Mem. S.A.It. Vol. 86, 211
© SAIt 2015

Memorie della

Metallicities and alpha-to-iron ratios in globular clusters stars in a homogeneous scale - Search for multiple populations -

B. Dias[1,2], I. Saviane[2], B. Barbuy[1], E. Held[3], G. Da Costa[4], and S. Ortolani[5]

[1] University of Sao Paulo, Rua do Matao 1226, Sao Paulo, 05508-900, Brazil
[2] European Southern Observatory, Alonso de Cordova 3107, Santiago, Chile
e-mail: bdias@astro.iag.usp.br, bdias@eso.org
[3] INAF, Osservatorio Astronomico di Padova, vicolo Osservatorio 5, 35122, Padova, Italy
[4] Research School of Astronomy & Astrophysics, Australian National University, Mt Stromlo Observatory, via Cotter Rd, Weston, ACT, 2611, Australia
[5] University of Padova, vicolo Osservatorio 5, 35122, Padova, Italy

Abstract. We are carrying out a survey of 51 poorly studied globular clusters, by means of spectroscopy of ∼20 red giants per cluster. Optical spectra (4600-5800 Å) were obtained with the FORS2@VLT/ESO, at a resolution $\Delta\lambda \sim 2.5$ Å. We are using ETOILE code to derive [Fe/H], T_{eff}, $\log g$ for each star, by finding the best fitting spectrum among a grid of ∼ 2000 stars of the ELODIE library. These parameters represent the initial guess for HALO, which finds [Mg/Fe] values by comparing the observed spectrum to a grid of 4000 synthetic spectra. The main contributions of this work are: to provide a homogeneous scale of [Fe/H], [Mg/Fe], and radial velocities for the 51 clusters — in particular for the 29 distant and/or highly reddened ones — to provide a catalogue of confirmed member stars for each cluster, as well as to find interesting cases for follow-up with high resolution (like M 22, and NGC 5824, for which we found a spread in [Fe/H]).

Key words. Stars: abundances – Stars: atmospheres – Galaxy: globular clusters

1. Introduction

The system of Galactic globular clusters (GGC) is of paramount importance to understand the formation and evolution of the Milky Way. These objects allow us to reconstruct the early evolution of the Milky Way (e.g. Gieles et al. 2007), to constrain galaxy formation scenarios (e.g. Eggen et al. 1962), to characterize the chemical evolution of the Galaxy (e.g. Brodie & Strader 2006), to uncover dynamical evolution and interactions with dwarf galaxies (e.g. Bekki & Freeman 2003), etc. In order to explore these topics, homogeneous photometric and spectroscopic surveys are needed, revealing trends of abundances and kinematics with age. However, extensive and homogeneous determinations of cluster ages and metallicities are still lacking, although recent years have seen much progress in both areas.

A detailed status of the literature concerning such surveys can be found in Saviane et al. (2012a). We remark that only 64 clusters are included in the relative-age study of Marín-

Franch et al. (2009), whose database of color-magnitude diagrams (CMD) is the largest obtained with a single telescope (HST) and uniform data reductions. In terms of [Fe/H], about 1/3 of GGC still do not have a spectroscopic measurement of their metallicity, or they only have integrated light spectroscopic data. The largest homogeneous study of individual GGC stars is still that of Rutledge et al. (1997), which determined metallicities of 52 clusters, based on the CaII triplet method. For the globular clusters with red giant stars brighter than V≈16.5 there are many high resolution spectra obtained with 10m-class telescopes, so we mostly focused on fainter targets. We obtained data for ∼ 20 red giant stars for each of 65 distant and/or highly reddened globular clusters (including a number of calibration clusters). All observations were carried out with FORS2@VLT/ESO between 2001 and 2012. Among the 65 clusters, 51 of them were observed in the *visible* (∼4600 - 5800Å), and 56 were observed in the *near infrared* (∼7700 - 9400Å: Da Costa et al. 2009; Saviane et al. 2012b; Held et al. *in prep.*), with 42 clusters observed in both spectral regions. Table 1 lists some of the main parameters of the 51 clusters that are the subject of the present study (Dias et al. *in prep.*), and Figure 1 shows the number of clusters in common between Table 1 and the surveys of Rutledge et al. and Marín-Franch et al. Thanks to the common clusters we will be able to cross check our metallicities with those of Rutledge et al., and to see the effect of our improved abundances on the cluster ranking of Marín-Franch et al.

