material and reductions

In the present study, 129 *V* and 127 *R* images, distributed in two fields of the cluster, as illustrated in Figures 1 and 2, were obtained in 2000 and 2001, using the 1.5 m telescope of San Pedro Mártir Observatory (SPM), in Baja California, Mexico. The telescope was equipped with a CCD Tektronix of 1024 x 1024 pixels with a size of 24 μ^2.

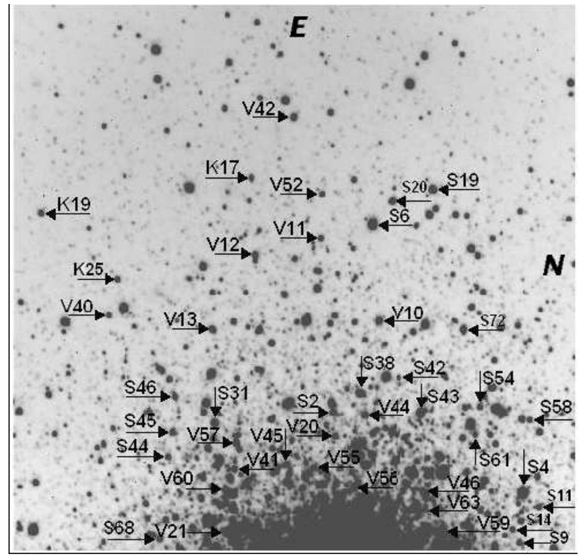

Figure 1. A selected image of the east field of M15, obtained in this work. Identifications of known RR Lyrae stars begin with "*V*", otherwise they are standard stars.

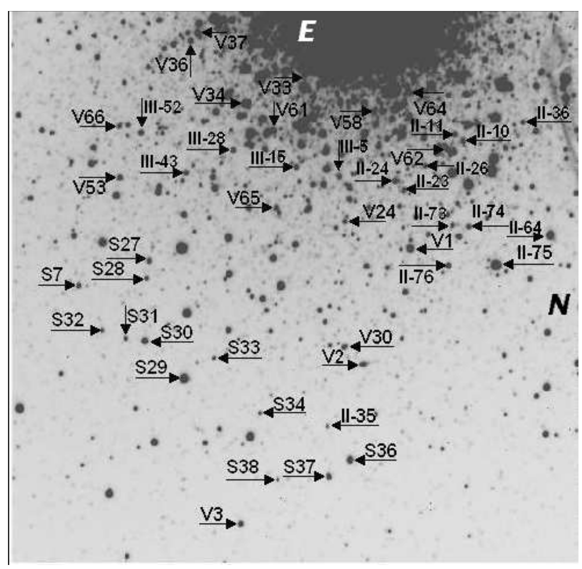

Figure 2. A selected image of the west field of M15, obtained in this work. Identifications of known RR Lyrae stars begin with "*V*", otherwise they are standard stars.

