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Research Note

Metallicity of the young halo globular cluster Ruprecht 106*

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Abstract. Medium resolution spectra of 3 stars have been used to determine the metallicity of the globular cluster Ruprecht 106. On the basis of a code developed by Cayrel et al. (1991), we computed a grid of synthetic spectra in order to derive the metallicity of these stars. We found an abundance of $[Fe/H] = -1.6 \pm 0.25$ which, although not formally at variance with the estimate of metallicity based on the slope of the RGB ($[Fe/H] = -1.9 \pm 0.2$) raises some puzzling questions concerning the true metallicity of this cluster.

Key words: globular clusters – Ruprecht 106 – stars: abundances

1. Introduction

Ruprecht 106 is a globular cluster located 5 kpc above the galactic plane and 20 kpc from the galactic center (Alter et al. 1961). Buonanno et al. (1990) carried out UBV CCD photometry for about 2500 stars of the cluster yielding the first ever published colour-magnitude diagram for this object. From the analysis of the CMD the following parameters were derived: $[Fe/H] = -1.90^{+0.2}_{-0.4}$ and a primordial helium abundance $Y_P = 0.20 \pm 0.05$. The metallicity was derived from the dereddened colour of the red giant branch $(B-V)_{0,g}$. Ruprecht 106 emerged as the first discovered young metal-poor Galactic globular cluster discovered, providing quite strong implications for our understanding of the collapse and enrichment of the Galactic halo. Da Costa et al. (1992) obtained medium resolution spectra (1.22 Å per pixel) of the CaII triplet region for seven stars. Their lines were compared with similar spectra of stars in NGC 4590, NGC 6397 and M4 yielding an abundance of $[Fe/H] = -1.69 \pm 0.05$ and suggesting that this cluster belongs to the class of clusters of intermediate metallicity, such as M 3 and M13. Note, however, that Da Costa & Armandroff, (1995, hereafter DA) have recalibrated such CaII line strenghts and obtained $[Fe/H] = -1.75 \pm 0.08$ for Ruprecht 106, in better agreement with the quoted estimate of Buonanno et al.(1990). More recently, Buonanno et al. (1993) completed B,V,I photometry of a sample of about 1000 stars of Ruprecht 106. To determine the metallicity, they defined a parameter which is well-correlated with the metallicity and independent of the reddening. This parameter is the slope of the RGB, defined as $sl = (V-I)_{-2.4} - (V-I)_{-1}$, where $(V-I)_{-2.4}$ is the color the RGB at a V magnitude 2.4 brighter than the observed HB, and analogously for $(V-I)_{-1}$. They obtained a value of $[Fe/H] = -1.90 \pm 0.2$ in substantial agreement with Buonanno et al. (1990). The problem of classifying Ruprecht 106 as a member of the metal-poor or intermediate metal cluster groups is of substance because Ruprecht 106 is significantly younger than the bulk of other globular clusters. It is therefore important to understand whether primordial (and, therefore, metal-poor) gas clouds survived 4-5 Gyr after the initial formation of our Galaxy. In this paper, we use medium resolution spectra of three stars of Ruprecht 106 to derive their metallicities by using spectrum synthesis techniques.

2. Observations and data reduction

In 1994, we observed 3 stars belonging to Ruprecht 106 as confirmed by Da Costa et al. (1992). We also observed with the same instrumentation 2 stars in NGC 6397 (C43 and C428). These stars have measured atmospheric parameters obtained by high resolution spectroscopy and detailed abundance analyses. They will be used as abundance reference stars. The observations have been made with the 2.2m telescope at the European Southern Observatory (ESO, La Silla) equipped with EFOSC2 employing grism # 8 and the CCD #19. The resolution per pixel was 1.3 Å. The log of the observations is shown in Table 1.

The spectra have been reduced at ESO using the long slit reduction package in MIDAS. This package includes the stan-

* Based on observations collected at ESO, La Silla

Table 1. Log book of the observations.