The main purpose of this work is: to provide a homogeneous scale of [Fe/H], [Mg/Fe], and radial velocities for the 51 clusters, in particular for the 29 distant and/or highly reddened ones; to provide a catalogue of confirmed member stars for each cluster; and to find interesting cases for follow-up in high resolution. In the cores of our study, we realized that our data permit discovering metallicity spreads inside clusters, thus revealing multiple populations for some of our program targets. Globular clusters present large intrinsic abundance variations of light elements, such as C, N, O, Na, Al, Mg, Si, and F. This is well

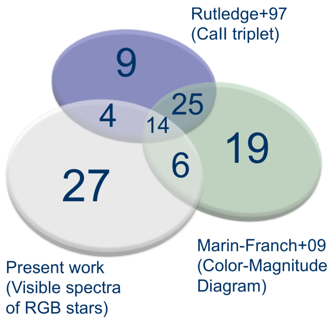

Fig. 1. Venn diagram to compare the number of globular clusters in common (or not) between the surveys of Rutledge et al., Marín-Franch et al., and the 51 clusters listed in the Table 1.

established, including recent work based on high-resolution spectroscopy for several clusters (see reviews of Gratton et al. 2012 and references therein). In particular Carretta et al. (2010a) defined the Na-O anticorrelation as a fundamental feature that separates the globular clusters from open clusters or even from dwarf galaxies. Moreover, six peculiar Milky Way globular clusters present also a heavy element (Fe abundance) dispersion: ω Centauri (NGC 5139, range in [Fe/H] of about 1.5 dex, e.g. Marino et al. 2011), M 54 (NGC 6715; σ[Fe/H] ≈ 0.19 dex, e.g. Carretta et al. 2010b), M 22 (NGC 6656; σ[Fe/H] ≈ 0.15 dex, e.g. Da Costa et al. 2009), NGC 2419 (σ[Ca/H] ≈ 0.2 dex, e.g. Cohen et al. 2010), Terzan 5 (two components in [Fe/H]=-0.2 and [Fe/H]=+0.3, e.g. Ferraro et al. 2009), and NGC 1851 (range in [Fe/H] of about 0.08 dex, e.g. Carretta et al. 2010c). Note however that the dispersion is still debated for some of these clusters (e.g. Mucciarelli et al. 2012; Villanova et al. 2010).

The dispersions of M 22 and M 54 were detected also by the present survey. In addition, a metallicity dispersion seems to be presented also in NGC 5824 which could join this group of peculiar clusters (Saviane et al. 2012a,b). For this cluster we already collected more spectra in order to populate the metallicity distribution function and better characterize the dispersion.

Table 1. List of the 51 observed clusters, sorted by magnitude of the horizontal branch. The clusters in the first group has $V_{HB} < 17$, for which it is feasible to observe RGB stars with high resolution spectrographs. For clusters in the second group, the brackets indicate why their RGB are fainter: either by the distance or by the reddening (or both). Parameters are from the Harris catalog. *Notes:* a) 2001 observations, ID 68.B-0482(A); b) 2002 observations, ID 69.D-0455(A); c) 2003 observations, ID 71.D-0219(A); d) 2006 observations, ID 077.D-0775(A); e) 2012 observations, ID 089.D-0493(B)