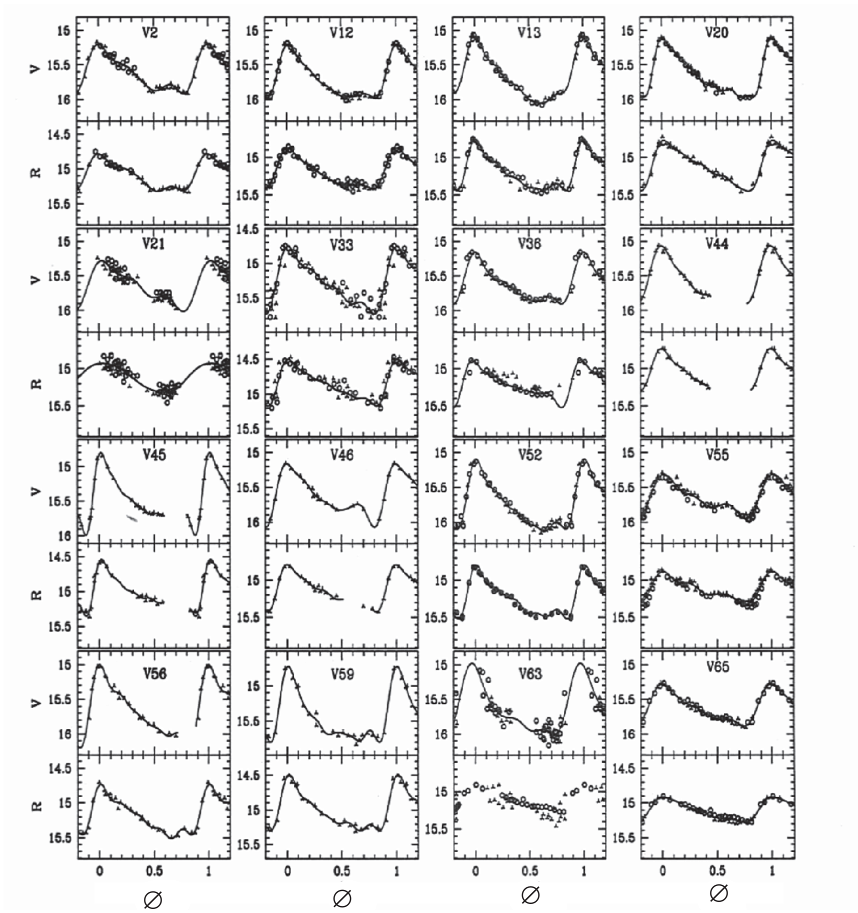

Figure 3. Light curves and Fourier fits of known RRab stars in M15.

The transformation to the standard system was performed differentially, relative to a group of standard stars in the observed fields of M15, available in Sandage (11). The accuracy of the photometry was estimated as ±0.031 and ±0.019 for the V and R filters, respectively.

The RR Lyrae stars in M15

In Clement's (12) data base of variables stars, a total of 158 variable stars are known, from which approximately 104 are RR Lyrae type stars. In this work, 30 known RR Lyrae stars, identified in Figures 1 and 2, have been studied. For all the stars, a new time of maximum light has been calculated; for others, the period also has been calculated, either because it was not reported in the list of variables of Clement (12) or, because it has been noticed that the reported period does not produce a coherent light variation.

a. Fourier parameters of the light curves

In order to estimate the Fourier parameters of the light curves, the data were fitted using the harmonic decomposition technique according to the following equation:

$$f(t) = A_o + \sum_{k=1}^{n} A_k \cos(2\pi k(t-E)/P + \phi_k). \qquad [1]$$

The solid curves in Figures 3 and 4 are the Fourier fits represented by equation [1].

