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Metallicity of the star III-17 in the bulge globular cluster NGC 6553*

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Abstract. CCD échelle spectra were obtained at the 3.6 m telescope at ESO for the star III-17 of the metal-rich globular cluster NGC 6553. This cluster was chosen because it is a relatively close bulge globular cluster and also it presented the possibility to be among the most metal-rich ones in the Galaxy.

The metallicity of the star III-17 is derived by fitting synthetic spectra to the spectrum observed in the wavelength region $\lambda\lambda$475–580 nm.

We derived an overall metallicity of $[M/H] = -0.2^{+0.2}_{-0.4}$, therefore approximately solar, whereas there may be an evidence for a CNO overabundance. Further observations of individual stars in NGC 6553 are necessary in order to definitely establish its metallicity.

Key words: bulge globular clusters – synthetic spectra – metallicity of metal-rich globular clusters

1. Introduction

The metallicity scale of the globular clusters in the Galaxy still is a contentious issue, especially as concerns the metal-rich clusters.

Besides, the discussions about the metallicity of metal-rich clusters in the last decade focused halo clusters such as 47 Tuc, M 71, NGC 5927, NGC 6352, of moderate metal-deficiency, showing metallicities in the range $[M/H] = -0.6$ to -1.2 dex (e.g. Gratton 1987).

The most metal-rich clusters in the Galaxy are located, instead, in the galactic bulge. The candidates to be the most metal-rich clusters are: NGC 6760, NGC 6440, NGC 6528, NGC 6553, Terzan 1, among a few others, as can be seen in Webbink (1985), Bica & Pastoriza (1983; hereafter BP83), Zinn & West (1984).

NGC 6553 appeared particularly promising from DDO photometric observations by BP83, who showed that this cluster should have $[M/H] = +0.47$, being the most metal-rich in their list of 91 globular clusters. On the other hand, Zinn (1980), in his first abundance scale, attributed $[M/H] = +0.04$ to this cluster. In a revised scale, Zinn & West (1984) established rather the value $[M/H] = -0.29$. Cohen (1983) analysed 5 stars of NGC 6553, having found $[M/H] = +0.24$ for the whole sample, but $[M/H] = +0.37$ for the two more metal-rich ones. Pilachowski (1984) gives $[M/H] = -0.70$ and Webbink (1985) reports $[M/H] = -0.41$.

In a further study, Bica & Alloin (1986a, b) obtained low-resolution spectroscopy of 63 clusters, confirming that NGC 6553 and NGC 6528 were the candidates to be the most metal-rich globular clusters of their list.

In a previous work, BVRI CCD colour–magnitude diagrams (CMDs) were presented (Ortolani et al. 1990; hereafter OBB90); these CMDs showed that, due to the high metallicity of NGC 6553, the red-giant branch (RGB) appeared to turn-over for the cooler stars. The star III-17 was chosen from our CCD photometry for being among the brightest stars of NGC 6553, cf. identification in Figs. 2a, b in *BV* and *VI* colours, respectively. Identification charts showing individual stars were published by Hartwick (1975).

In the present work, high-resolution spectra of one individual star of NGC 6553 were obtained at the 3.6 m telescope using the Caspec spectrograph at ESO.

In Sect. 2 the observations are described. In Sect. 3 the derivation of the stellar parameters temperature and gravity is discussed. In Sect. 4 the derivation of the metallicity is carried out through spectral synthesis computations. In Sect. 5 the results are discussed.

2. Observations

The individual star III-17 of the globular cluster NGC 6553 at coordinates $\alpha_{1950} = 18^h06^m.3$, $\delta_{1950} = -25°56'$, was observed using the Cassegrain Échelle Spectrograph (CASPEC) at the 3.6 m telescope of the European Southern Observatory – ESO, at La Silla, Chile.

The 31.6 lines mm^{-1} grating was used, and the detector was the ESO No. 8 RCA CCD of 1024×640 pxl with 15 µm size. With an exposure time of 1, 30 h and a wavelength resolution of $\Delta\lambda = 0.20$ Å, and S/N$\approx$40 was obtained. A typical spectral region is presented in Fig. 1.

The reductions were done with the use of the Midas special package for Caspec data.

3. Stellar parameters for the star III-17

The position of the star III-17 in the V vs. $(B-V)$ and I vs. $(V-I)$ CMDs are shown in Figs. 2a, b.