ID	Other names	$R_\odot$ (kpc)	E(B-V)	V_{HB} (mag)	[Fe/H]	# of stars	Bulge or Halo/Disc
Brighter RGB stars - 22 globular clusters (possible to observe with high resolution)							
NGC6397[c,d]		2.3	0.18	12.87	-2.02	24	H/D
NGC6121[d]	M4	2.2	0.35	13.45	-1.16	15	H/D
NGC6752[a]		4.0	0.04	13.70	-1.54	9	H/D
NGC104[a]	47Tuc	4.5	0.04	14.06	-0.72	16	H/D
NGC6656[d]	M22	3.2	0.34	14.15	-1.70	56	H/D
NGC6838[d]	M71	4.0	0.25	14.48	-0.78	13	H/D
NGC6254[d]	M10	4.4	0.28	14.65	-1.56	19	H/D
NGC3201[d]		4.9	0.24	14.76	-1.59	16	H/D
NGC5904[c]	M5	7.5	0.03	15.07	-1.29	9	H/D
NGC6352[e]		5.6	0.22	15.13	-0.64	14	B
NGC4372[c]		5.8	0.39	15.50	-2.17	11	H/D
NGC6366[e]		3.5	0.71	15.65	-0.59	17	H/D
NGC4590[b]	M68	10.3	0.05	15.68	-2.23	9	H/D
NGC6171[b]	M107	6.4	0.33	15.70	-1.02	4	B
NGC7078[d]	M15	10.4	0.10	15.83	-2.37	16	H/D
NGC2298[a]		10.8	0.14	16.11	-1.92	7	H/D
NGC2808[d]		9.6	0.22	16.22	-1.14	19	H/D
NGC5897[b]		12.5	0.09	16.27	-1.90	8	H/D
NGC6558[d]		7.4	0.44	16.30	-1.32	19	B
NGC5927[b]		7.7	0.45	16.55	-0.49	5	H/D
NGC6553[d]		6.0	0.63	16.60	-0.18	18	B
NGC6528[c,d]		7.9	0.54	16.95	-0.11	26	B
Fainter RGB stars - 29 globular clusters (distant and/or highly reddened)							
NGC5946[e]		{10.6}	{0.54}	17.40	-1.29	15	H/D
NGC6284[e]		{15.3}	0.28	17.40	-1.26	17	H/D
Lynga7[d]	BH184	8.0	{0.73}	17.43	-1.01	15	B
Pal11[e]		{13.4}	0.35	17.46	-0.40	12	H/D
NGC6316[e]		{10.4}	{0.54}	17.50	-0.45	16	B
NGC6356[d]		{15.1}	0.28	17.50	-0.40	18	H/D
NGC6441[d]		{11.6}	{0.47}	17.51	-0.46	19	B
NGC6569[d]		{10.9}	{0.53}	17.52	-0.76	18	B
Djorg2[e]	ESO456-SC38	6.3	{0.94}	17.60	-0.65	15	B
NGC5634[e]		{25.2}	0.05	17.68	-1.88	9	H/D
IC1276[d]	Pal7	5.4	{1.08}	17.70	-0.75	17	B
NGC6864[e]	M75	{20.9}	0.16	17.70	-1.29	12	H/D
NGC6355[e]		9.2	{0.77}	17.80	-1.37	16	B
Rup106[d]		{21.2}	0.20	17.80	-1.68	15	H/D
NGC6453[e]		{11.6}	{0.64}	17.88	-1.50	16	B
Terzan8[e]		{26.3}	0.12	17.95	-2.16	13	H/D
NGC6401[e]		10.6	{0.72}	18.00	-1.02	18	B
NGC6426[e]		{20.6}	0.36	18.16	-2.15	11	H/D
NGC6539[e]		7.8	{1.02}	18.33	-0.63	15	B
NGC5824[d]		{32.1}	0.13	18.45	-1.91	18	H/D
NGC5694[e]		{35.0}	0.09	18.50	-1.98	11	H/D
HP1[d]	BH229	8.2	{1.12}	18.70	-1.00	35	B
NGC6440[d]		8.5	{1.07}	18.70	-0.36	19	B
NGC7006[d]		{41.2}	0.05	18.80	-1.52	28	H/D
BH176[e]		{18.9}	0.54	18.86	0.00	15	H/D
Pal6[e]		5.8	{1.46}	19.00	-0.91	17	B
NGC6749[e]		7.9	{1.50}	19.70	-1.60	17	H/D
Pal10[e]		5.9	{1.66}	19.80	-0.10	13	H/D
Pal14[e]	AvdB	{76.5}	0.04	20.10	-1.62	7	H/D

2. Method

The atmospheric parameters ([Fe/H], [Mg/Fe], T_{eff}, $\log g$) of each RGB star are determined by full spectrum fitting techniques, which have the advantage to use all the information present in the spectra. We use two different codes employing observed or synthetic stellar libraries, respectively. One code is ETOILE (Katz et al. 2011), which compares each spectrum with all the stellar spectra in the ELODIE empirical library (Prugniel & Soubiran 2001), and finds the best fit by χ^2 minimization. Then the parameters of the respective library star are assigned to the studied star. Therefore the precision of the parameters is limited by the resolution and uniformity of the grid.