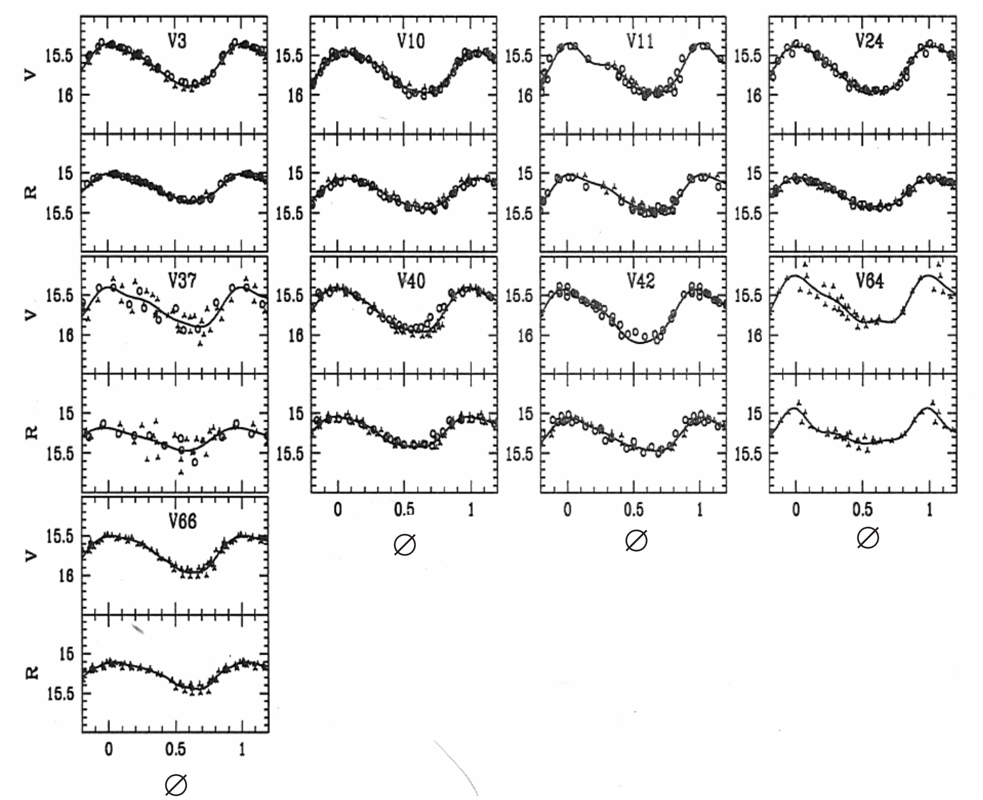

Figure 4. Light curves and Fourier fits of known RRc stars in M15.

From the amplitudes and phases of the harmonics in equation [1], the Fourier parameters, defined as $\phi_{ij} = J\phi_i - i\phi_j$ and $R_{ij} = A_i / A_j$ were calculated.

b. The physical parameters of the RR Lyrae stars from their light curves

For RR Lyrae stars of Bailey's type RRc stars, Simon & Clement (5) applied hydrodynamic pulsation models to calibrate equations for the effective temperature T_{eff}, a helium content parameter *Y*, the stellar mass $M/M\odot$, and the luminosity log≠*L*, in terms of the period and Fourier parameter ϕ_{31}. Their work has been extended to RRab stars, by Jurcsik & Kovács (13) (JK96), Kovács & Jurcsik (6) (KJ96); (7), and Jurcsik (14) (J98). We have adopted Morgan et al. (15) calibration for RRc type stars to estimate [Fe/H]. These parameters are summarized in Tables 1 and 2.

Discussion

a. The iron abundance of M15

The calibrations mentioned above are strongly dependent on ϕ_{31}. Hence, if the dispersion of the light curve is large, ϕ_{31} is uncertain and the value of [Fe/H] is unreliable. We decided to keep the physical parameter calculations limited to those stars with well defined light curves. These stars and their physical parameters are listed in Tables 1 and 2.

The mean values are [Fe/H]≠ -1.87 ± 0.24 for the RRab stars and [Fe/H]≠ -2.12 ± 0.16 for the RRc stars. Our overall average for [Fe/H] is then – 1.98 ± 0.24 for M15.

b. The distance to M15

An important fact is that the above results can be used to estimate the distance to

Table 1
Physical parameters for the RRab stars

Start	[Fe/H]*	*log* T_{eff}	M_v
V2	-1.70	3.794	0.67
V12	-1.97	3.800	0.72
V13	-2.23	3.800	0.68
V20	-1.77	3.784	0.64
V36	-1.99	3.797	0.71
V44	-1.99	3.800	0.70
V45	-2.25	3.793	0.61
V46	-1.60	3.792	0.67
V52	-1.84	3.804	0.71
V55	-1.51	3.789	0.65
V65	-1.70	3.789	0.66
Mean	-1.87	3.795	0.67
σ	±0.24	±0.006	±0.03

*From the calibration of JK96.