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* Observations collected at the European Southern Observatory, La Silla, Chile

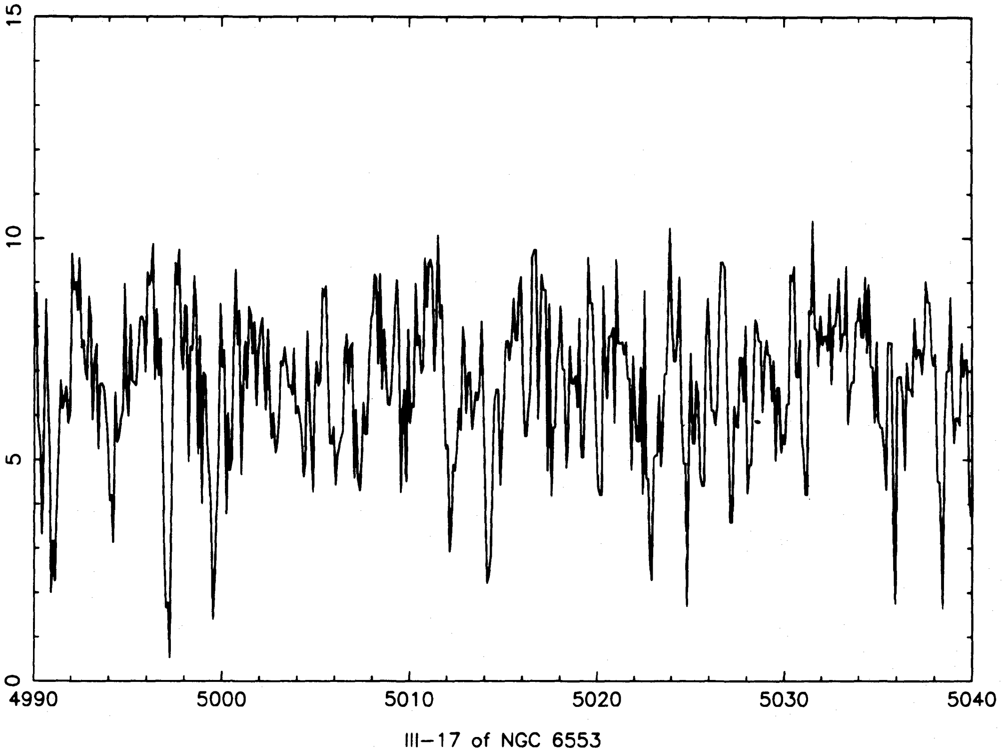

Fig. 1. A typical spectral region at λλ499–504 nm, illustrating the S/N obtained, and the intensity of lines

Colours $V=15.03$, $(B-V)=2.33$, $(V-I)=2.82$, $(B-I)=5.15$, $(V-R)=1.41$, $(R-I)=1.41$ are obtained from the CCD *BVRI* photometry by OBB90.

3.1. Extinction and reddening correction

A total colour shift of $E(B-V)=1.0$ with respect to 47 Tuc was found by OBB90, of which a fraction $\Delta E(B-V)=0.2$ was attributed to blanketing, and $E(B-V)=0.8$ to reddening. Values of reddening $E(B-V)=$ in the range 0.75 to 0.8 are obtained by fitting 15 Gyr solar metallicity isochrones from Bertelli et al. (1991). $E(B-V)=0.73$ was finally adopted from a comparison with CMDs of Terzan 1 (Ortolani et al. 1992).

The measured colours are in the Cousins system; we recall that the effective wavelengths of the *BVRI* Cousins bands are $\lambda_B=440$ nm, $\lambda_V=550$ nm (*B* and *V* are the same as in the Johnson's system), $\lambda_R=640$ nm (opposed to the 700 nm in Johnson's system), $\lambda_I=790$ nm (opposed to the 900 nm in Johnson's system).

Adopting the $A_\lambda/E(B-V)$ laws by Savage & Mathis (1979), and Mathis (1990) we derive $A_I=1.42$, $A_R=1.9$, $A_V=2.19$, $A_B=2.95$, $E(R-I)=0.48$, $E(V-R)=0.45$, $E(V-I)=0.77$.

The corrected Cousins colours for our stars are, therefore:

$(B-V)_o=1.6$, $(R-I)_o=0.93$, $(V-I)_o=2.05$, $(V-R)_o=0.96$.