Cluster	star	ID[a] Source	V	date	λ(nm)	exp. (min)
Rup106	2205	1	15.50	04/05/94	470-580	2 x 60
Rup106	1951	1	15.49	04/05/94	470-580	2 x 60
Rup106	1445	1	16.55	04/05/94	470-580	2 x 60
NGC 6397	C428	2	10.56	04/05/94	470-580	4 x 15
NGC 6397	C43	2	10.94	04/05/94	470-580	4 x 15

[a] Sources: (1) Buonanno 1992; (2) Cannon 1974

Table 2. Photometry and atmospheric parameters for the program stars

Cluster	star	V	B-V	V-I	T_{eff}	log g	[Fe/H]
Rup106	1445	16.55	1.10	1.25	4800	1.95	
Rup106	1951	15.49	1.32	1.46	4400	1.30	
Rup106	2205	15.50	1.24	1.50	4350	1.3	
NGC 6397	C428[a]	10.56			4780	1.5	-1.90
NGC 6397	C43[b]	10.94			4526	1.3	-1.96

[a] Minniti et al. (1993); [b] Gratton and Ortolani (1989)

dard operations such as flatfielding, sky subtraction, optimal extraction along the slit and wavelength calibration.

2.1. Atmospheric parameters

The temperatures of the stars belonging to Ruprecht 106 have been derived from the photometric indices (B-V) and (V-I) (Buonanno 1994). From the Burstein and Heiles (1982) study, the reddening in the direction of R106 is $E(B-V)$ = +0.24 $\pm$ 0.06. Given the $E(V-I)/E(B-V)$ = 1.2 ratio taken from Dean et al. (1978), we assume E(V-I)=0.29. We interpolated the grids of synthetic colours from Buser and Kurucz (1992) adopting the reddenings E(B-V)=0.24 and E(V-I)=0.29 (Da Costa et al. (1992), Buonanno et al. (1993)) and [Fe/H]=-2.00. The temperatures obtained from (B-V) and (V-I) colors are in good agreement for the 2 stars 1951 and 2205. For the star 1445, the temperatures are different by 200K. We adopted the colours from (V-I) which is less sensitive to gravity and [Fe/H]. The distance modulus of the cluster has been taken as d = 20.3 kpc (Buonanno et al. 1990) and the bolometric corrections of Buser and Kurucz (1992) have been used to derive an estimate of the gravity using the relation

$$log\ g = log(M/M_{\odot}) + 0.4M_{Bol} + 4\ logT_{eff} - 12.51$$

and assuming a mass of 0.8 $M_{\odot}$. The adopted dereddened photometry and the resulting T_{eff} and log g are shown in Table 2. The 2 stars of NGC 6397 are 2 objects for which high resolution spectroscopy is reported in the literature, hence providing a precise determination of the atmospheric parameters. We have adopted the atmospheric parameters from Minniti et al. (1993) for C428 and from Gratton and Ortolani (1989) for C43 which give a metallicity of $[Fe/H] \simeq -1.90$. Carreta and Gratton (1997) made a new determination of the metallicity and found a slightly higher metallicity for these 2 stars and a mean metallicity of $[Fe/H] = -1.82$ for NGC 6397. The adopted parameters are also shown in Table 2.

Table 3. Test of the best fit procedure for the 2 reference stars

Cluster	star	T_{eff}	log g	[Fe/H]	rms
NGC 6397	C43	4500	1.30	-2.28	0.016
NGC 6397	C428	4800	1.50	-2.05	0.017

3. Analysis and results

3.1. The code for spectrum synthesis

The code for spectrum synthesis is the one described in Cayrel et. al (1991) where detailed information can be found. Here we recall the main assumptions. This code is based on LTE calculations (Spite 1967). The synthetic spectra cover the spectral domain λ 4780 - λ 5300 Å. All the atomic lines from Moore et al. (1966) are included in the line list. Unidentified lines are attributed to FeI with an excitation potential χ_{exc} = $3eV$. Oscillator strengths are obtained by adjusting the computed lines with the solar spectrum (Delbouille et al. 1973). The molecular lines of $MgH(A^2\Pi - X^2\Sigma), C_2((A^3\Pi - X^3\Pi), CN(A^2\Pi - X^2\Sigma)$ and $TiO(C^3\Delta - X^3\Delta)$ are also taken into account thanks to Barbuy (Cayrel et al. 1991).