Table 2
Physical parameters for the RRc stars

Star	$M/M_\odot$	$Log(L/L_\odot)$	*Y*	M_v	*Log* T_{eff}	[Fe/H]*
V3	0.81	1.841	0.23	0.72	3.848	-2-29
V10	0.81	1.839	0.23	0.73	3.848	-2.28
V11	0.79	1.793	0.24	0.71	3.855	-2.02
V24	0.80	1.822	0.24	0.76	3.851	-2.19
V40	0.62	1.771	0.26	0.66	3.855	-1.91
V42	0.82	1.819	0.24	0.74	3.852	-2.15
V64	0.88	1.840	0.23	0.76	3.849	-2.21
V66	0.62	1.774	0.25	0.72	3.855	-1.93
Mean	0.76	1.812	0.24	0.72	3.852	-2.12
σ	±0.08	±0.028	±0.01	±0.03	±0.003	±0.16

*From the calibration of Morgan et al. (15).

the cluster. For the RRc stars, the luminosity values in Table 2 have been firstly transformed into Mv. In doing so, we have adopted the expression for the bolometric correction BC = 0.06 [Fe/H] + 0.06 (16) and $M_{bol\odot}$ = 4.75. To obtain the true distance modulus we have adopted E(B-V)= 0.08 (17) and a total-to-selective absorption ratio R≠3.2. For the RRab stars the Mv values in Table 1, obtained from the calibrations, have been used to calculate the distance modulus. We find the mean true distance moduli 14.72 ± 0.05 mag and 14.87 ± 0.15 for the RRab and RRc stars, respectively. The average of these moduli corresponds to a distance of 8.67 ± 0.41 kpc, where the uncertainty is the standard deviation of the mean from individual stars. This value of the clusters distance is to be compared with 10.3 kpc listed in the catalogue of Harris (18), 10.11 ± 0.46 kpc from Cox et al. (19), and with the dynamical estimate of 9.98 ± 0.47 kpc obtained by McNamara et al. (20), from the proper motion and radial velocity dispersion of 237 stars.

As for NGC 4147 (9), the Fourier decomposition approach places M15 about 17% closer than the adopted distance in Harris (18). In the present work, both values of the luminosity and absolute magnitude of the RR Lyrae stars, also have been obtained with Fourier's technique. Nevertheless, as seen in Tables 3 and 4, these values produce a coherent sequence of physical parameters with metallicity, within the Oosterhoff type of the cluster, as it will be discussed in the following subsection.

c. Physical parameters of globular clusters as a function of metallicity

Tables 3 and 4 are updates of Tables 3 and 6 of Kaluzny et al. (8), with new clusters added to the list. In these Tables the clusters are ordered according to their Oosterhoff type and their [Fe/H] value. It is easy to confirm that the mass and the luminosity increase with decreasing, metallicity. These trends were first foreseen by Simon & Clement (5) (3). It can be seen that the mean values of the physical parameters of the RR Lyrae stars in M15, obtained in this work, locate the cluster in the expected place in the general sequences. In particular, our average values [Fe/H] = 2.12 ± 0.16 for the RRc and [Fe/H] = -1.87 ± 0.24 for the RRab stars make the rest of the parameters consistent with the general sequences. The above [Fe/H] values are consistent, within the uncertainties, with the generally accepted value of [Fe/H] = 2.26 (18) and are bracketed by the several independent determinations listed by Buonanno et al. (4), that range from -2.15 to -1.76.