3.2. Temperature

3.2.1. Relations temperature vs. colours

In order to transform our Cousins colours to the Johnson system, transformations given by Bessell (1979, 1983) were used. Then, an attempt to derive the temperature was done by using the $(R-I)$, $(V-R)$ and $(B-V)$ indices. The resulting temperatures, obtained with the use of different relations between indices and temperatures varied from 3200 to 4200 K. This indicates the uncertainty in the use of such relations. This method was therefore discarded.

3.2.2. Method using CMDs for metal-rich clusters

High metallicities and low temperatures have both the effect of strengthening the atomic and molecular lines; it is therefore difficult to disentangle these two effects. In this sense, we developed here a more clear method for temperature derivation, in the light of our recent data on colour–magnitude diagrams for bulge clusters, as described below.

The I_0 vs. $(V-I)_0$ mean locus CMDs for the globular clusters M 15, 47 Tuc (da Costa & Armandroff 1990), NGC 6553, NGC 6528 and Terzan 1 were shown in Fig. 1 of Bica et al. (1991). In that figure, a colour shift of the red-giant branch is seen, as a result of metallicity differences.

In Fig. 3, the V_o vs. $(B-V)_o$ CMD is shown for: (a) 47 Tuc: mean locus by Fahlman et al. (1985) and data by Frogel et al. (1981) and Brown et al. (1990); (b) mean locus of NGC 6553 (cf. OBB90). In a similar figure we have also plotted field giants corresponding to $[M/H]\approx 0.0$, using data given in Cayrel de Strobel et al. (1985) and Johnson (1964). These points for which $M(V)$, $(B-V)$ and T_{eff} were available, allowed us to draw lines of constant temperatures, as shown in Fig. 3, joining the same-temperature stars of different metallicities: following the indication given by these lines, the star III-17 should have a temperature of $T_{eff}=3850$ K. This is the temperature adopted for III-17 in the present work.

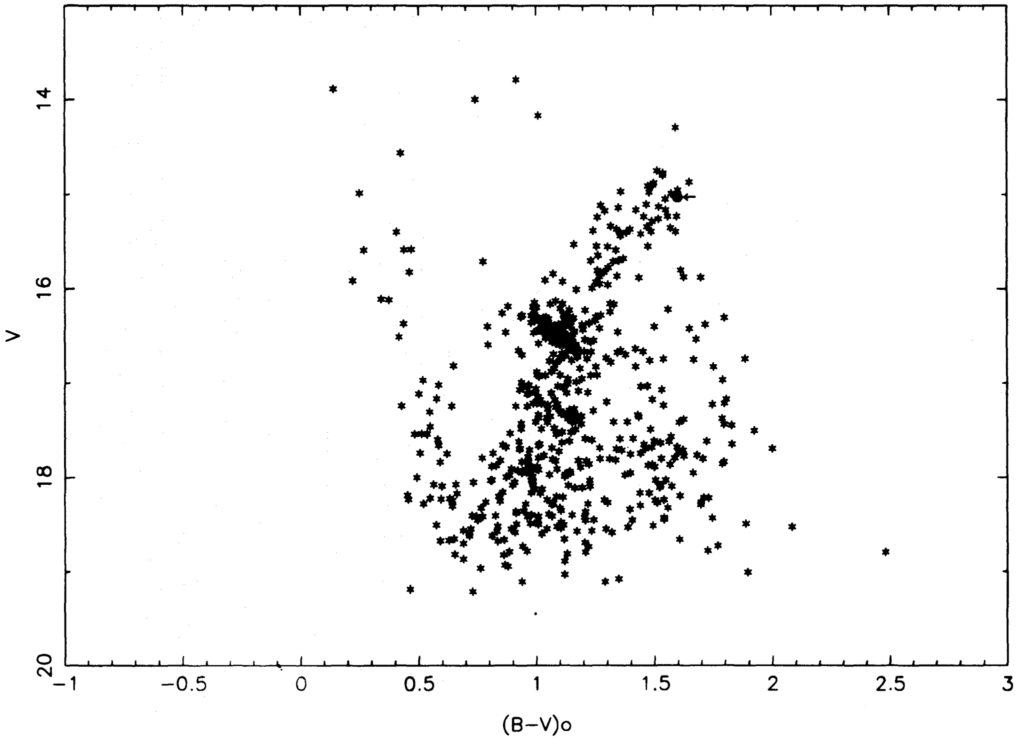

Fig. 2a. V vs. $(B-V)$ colour–magnitude diagram (CMD) of NGC 6553, where the star III-17 is identified with a circle plus an arrow