3.2. Fitting procedure

With this code of spectrum synthesis, we constructed a grid of synthetic spectra covering the ranges $4200K < T_{eff} < 4900K$, $1.1 < log\ g < 2.0$ and $-2.2 < [Fe/H] < -1.4$. These synthetic spectra are then brought to the same resolution as the observed spectra by applying a convolution with a gaussian filter of FWHM of 3 Å typically.

There are basically two ways of using the grid, one is to directly interpolate a synthetic spectrum in the grid which will give the “best fit” (see Cayrel et al. 1991) with the observed spectrum and then derived the main parameters (T_{eff}, log g and $[Fe/H]$). This method suffers from uncertainties mostly for cool giants where systematic errors have been found.

One may also use the grid differentially, to find what changes in T_{eff}, log g and $[Fe/H]$ will be needed to explain the spectral differences between a well known reference star, for which a detailed analysis may be available and the program star. This last approach is more reliable. The grid acts as an “intelligent” interpolation procedure which knows what results from temperature changes, what results from gravity changes and what results from $[Fe/H]$ changes in the logarithmic difference between 2 stellar spectra.

3.3. The reference stars

As a first test, we checked the precision of the direct method with the 2 stars of NGC 6397. For the 2 stars, we used a starting spectrum with the atmospheric parameters as shown in Table 2 and kept only the metallicity as a variable. Direct interpolation in the grid of spectra gave the best fit results shown in Table 3.

The determinations are in good agreement with the determination obtained by detailed analysis. We found the same effect as in Cayrel et al. (1991) i.e. a lower metallicity than the one de-

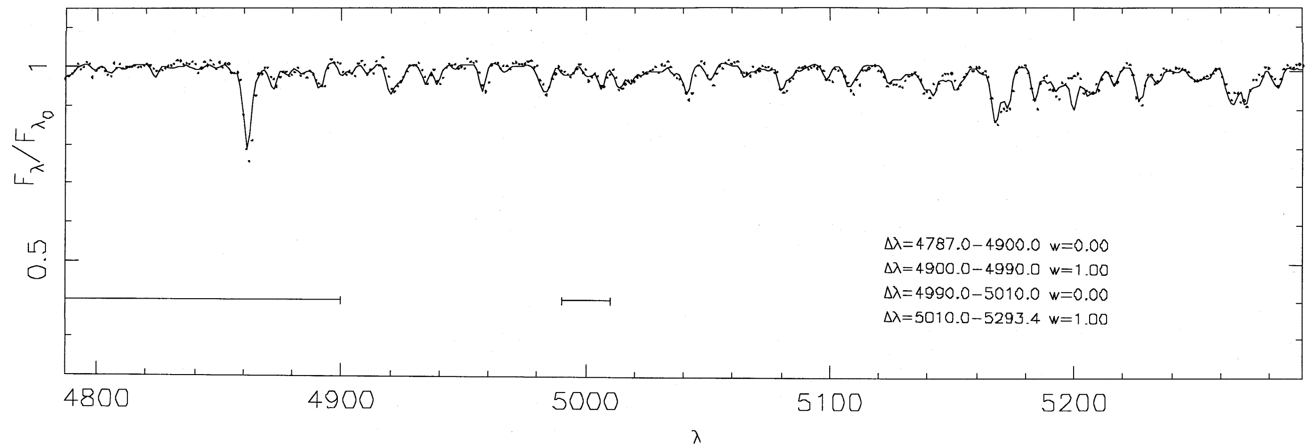

Fig. 1. Comparison of the observed spectrum of NGC 6397 C428 with a synthetic spectrum with the atmospheric parameters T_{eff}= 4800K, log g = 1.5 and [M/H]=-2.05. The horizontal bars indicate that the wavelength range corresponding to this segment has not been taken into account for the observed-computed spectra fitting

duced from high resolution spectroscopy. Another test has been performed for the star C43. We used a model with a slightly different temperature or gravity (the 3 parameters are variable), i.e. at a different starting point in the grid of spectra to have an estimation of the propagated error on the $[M/H]$ determination. Best fit models with the same rms were obtained for models with $[Fe/H]$ ranging from -2.09 to -2.27. Fig. 1 shows the comparison between the observed spectrum and the computed "best fit" for the star C428.

