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MATCHING STELLAR POPULATION MODELS TO BULGE GLOBULAR CLUSTERS[1]

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ABSTRACT

We compare observed color-magnitude diagrams (CMDs) of the three metal-rich bulge globular clusters NGC 6553, NGC 6528, and Terzan 5, and integrated spectral energy distributions (SEDs) of NGC 6528, and 47 Tuc, to theoretical isochrones and model SEDs computed with the code of Bruzual & Charlot (1997, ApJ, in preparation, hereafter BC97). The BC97 models provide the evolution in time of the spectrophotometric properties of simple stellar populations (SSPs) for a wide range of stellar metallicity. These models allow us to compare predictions based on different sets of evolutionary tracks and various choices of the stellar spectral libraries with observational data. We conclude that: (a) At least for solar metallicity models, the semi-empirical flux corrections applied by Lejeune *et al.* (1997, A&A, in press; 1997, A&A, in preparation) to available grids of synthetic stellar spectra improve the agreement between population model predictions and observations. (b) The adopted reddening and distance moduli for the three clusters seem well determined, since the theoretical isochrones fit quite well the observed CMDs. (c) The overall metallicity of these clusters is close to solar. (d) Based on our CMD and SED models we estimate that the ages of NGC 6553 and NGC 6528 must be $\approx 12 \pm 2$ Gyr. These are the only two clusters in our sample with main sequence photometry. From the UV-optical SED of 47 Tuc we estimate an age of $\approx 14 \pm 2$ Gyr. © *1997 American Astronomical Society.* [S0004-6256(97)02509-0]

1. INTRODUCTION

The galactic bulge is a key component of our Galaxy. The detailed study of its stellar populations may provide a closer understanding of E/S0 galaxies and of the bulge of other spiral galaxies. Our knowledge of the bulge stellar population has improved in the last years through: (a) low resolution spectroscopy (Rich 1988; Terndrup *et al.* 1995; Sadler *et al.* 1996); (b) detailed abundance analysis (McWilliam & Rich 1994); (c) integrated SEDs of clusters (Bica 1988, and references therein) and of the Baade's Window field (Idiart *et al.* 1996); (d) CMDs of globular clusters (Ortolani *et al.*

[1]Based on observations collected at ESO, La Silla, Chile and with the NASA/ESA *Hubble Space Telescope*.

1997, and references therein), and of the Baade's Window field (Terndrup 1988; Ortolani & Rich 1997); and (e) population synthesis of metal rich globular clusters using observed CMDs combined with observed stellar libraries (Santos *et al.* 1995), or with a library of synthetic spectra (Barbuy 1994). For instance, Ortolani *et al.* (1995) have shown that the ages and mean metallicities inferred from the CMDs of the two metal-rich bulge clusters, NGC 6528 and NGC 6553, are very similar to those of the stars in Baade's Window, although the latter show a larger spread in color, due to depth effects and to the presence there of stars with a range of metallicities.

Population synthesis models, frequently used to study composite stellar populations in distant galaxies, are rarely confronted with observations of local simple stellar populations, such as globular star clusters, whose age and metal content have been constrained considerably in later years. If the models cannot reproduce the CMDs and SEDs of these objects for the correct choice of parameters, their predictive power becomes weaker and their usage to study complex galaxies may not be justified. The high quality and depth of the *Hubble Space Telescope* (*HST*) *VI*-photometry, and the *European Southern Observatory* (*ESO*) *New Technology Telescope* (*NTT*) and ESO 2.2 m *VI*- and *JK*-photometry of NGC 6553, NGC 6528 ($Z \lesssim Z_\odot$), and Terzan 5 ($Z \sim Z_\odot$), as well as the high signal-to-noise ratio of the integrated SEDs of NGC 6528 and 47 Tuc ($Z \approx 0.004$) currently available, provide an excellent framework for testing the range of validity of population synthesis models.

With this motivation in mind, in this paper we test the ability of the multi-metallicity evolutionary models of BC97 to reproduce the CMDs and SEDs of the most metal-rich galactic bulge globular star clusters. Conversely, to the extent that the models can be considered reliable, we are probing simultaneously the correctness of the adopted cluster ages and other cluster parameters.

In Sec. 2 we describe briefly the characteristics of the BC97 models. In Sec. 3 we list the observations of globular clusters that we will use towards our goal. The fitting of theoretical isochrones to the observed CMDs and the comparison of integrated spectra of sample clusters and models are presented and discussed in Sec. 4. The conclusions are summarized in Sec. 5.