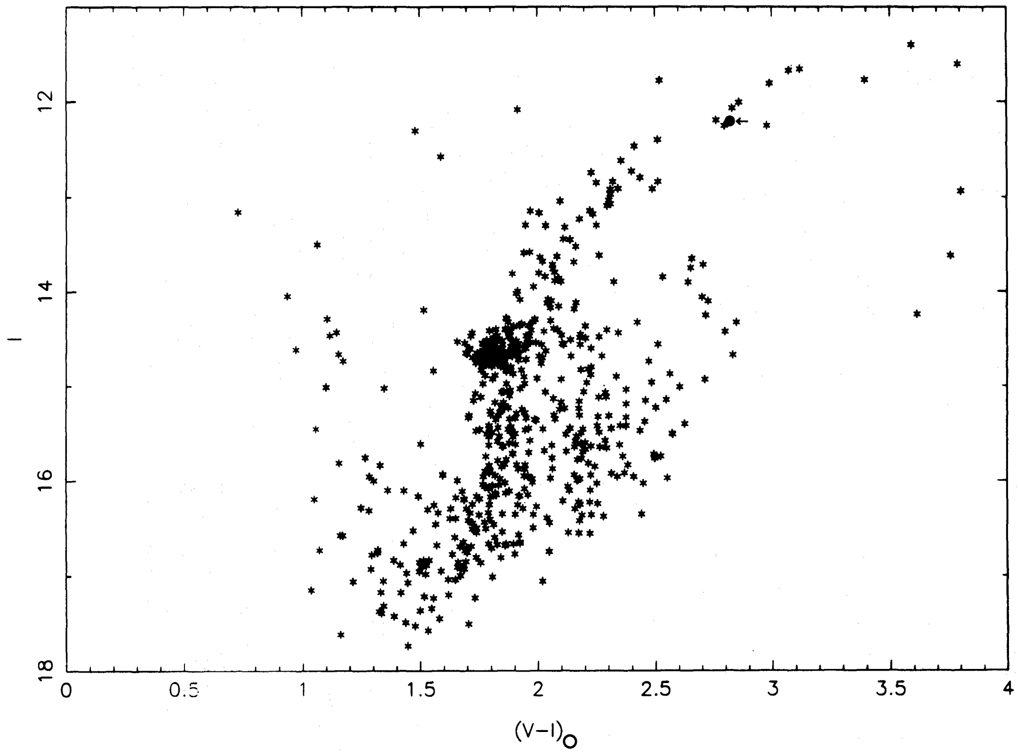

Fig. 2b. I vs. $(V-I)$ colour–magnitude diagram (CMD) of NGC 6553, where the star III-17 is identified with a circle plus an arrow

3.3. Gravity

The gravity is derived using the classical relation:

$$\log g = 4.44 + 4 \log T_*/T_\odot + 0.4(M_{\rm bol} - M_{\rm bol\odot}) + \log M_*/M_\odot .$$

A mass of $0.8 M_\odot$ was adopted: masses of 0.9 or $0.7 M_\odot$ would shift the gravity of only $\Delta \log g \approx \pm 0.06$. The absolute magnitude $M_{\rm v}$ was derived considering that $M_{\rm v}$(HB) = 1.06 (where HB = horizontal branch) (cf. Buonnano et al. 1989), and using V(HB) = 16.6 (cf. OBB90), resulting in $M_{\rm v}$ (III-17) = −0.51. Then the bolometric magnitude $M_{\rm bol}$ was obtained using the bolometric corrections (BC) by Persson et al. (1980), where $M_{\rm bol}$(III-17) = −1.8.