3.4. *Metallicity of Ruprecht 106*

For the three stars of the program, we used the differential analysis. Best fits have been obtained by allowing variations of T_{eff}, log g and [M/H]. Fig. 2 shows an example of the comparison between observed and interpolated synthetic spectra for the program star 1445. Cayrel et al. (1991) showed that $H\beta$ is not a good temperature indicator for stars cooler than 5000K. In such stars, the Balmer lines have almost no wings and are mostly chromospheric. Thus the flux and profile of the $H\beta$ line used as a temperature indicator are no longer useful. In our fitting procedure, we suppressed the region around the $H\beta$ line to avoid spurious results. Standard deviations are typically of 0.033 (see Cayrel et al. for its definition). This value is higher than in the case of the NGC 6397 stars. It is explained by the fact that the quality of reference spectra is much higher than for the program stars.

Best fit models have been obtained with different sets of temperature, log g and [Fe/H] values which are shown in Table 4.

The results are consistent with a metallicity for Ruprecht 106 of about -1.6 dex. This result confirms a first simple inspection of the spectra of stars belonging to NGC 6397 having similar temperatures and gravities where the lines appeared weaker than in the spectra of stars from Ruprecht 106.

We also computed synthetic models with an imposed metallicity of [Fe/H]=-2.00. We obtained rms errors of the order of 0.05 which is higher than the best fit cases favouring the high metallicity solution.

Table 4. Abundance results for the 3 stars belonging to R106

Cluster	star	T_{eff} range	log g range	[Fe/H] range
Rup 106	1445	4700 to 4900	1.85 to 2.05	-1.6 to -1.87
Rup 106	1951	4300 to 4500	1.20 to 1.40	-1.4 to -1.8
Rup 106	2205	4250 to 4450	1.30 to 1.50	-1.3 to -1.5

4. Discussion

Our abundance for Ruprecht 106 ranging from -1.3 to -1.87 is in fair agreement with the derived value $[Fe/H] = -1.75 \pm 0.08$ from DA obtained from the analysis of the CaII triplet. These findings seem supported by Kaluzny et al. (1995) who studied 12 RR Lyr variables discovered in Ruprecht 106. The analysis of the period vs amplitude and the period vs rise-time for these 12 variables suggested similar metallicities of Ruprecht 106 and M 3.

While the spectroscopic determinations are not formally inconsistent with the photometric abundances, nevertheless judging only from the former, one could object to classifying Ruprecht 106 as a member of the most metal-poor group of clusters. Trying to obtain a better match of the two classes of abundance determinations, Sarajedini (1994) suggested that the reddening to Ruprecht 106 could be as low as E(B-V)=0.13. This figure, when applied to the color of the RGB would lead to $(B-V)_{0,g}$ = 0.79 and, then, to $[Fe/H] = -1.61$, in excellent agreement with the present determination. This solution, however, leads to an unpalatable inconsistency with the overall (I, V-I) photometry. Such inconsistency is evident from a simple inspection of Fig. 4 of Buonanno et al. (1993), where the ridge lines of the RGB of clusters with different metallicities are compared with the RGB of Ruprecht 106 in the plane $M_I, (V-I)_0$. If one adopts, in fact, E(B-V)=0.13 and, therefore, E(V-I)=0.16, the RGB of Ruprecht 106 would shift noticeably to higher values of $(V-I)_0$ and would intersect the ridge lines of three clusters, i. e., NGC 1851, NGC 6752 and NGC 7089 (respectively