2. POPULATION SYNTHESIS MODELS

BC97 have extended the Bruzual & Charlot (1993, hereafter BC93) evolutionary population synthesis models to provide the evolution in time of the spectrophotometric properties of SSPs for a wide range of stellar metallicity. The BC97 models are based on the stellar evolutionary tracks computed by Alongi *et al.* (1993), Bressan *et al.* (1993), Fagotto *et al.* (1994a, 1994b, 1994c), and Girardi *et al.* (1996), which use the radiative opacities of Iglesias *et al.* (1992). This library includes tracks for stars with initial chemical composition Z=0.0001, 0.0004, 0.004, 0.008, 0.02, 0.05, and 0.10, with $Y=2.5Z+0.23$, and initial mass $0.6 \leqslant m/M_\odot \leqslant 120$ for all metallicities, except $Z=0.0001$ ($0.6 \leqslant m/M_\odot \leqslant 100$) and $Z=0.1$ ($0.6 \leqslant m/M_\odot \leqslant 9$). This set of tracks will be referred to as the Padova or P-tracks hereafter. To allow for uncertainties in the stellar evolution theory, BC97 consider the evolutionary tracks computed by Schaller *et al.* (1992) ($m \geqslant 2\,M_\odot$) and Charbonnel *et al.* (1996) ($0.8 \leqslant m/M_\odot < 2$) for solar metallicity as an alternative to the P-tracks. In this case the abundances are $X=0.68$, $Y=0.30$, and $Z=0.02$, and the opacities are from Iglesias *et al.* (1992) (for $m \geqslant 2\,M_\odot$) and Iglesias & Rogers (1993) (for $0.8 \leqslant m/M_\odot < 2$). This set of tracks will be referred to as the Geneva or G-tracks hereafter. For $Z_\odot=0.02$ both sets of tracks are normalized to the temperature, luminosity, and radius of the Sun at an age of 4.6 Gyr. The published tracks go through all phases of stellar evolution from the zero-age main sequence to the beginning of the thermally pulsing regime of the asymptotic giant branch (AGB, for low- and intermediate-mass stars) and core-carbon ignition (for massive stars), and include mild overshooting in the convective core of stars more massive than $1M_\odot$ (Padova set) and $1.5M_\odot$ (Geneva set). The Post-AGB evolutionary phases for low- and intermediate-mass stars were added to the tracks by BC97 from different sources (see BC97 for details).

The BC97 models use the library of synthetic stellar spectra compiled by Lejeune *et al.* (1997a, 1997b, hereafter LCB97) for all the metallicities listed above. This library consists of Kurucz (1995) spectra for the hotter stars (O−K), Bessell *et al.* (1989, 1991) and Fluks *et al.* (1994) spectra for M giants, and Allard & Hauschildt (1995) spectra for M dwarfs. There are two versions of this atlas. One version (LCB97-O hereafter) contains the model spectra as published, but rebinned in a homogeneous fundamental parameter (effective temperature, gravity, metallicity) and wavelength scale (Leitherer *et al.* 1996). In the second version (LCB97-C hereafter), LCB97 corrected the original model spectra for systematic deviations that become apparent when color-temperature relations computed from the models are compared to empirical ones at $Z_\odot$. The corrections are especially important for the M star models. These semi-empirical blanketing corrections are defined for every wavelength, and should be a function of the fundamental model parameters: temperature, gravity, and Z. Due to the lack of calibration standards at various metallicities, LCB97 applied the corrections derived for $Z_\odot$ at all metallicities. Since the blanketing correction functions are multiplicative, the differential properties of the libraries are nearly conserved (see LCB97a,b for details). For instance, well known photometric differential metallicity indicators for F-G-K stars, such as the ultraviolet excesses, $\delta(U-B)$ in *UBV* photometry, and $\delta(C-M)$, $\delta(C-T_1)$ in Washington photometry, are very well reproduced for dwarf and giants by both the original and the corrected versions of the Kurucz (1995) library (Lejeune & Buser 1996). For $Z=Z_\odot$, BC97 also use an extended version of the Gunn & Stryker (1983) atlas, assembled from mostly empirical stellar data (EGS atlas hereafter, see BC97 for details).