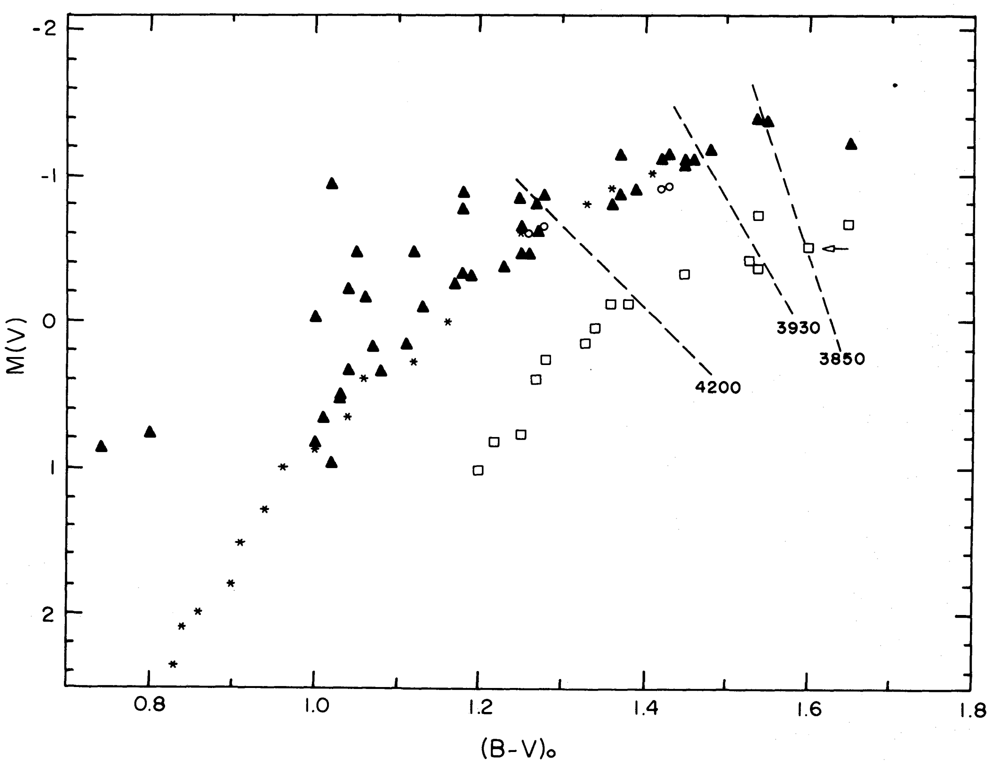

Fig. 3. $M(V)$ vs. $(B-V)_o$ for 47 Tuc: mean locus from Fahlman et al. (1985) (∗) and data from Frogel et al. (1981) (▲) and Brown et al. (1990) (○); mean locus of NGC 6553 (□), where the star III-17 is indicated with an arrow

Surface gravities derived with this classical formula are more reliable than those derived by ionization equilibrium. Lines in these cool giants are affected by departures from LTE, revealed by an overionization effect: the abundances derived from Fe II lines are larger than those derived from Fe I lines. Following Pilachowski et al. (1983) and François et al. (1988), in order to bring the neutral and ionized species into balance, a change in the gravity log g of at least 0.6 dex has to be applied, for stars in the temperature range $T_{\rm eff}<4200$, and this correction was applied for the gravity of III-17.

For the adopted temperature of 3850 K, the resulting gravity is log $g=0.42$, where a 0.6 dex correction was applied.

4. Synthetic spectra

The observed spectrum was compared to synthetic spectra in the wavelength region $\lambda\lambda$475–588 nm. Of particular interest are the regions $\lambda\lambda$515–520 nm, containing the MgH lines and the Mg I triplet, the [O I] λ557.73 nm, and $\lambda\lambda$560–565 nm, containing C_2 lines, and for the metallicity derivation, regions essentially deprived of molecular bands, such as $\lambda\lambda$490–495 nm and $\lambda\lambda$522–540 nm. The spectrum synthesis code and the input data are described in detail in Barbuy (1989), Cayrel et al. (1991) and Barbury et al. (1992) for $\lambda\lambda$478–530 nm and in Barbuy et al. (1991) for $\lambda\lambda$560–565 nm. The atomic data (oscillator strengths and damping constants) in the wavelength region 530–560 nm has been derived in the present work, throughout iterative fittings, line-by-line, to the solar spectrum.

The molecular lines included in the present calculations are CN, C_2, MgH and TiO.

4.1. Metallicity

In Figs. 4a, b are shown the observed spectrum and synthetic spectra in selected spectral regions, for metallicities [M/H] = −0.5, −0.2, +0.1.

The quality of our spectra, with S/N ≈ 40, and wavelength resolution ≈ 0.20, combined to the fact that a metal-rich giant shows many blends, did not allow us to carry out a detailed analysis.