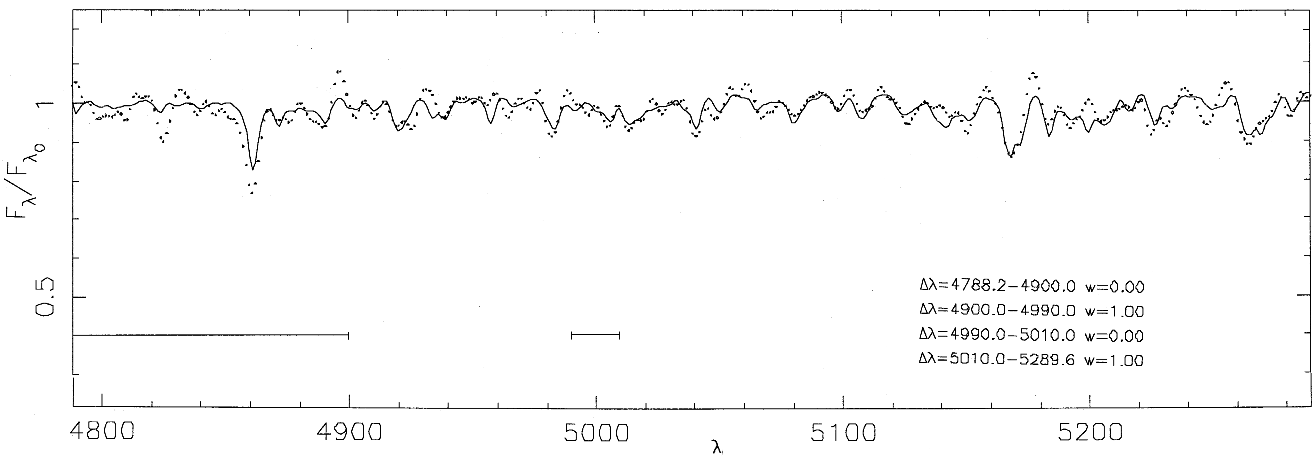

Fig. 2. Comparison of the observed spectrum of Ruprecht 106/1445 with a synthetic spectrum with the atmospheric parameters T_{eff}= 4800K, log g = 1.9 and [M/H]=-1.80.The horizontal bars indicate that the wavelength range corresponding to this segment has not been taken into account for the observed-computed spectra fitting

with $[Fe/H] = -1.29, -1.52, and, -1.58$), while one would expect that clusters of similar metallicity run parallel in the figure. In conclusion, it is difficult to reconcile the photometry of Ruprecht 106 with the relatively high abundance obtained from our spectroscopic analysis.

One can speculate that Ruprecht 106 shares this condition with other two globular clusters which have been found to be younger than others of similar metallicity, Terzan 7 and Pal 12. Specifically the abundances from the CaII triplet (DA) give $[Fe/H] = -0.36 \pm 0.09 and -0.64 \pm 0.09$ for Terzan 7 and Pal 12, while the photometry gives respectively $[Fe/H] = -1.00 \pm 0.13$ (Buonanno et al. 1995a) and $[Fe/H] = -1.09 \pm 0.06$ (Da Costa & Armandroff, 1990).

For the last discovered "young" globular cluster Arp 2 (Buonanno et al. 1994), the CaII triplet gives $[Fe/H] = -1.70 \pm 0.11$ (DA) while the photometry gives an indication of $[Fe/H] = -1.84 \pm 0.25$ (Buonanno et al. 1995b), and, therefore, the two determinations are formally consistent. One can speculate, however, that it would not be surprising to discover that globular clusters with different genesis could present different relative abundances. If, in particular, the $alpha-$elements in a given cluster are not overabundant with respect to the iron (as is the case for most globular cluters) one would find that the RGB of this particular cluster is steeper than expected on the basis of the spectroscopic determinations. In the same vein one can speculate that peculiar element abundances are more likely in systems which could have been captured from the LMC, such as Ruprecht 106 (Lin & Richer, 1992), or which could be associated with the Sagittarius dwarf spheroidal galaxy, such as Terzan 7 (and Arp 2), as suggested by DA. These suggestions could be verified through a detailed abundance analysis of the young globular clusters which could reveal anomalies such as those found by Hill et al. (1995) in the LMC and by Spite et al. (1989) in SMC. This would then suggest a more complex history of formation of the outer halo.

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