3. OBSERVED COLOR-MAGNITUDE DIAGRAMS AND INTEGRATED SPECTRA

We will compare the BC97 model predictions with the data described below for each individual cluster. We stress that the observational data presented in this section are overplotted to the models (Sec. 4) with no adjustments. In all cases, the adopted values of $E(V-I)/E(B-V)$ take into account the dependence of this quantity on the cluster metallicity (see equation A1 of Dean *et al.* 1978) and also the dependence of the total-to-selective absorption $R=A_V/E(B-V)$ on the effective wavelength shift of the filters due to metallicity and $E(B-V)$ itself. The adoption of a constant value for R would be an oversimplification, since this dependence can be neglected in the halo but not in the low latitude bulge fields, because of the high reddening and metallicity. These questions are further discussed in Barbuy *et al.* (1997b). It is interesting to note that such a change in the value of R has an impact on the cluster distance but a negligible effect on the resulting absolute V magnitudes and $(V-I)$ colors. Ideally, the value of R should be taken as variable from the hottest stars (HB, TO) to the coolest ones (RGB tip; see, e.g., Cameron 1985). This would distort the CMD and, consequently, change the stellar population which fits the cluster data.

3.1 NGC 6553

HST VI-photometry and ESO 2.2 m *JK*-photometry by Ortolani *et al.* (1995) and Guarnieri *et al.* (1997) is available for this cluster. From a detailed high resolution spectral analysis of individual member stars, Barbuy *et al.* (1997a) have derived [Fe/H]=−0.35, whereas [α-elements/Fe] $\approx$0.3 (except for Ca). We use the reddening corrections as given by Guarnieri *et al.* (1997): $E(V-I)=0.95$, $A_V=2.5$, $E(B-V)=0.7$ (for $A_V/E(B-V)=3.6$), $E(J-K)=2.74$, $A_K=0.25$ (for $E(V-K)/E(B-V)=0.527$, Rieke & Lebofsky 1985). A true distance modulus of $(m-M)_0=13.6$ is adopted (Guarnieri *et al.* 1997).

3.2 NGC 6528

The *HST VI*-photometry of this cluster shows very similar features in the CMD compared to NGC 6553, and both clusters should have similar metallicity (Ortolani *et al.* 1995). A detailed discussion of the *HST* CMD of this cluster will be provided elsewhere. For the CMD we use the reddening corrections as given by Barbuy *et al.* (1997b): $E(B-V)=0.52$, $E(V-I)=0.68$, $A_V=1.80$, $(m-M)_0=14.45$, and $d_\odot=7.83$ kpc.

The integrated spectrum of NGC 6528 in the wavelength range $\lambda=3500$–9800 Å was obtained by combining the visible, near-infrared, and near-ultraviolet spectra of Bica & Alloin (1986, 1987) and Bica *et al.* (1994), respectively. We applied a reddening correction of $E(B-V)=0.62$, slightly less than the value $E(B-V)=0.66$ adopted in Bica *et al.* (1994, and references therein) and closer to that adopted in Barbuy *et al.* (1997b).[2]

3.3 Terzan 5

Applying the Red Giant Branch morphology criterion to their *ESO*-NTT *VI*-photometry, Ortolani *et al.* (1996, hereafter OBB96) estimate that Terzan 5 should have about solar abundance ([Fe/H]=0.0). We consider two possible ways to apply the reddening and distance modulus correction: (i) as given in OBB96, i.e., $E(B-V)=2.49$, $E(V-I)=3.31$ (adopting $E(V-I)/E(B-V)=1.33$ as in Dean *et al.* 1978), $A_V=7.71$ (adopting $A_V/E(B-V)=3.1$), and a true distance modulus of $(m-M)_0=13.74$. (ii) Revised reddening and distance modulus corrections were discussed in Barbuy *et al.* (1997b), taking into account the dependence of the total-to-selective absorption $R=A_V/E(B-V)$ on the effective wavelength shift of the filters due to metallicity and on $E(B-V)$. For Terzan 5 this results in $R=3.64$, $E(B-V)=2.39$, $E(V-I)=3.23$, $A_V=8.70$, and $(m-M)_0=12.80$. Assumptions (i) and (ii) have an impact on the cluster distance ($d_\odot=5.6$ kpc for $R=3.1$, and $d_\odot=3.63$ kpc for $R=3.64$), but essentially does not change the absolute V magnitudes and $(V-I)$ colors. We will adopt option (ii).

3.4 47 Tuc

For this cluster we also combined integrated spectra in different wavelength ranges from Bica & Alloin (1986) and Bica *et al.* (1992, 1994). The metallicity of 47 Tuc was found to be [Fe/H]=−0.80 with [O/Fe]=+0.4 by Tripicco & Bell (1992) and Brown *et al.* (1990). Hesser *et al.* (1987) give [Fe/H]=−0.65 and [O/Fe]=+0.3, whereas Zinn & West (1984) report [Fe/H]=−0.71. For these values there results $Z\approx0.0055$. Given that the Padova isochrones are given for $Z=0.004$ or $Z=0.008$, we adopt $Z=0.004$. The study of the CMD of 47 Tuc is the subject of an independent paper by Desidera & Ortolani (1997).