We find that the result of the derivation of metallicity based on the synthetic spectra is [M/H] = -0.2 ± 0.3. The error of ±0.3 would come from the fitting, since in most spectral regions, [M/H] = −0.2 appear the most appropriate fit but in some regions would be adequate for [M/H] = −0.5 and in others with [M/H] = +0.1. In the case of imprecisions in stellar parameters, and specially on the temperature, the error would be larger.

We conclude that further spectra at higher S/N and resolution have to be obtained in order to carry out a detailed analysis for a sample of a few stars in NGC 6553, in order to definitively derive its metallicity.

4.2. Errors

The major source of uncertainty is the temperature. We believe to have established a relatively accurate method to derive temperatures for giant stars in metal-rich globular clusters (cf. Fig. 3), using their CMDs. The temperature adopted was checked with Fe I lines of different excitation potential $\chi_{\rm ex}$, and there appears to be a best fit for $T_{\rm eff}=3850$ K, confirming the quality of our CMD method.

An error in the temperature of ±100 K would be reflected in an error in metallicity of $\approx ^{+0.1}_{-0.3}$. This is illustrated in Fig. 5 which

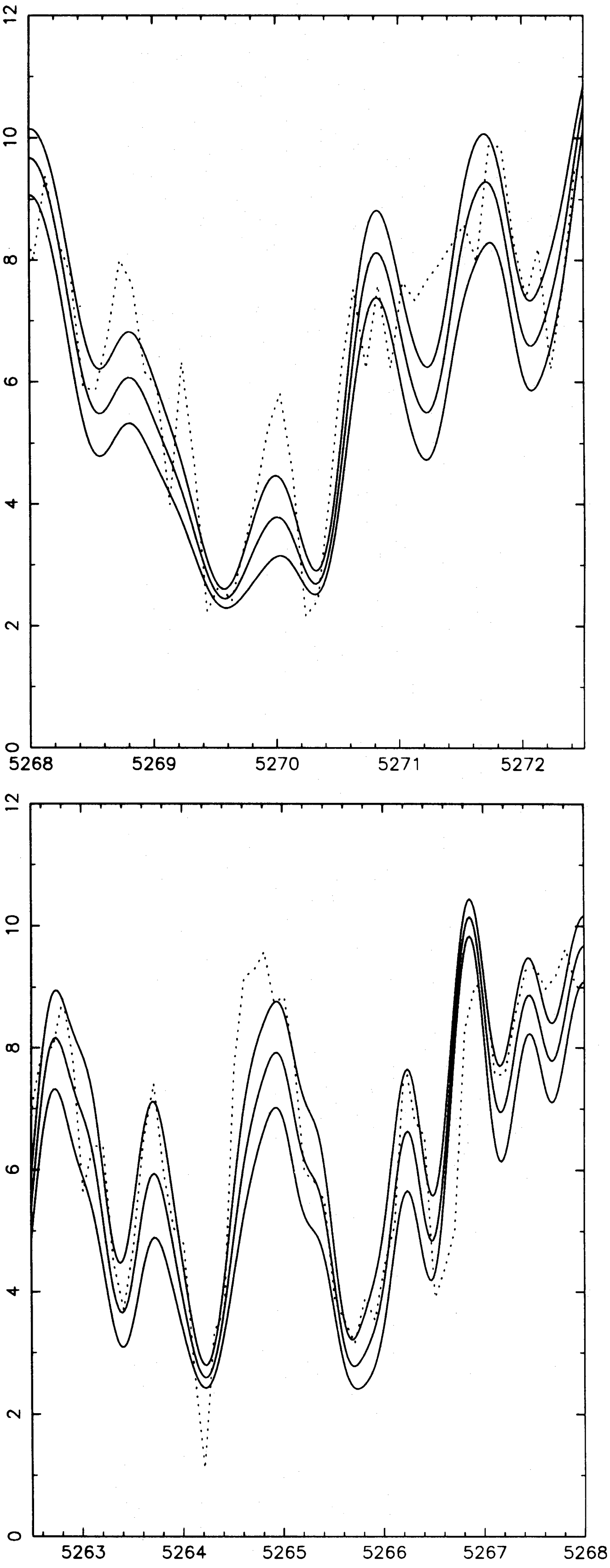

Fig. 4a and b. Observed spectrum (dotted line) and synthetic spectra (solid lines) computed with [M/H] = −0.5, −0.2 and +0.1 in the spectral regions **a** $\lambda\lambda$526.3–526.8 nm and **b** $\lambda\lambda$526.8–527.2 nm