Table 3
Mean physical parameters obtained from RRab stars in globular clusters

Cluster (Oo type)	N	$[Fe/H]$	T_{eff}	M_v
NGC6171[1](I)	3	-0.91	6619	0.85
NGC4147[2](I)	5	-1.22	6633	0.81
NGC1851[3](I)	7	-1.22	6494	0.80
M5[4] (I)	26	-1.23	6465	0.81
M3[5](I)	17	-1.42	6438	0.78
M2[6](II)	20	-1.52	6687	0.71
M55[7](II)	3	-1.56	6325	0.68
M92[8](II)	5	-1.87	6160	0.67
M15[9](II)	11	-1.87	6237	0.67

1. Clement & Shelton (3), 2. Arellano Ferro et al. (9), 3. Walker (21), 4. Kaluzny et al. (8), 5. Kaluzny et al. (22), 6. Lázaro et al. (10), 7. Olech et al. (23), 8. recalculated in this work from the data in Marín (24), 9. this work. N is the number of stars studied.

Table 4
Mean physical parameters obtained from RRc stars in globular clusters.

Cluster (Oo Type)	[Fe/H]	N	$M/M_\odot$	$\log L/L_\odot$	T_{eff}	Y
NGC6171 (I)	-0.68	6	0.53	1.65	7447	0.29
NGC4147[1] (I)	-1.22	9	0.54	1.69	7334	0.28
M5 (I)	-1.25	7	0.58	1.68	7338	0.28
M5[2] (I)	-1.25	14	0.54	1.69	7353	0.28
M3[3] (I)	-1.47	5	0.59	1.71	7315	0.27
M2[4] (II)	-1.52	11	0.60	1.71	7320	0.28
M9 (II)	-1.72	1	0.60	1.72	7299	0.27
M55[5] (II)	-1.90	5	0.53	1.75	7193	0.27
NGC2298 (II)	-1.90	2	0.59	1.75	7200	0.26
M92[6] (II)	-1.87	3	0.64	1.77	7186	0.26
M68 (II)	-2.03	16	0.70	1.79	7145	0.25
M15 (II)	-2.28	6	0.73	1.80	7136	0.25
M15[7] (II)	-2.12	8	0.76	1.81	7112	0.24

Data taken from Clement & Shelton (3), except: 1. Arellano Ferro et al. (9), 2. Kaluzny et al. (8), 3. Kaluzny et al. (22), 4. Lázaro et al. (10), 5. Olech et al. (23), 6. recalculated in this work from the data in Marín (24), 7. this work. N is the number of stars studied.

Conclusions

V and *R*-band CCD photometry for 33 known RR Lyrae variables in M15 have been presented. The Blazhko variation in V12 is not confirmed. The stars V30, V58, and V60 were confirmed as double mode pulsators or RRd type variables. For the star V34, whose variability has been questioned in the past (25), we find authentic variations but a peculiar and scattered light curve that precludes classifying the star's variable type.

From the Fourier parameters derived from the light curves of RRab and RRc stars, and the physical parameters calibrations available in the literature, we estimate for the RRc stars the mean mass and effective temperature as 0.75 ± 0.08 $M_\odot$ and $\log T_{eff}$= 3.852 ± 0.003, respectively; [Fe/H]≠ -2.12 ± 0.16, $\log(L/L_\odot)$≠ 1.812 ± 0.028, and a mean relative abundance of helium Y≠ 0.24 ± 0.01. For the Rrab stars, we find $\log T_{eff}$ ≠ 3.795 ± 0.006, [Fe/H]≠-1.87 ± 0.24, and Mv≠ 0.67 ±0.03. The average metallicity and distance of the cluster are thus estimated as [Fe/H]≠-1.98 ± 0.24 and 8.67 ± 0.41 kpc, respectively. This estimate of the metallicity is in agreement with previous determinations, although the cluster appears closer to the sun. Furthermore, when compared with other globular clusters, both RRab and RRc stars place M15 in the correct place in the sequences first forseen by Clement & Shelton (3), in the sense that Oosterhoff type II clusters are more metal deficient than those of type I and the mean temperature of their RR Lyrae stars decreases with a decreasing iron content.