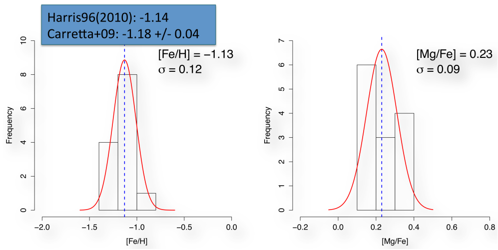

Fig. 2. Example of results from the ETOILE+HALO for NGC2808, compared with the literature.

The second code is HALO (Cayrel et al. 1991) which employs a more physical approach than ETOILE. It takes one *pivot* spectrum from a library of 4000 synthetic spectra, chosen by the user as initial guess, and then it performs perturbations in this spectrum due to each of the atmospheric parameters. The resulting spectra with different combinations of these perturbations are compared with the studied spectrum, until finding the best fit. This process is done first varying [Fe/H], $T_{\rm eff}$, $\log g$, and then both $T_{\rm eff}$, $\log g$ are fixed, in order to derive [Fe/H], and [Mg/Fe]. In this case, the precision of the parameters are limited by the S/N of the studied spectra, and by the initial guesses/*pivot*, given by ETOILE.

In both cases it is important to take care of the degeneracy [Fe/H]–$T_{\rm eff}$. If there are two discrepant results for a same spectrum, we decide between them by using the colors of the stars as a reference for the $T_{\rm eff}$ (relation by Alonso et al. 1999), because the spectra are quite sensitive to $T_{\rm eff}$. Another quality control is to compare the luminosities with the $\log g$ values, when it is possible.

Before starting the analysis it is crucial to convolve the libraries to the same spectral resolution of the studied spectra. Since the full spectra are fitted, it is necessary to properly remove cosmic rays, and to account for unwanted effects at the spectral extremes, such as vignetting, and grism limits. After this initial steps, the radial velocities are derived by cross-correlation with a template spectrum, using a task inside ETOILE. The spectra are all corrected to the rest frame, and then are ready for analysis, as described above.

3. Results

Figure 2 shows an example of the results for [Fe/H] and [Mg/Fe] derived for NGC2808, proving that the value we find is compatible with the literature (Harris 2010; Carretta et al. 2009). The complete analysis of our data set is in progress, and we expect to have it published in the course of 2013 (Dias et al. *in prep.*).

References

Alonso et al. 1999, A&AS, 140, 261
Bekki & Freeman 2003, MNRAS, 346, 11
Brodie & Strader 2006, ARA&A, 44, 193
Carretta et al. 2009, A&A, 508, 695
Carretta et al. 2010a, A&A, 516, 55
Carretta et al. 2010b, A&A, 520, 95
Carretta et al. 2010c, ApJ, 722, 1
Cayrel et al. 1991, A&A, 247, 108
Cohen et al. 2010, ApJ, 725, 288
Da Costa et al. 2009, ApJ, 705, 1481
Eggen et al. 1962, ApJ, 136, 748
Ferraro et al. 2009, Nature, 462, 483
Gieles et al. 2007, MNRAS, 376, 809
Gratton et al. 2012, A&ARv, 20, 50
Harris 2010, arXiv1012.3224
Katz et al. 2011, A&A, 525, 90
Marín-Franch et al. 2009, ApJ, 694, 1498
Marino et al. 2011, ApJ, 731, 64
Mucciarelli et al. 2012, MNRAS, 426, 2889
Prugniel & Soubiran 2001, A&A, 369, 1048
Rutledge et al. 1997, PASP, 109, 883
Saviane et al. 2012a, Msngr, 149, 23
Saviane et al. 2012b, A&A, 540, 27
Villanova et al. 2010, ApJ, 722, 18