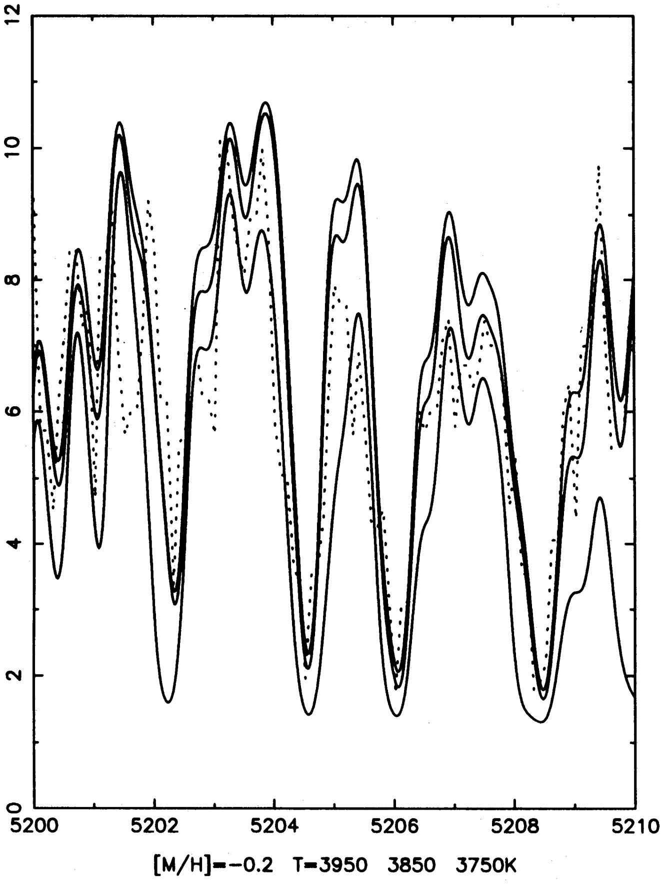

Fig. 5. Synthetic spectra computed with temperatures $T_{\rm eff}$ = 3750, 3850 and 3950 K, illustrating the error induced in metallicity for an error of ±100 K in temperature

shows synthetic spectra for $T_{\rm eff}$ = 3750 K, 3850 K and 3950 K, compared with the observed spectrum, in the wavelength region $\lambda\lambda$520–521 nm. Since the opacity is strong in such metal-rich evolved atmosphere there, is an imprecision in the continuum fit, and we might admit a larger error of $^{+0.2}_{-0.4}$ dex.

4.3. CNO abundances

We have tried to derive the C and N abundances from the relatively unblended lines of C_2(0, 1) at λ563.53 nm, and CN(5, 0) at λ563.44 nm (see Fig. 6). We note the presence of a non-identified line at λ563.50 nm.

The derived C and N abundances are [C/Fe] < 0.0 ± 0.3, and [N/Fe] = +0.6 ± 0.3.

A tentative derivation of the oxygen abundance was done, using the [O I] λ557.73 nm line. Although strong, this line is either heavily blended with MgH, or with unidentified lines, or there is a defect in the spectrum at that region. The synthesized [O I] spectrum is consistent with an abundance [O/Fe] ≈ 0.0, but this value has to be checked with further spectra.

5. Discussion

In Table 1 are reported the metallicities attributed to NGC 6553 by different authors. The metallicity values range from [M/H] +0.47 − 0.70, over a factor 10.