The temperatures and luminosities for the RRab stars are consistent with those found by J98 for the large sample of 272 RRab stars. A comparison with the models of Lee & Demarque (26), indicates that, for Y=0.24, the RRab stars have not evolved from zero age horizontal branch (ZAHB). However, we have found a clear correlation between the luminosity and the temperature with the metallicity for the RRc stars, suggesting evolutionary effects for these stars. Further details on this investigation can be found in Arellano Ferro et al. (27).

Acknowledgments

The authors acknowledge support from DGAPA-UNAM grant through project IN110102, the Universidad de Los Andes for hospitality, the financial support provided by C.D.C.H.T.-U.L.A. through Project C-1245-04-05-B, the financial aid given by Sigma Xi Grant-in-Aid 12030111, Mr. Luis O Porras in some reductions, and the SIMBAD and ADS services.

References

1. BROWN A. ***ApJ*** 113: 344, 1951.
2. SILBERMANN N.A., SMITH H.A. ***AJ*** 109: 1119, 1995.
3. CLEMENT C., SHELTON, I. ***AJ*** 113: 1711, 1997.
4. BUONANNO R., CORSI C.E., FUSI PECCI F. ***A&A*** 145: 97, 1985.
5. SIMON N.R., CLEMENT C.M. ***ApJ*** 410: 526, 1993.
6. KOVÁCS G., JURCSIK J. ***ApJ*** 466: L17, 1996.
7. KOVÁCS G., JURCSIK J. ***A&A*** 322: 218, 1997
8. KALUZNY J., OLECH A., THOMPSON I., PYCH W., KRZEMINSKI W., SCHWARZENBERG-CZERNY A. ***A&A*** 143: 215, 2000.
9. ARELLANO FERRO A., ARÉVALO M.J., LÁZARO C., REY M., BRAMICH D.M., GIRIDHAR S. ***RMAA*** 40: 209, 2004.
10. LAZARO C., ARELLANO FERRO A., ARÉVALO M.J., BRAMICH D.M., GIRIDHAR S., PORETTI E. ***MNRAS*** 372: 69, 2006.
11. SANDAGE A. ***ApJ*** 162: 841, 1970.
12. CLEMENT C. *Catalogue of Variable Stars in Globular Clusters;* http://www.astro.utoronto.ca/cclement/read.html. 2002.
13. JURCSIK J., KOVÁCS G. ***A&A*** 312: 111, 1996.
14. JURCSIK J. ***A&A*** 333: 571, 1998.
15. MORGAN SIOBAHN M., WAHL JENNIFER N., WIECKHORST RACHEL M. ***MNRAS*** 374: 1421, 2007.
16. SANDAGE A., CACCIARI C. ***ApJ*** 350: 645, 1990.
17. SANDAGE A., KATEM B., SANDAGE M. ***APJS*** 46: 41, 1981.
18. HARRIS W.E. ***AJ*** 112: 1487, 1996 (http://www.physics.mcmaster.ca/Globular.html).
19. COX A. N., HUDSON S.W., CLANCY S.P. ***ApJ*** 266: 94, 1983.
20. MCNAMARA B.J., HARRISON T.E., BAUMGARDT H. ***AJ*** 602: 264, 2004.
21. WALKER A.R. ***AJ*** 116: 220, 1999.
22. KALUZNY J., HILDITCH R. W., CLEMENT C., RICINSKI S.M. ***MNRAS*** 296: 347, 1998.
23. OLECH A., KALUZNY J., THOMPSON I.B., PYCH W., KRZEMINSKI W., SHWARZENBERG-CZERNY A. ***AJ*** 118: 442, 1999.
24. MARÍN Z. (MSc. Thesis), Universidad de Los Andes, Mérida (Venezuela). 2002.
25. NOTNI P., OLEAK H. ***AN*** 284: 49, 1958.
26. LEE Y-W., DEMARQUE P. ***ApJS*** 73: 709, 1990.
27. ARELLANO FERRO A., GARCIA LUGO G., ROSENZWEIG P. ***RMARA*** 42-75; 2006.