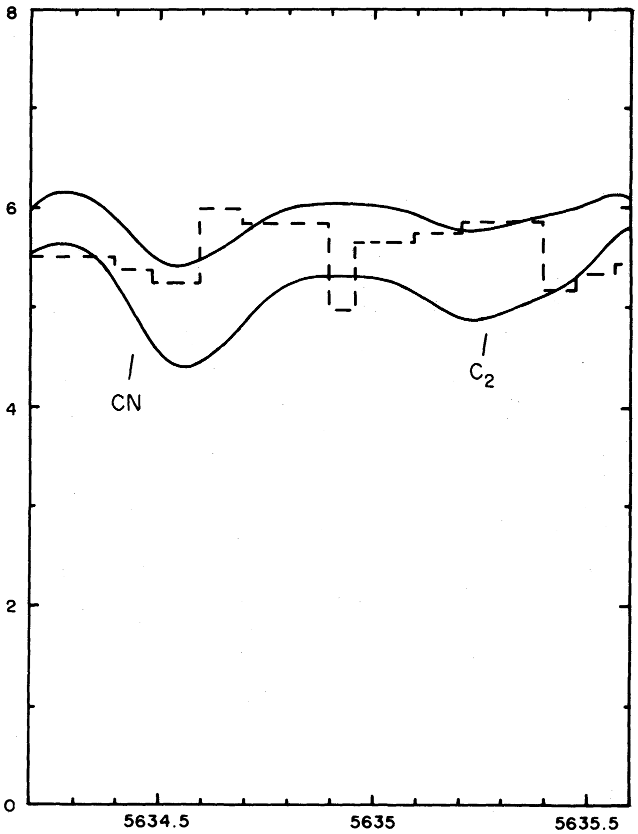

Fig. 6. Observed spectrum (dashed line) and synthetic spectra (solid lines) for $C_2(0, 1)$ at λ563.53 nm and CN(5, 0) at λ563.4 nm, computed with $[C/Fe] = +0.1$, $+0.3$ and $[N/Fe] = +0.4$

Table 1. Metallicities attributed to NGC 6553 in the literature

[M/H]	References
+ 0.47	Bica & Pastoriza (1983)
+ 0.24, + 0.37	Cohen (1983)
− 0.29	Zinn & West (1984)
− 0.70	Pilachowski (1984)
− 0.41	Webbink (1985)
− 0.20	Present work

Table 2. Metallicity and CNO abundances derived for the star III-17

$T_{\rm eff}$	$\log g$	[M/H]	[C/Fe]	[N/Fe]	[O/Fe]
3850	0.42	− 0.2	0.0 ± 0.3	$+ 0.4 \pm 0.3$	0.0 ± 0.3

The major source of uncertainty is the temperature; we have derived a method to find the correct temperature, using CMDs of metal-rich globular clusters. The maximum error induced in metallicity is estimated to be $^{+0.2}_{-0.4}$: this would place the metallicity in the range $[M/H] = -0.2^{+0.2}_{-0.4}$, or $[M/H]_{\rm min} = -0.6$ and $[M/H]_{\rm max} = 0.0$.

We consider that the value $[M/H] = -0.7$ given by Pilachowski (1984) is too low but, on the other hand, she gives relative results consistent with location of the CMDs of NGC 6553 and NGC 6528: their locations coincide in Fig. 1 of Bica et al. (1991), and she obtained the same metallicity for these two clusters.

Considering that the metallicity of the star III-17 corresponds to the metallicity of the cluster, from Table 2 we see that the present result of $[M/H] = -0.2$ is consistent with the work by Zinn & West (1984).

We consider that the disagreement with Cohen (1983) might be explained by differences in the reddening and temperatures adopted.

Otherwise, the disagreement with BP 83 can be explained as a result of the DDO photometric system, which measures essentially CN, CH and C_2 bands. The integrated light of globular clusters is dominated by the contribution of giants; it is well known that the giants show stronger CN bands, and more so in NGC 6553, given that it is a metal-rich cluster, where the intensity of diatomic molecules increases with the square of metallicity. In other words, the stronger DDO photometric indices measured by BP 83 would be due to a CNO excess, rather than to a higher metallicity. Moreover, recent analyses of metal-rich clusters in our Galaxy and in M 31 suggest that other absorbers, possibly molecules involving CNO elements, are responsible for the global blanketing in this region, in addition to the localized bands of CH, CN and C_2 (Bica 1991 and references therein). On the other hand, BP 83 also found a metallicity difference between NGC 6553 and that of NGC 6528 ($[M/H] = -0.18$): this might imply that NGC 6528 is not CNO-rich.

The CNO abundances can be interpreted as follows:

N overabundances are always expected for old giants. *If confirmed*, $[C/Fe] \approx 0.0$ is difficult to explain. We point out that the same was found in giants of ω Centauri (Milone et al. 1991).

A solar oxygen-to-iron ratio, *if confirmed*, would indicate that the chemical enrichment of the proto-globular gas was not essentially due to supernovae type II (SNII), as the halo globulars; Supernovae type I (SNI) would also have had an important role in their enrichment. An age estimation by OBB90, of about 14 Gyr for NGC 6553, if the halo globular clusters are considered to be 16 Gyr old, is consistent with the SNII plus SNI chemical enrichment, since the evolution of SNI lasts $\approx 10^8$ yr.

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