4. RESULTS FROM POPULATION SYNTHESIS MODELS

For each value of the metallicity Z listed in Sec. 2 ($Z=0.0001$, 0.0004, 0.004, 0.008, 0.02, 0.05, and 0.10) and a particular choice of the initial mass function (IMF), a BC97

[2]It is important to note that $E(B-V)$ values derived from CMDs or from integrated spectra are different. In fact, more attention to this question should be given in the literature. The origin of the differences in $E(B-V)$ is basically the amount of "reddening" attributed to blanketing in clusters more metal rich than 47 Tuc, which competes with the effect of interstellar reddening, especially in the blue. In order to derive the reddening of NGC 6553, [Fe/H]≈-0.35, we compare its CMD to that of 47 Tuc, [Fe/H] ≈-0.71 (Zinn & West 1984). The subgiant branch color of NGC 6553 relative to that of 47 Tuc is $\Delta(V-I)=1.11\pm0.15$, whereas for 47 Tuc a de-reddening of $E(B-V)=0.04$ (or $E(V-I)=0.05$) (Hesser *et al.* 1987) is applied. Finally, in order to take into account the blanketing difference between 47 Tuc and NGC 6553, Guarnieri *et al.* (1997) attribute $\Delta(V-I)=0.16$ to blanketing in NGC 6553, resulting in $E(V-I)=0.95$. NGC 6528 has $\Delta(V-I)\approx-0.27$ relative to NGC 6553, and since these two clusters have the same metallicity, then $E(V-I)=0.68$, or $E(B-V)=0.52$, for NGC 6528. If we assume for NGC 6553 a blanketing contribution of $\Delta(V-I)=0.03$, still within the errors, then for NGC 6528, $E(V-I)=0.81$, or $E(B-V)=0.62$.

TABLE 1. $Z_\odot$ model fits to SED of NGC 6528.

Model	Spectral Library	Stellar Tracks	Best-fitting age (Gyr)	Σ^2_{min}
1	EGS	P	14.75	1.81
2	,,	G	13.25	1.76
3	LCB97-C	P	13.00	2.10
4	,,	G	10.75	1.49
5	LCB97-O	P	14.50	3.98
6	,,	G	11.75	2.65

SSP model consists of a set of 221 evolving integrated SEDs spanning from 0 to 20 Gyr. The isochrone synthesis algorithm (BC93) used to build these models renders it straightforward to compute the loci described by the stellar population in the CMD at any time step and in any photometric band. We can extract the model SED that best reproduces a given observed SED and assign an age to the program object, and then examine how well the isochrone computed at this age fits the most significant features in the CMD of this object, if available. Thus, we can study objectively which of the basic building blocks used by BC97 for $Z=Z_\odot$ (P or G tracks; EGS, LCB97-O, or LCB97-C stellar libraries) is most successful at reproducing the data. In the rest of this section we will perform this type of analysis for the clusters listed in Sec. 3. All the model SEDs used in this paper were computed according to the Salpeter (1955) IMF.

4.1 NGC 6528

The SED of NGC 6528 is typical of old stellar populations of high metal content (Santos *et al.* 1995). It may happen that NGC 6528, similarly to NGC 6553, has [Fe/H]<0.0 (Barbuy *et al.* 1997a), whereas the [α-elements/Fe] are enhanced, resulting in $[Z/Z_\odot]\approx 0.0$, or possibly slightly below solar. Since we have evolutionary tracks for $Z=0.02$ and $Z=0.008$, we adopt $Z=0.02$.

The data available for this cluster provide a unique opportunity to examine the 6 different options for the $Z=Z_\odot$ models considered by BC97. In Table 1 we show the age at which Σ^2, defined as the sum of squared residuals $[\log F_\lambda(\text{observed})-\log F_\lambda(\text{model})]^2$, is minimum for various $Z=Z_\odot$ models. The values of Σ^2_{min} given in Table 1 indicate the goodness-of-fit. According to this criterion, model 4 provides the best fit to the integrated SED of NGC 6528 in the wavelength range λ3500–9800 Å. This fit is shown in Fig. 1. Except for the differences in the best-fitting age, models 1 through 3 provide comparable, although somewhat poorer, fits to the SED of this cluster. The residuals for models 5 and 6 are considerably larger. Figure 2 shows the residuals of the fits on the same scale as Fig. 1 and in increasing order of Σ^2_{min} (top to bottom). Spectral evolution is slow at these ages, and the minimum in the function Σ^2 vs age is quite broad. Reducing or increasing the model age by 1 or 2 Gyr produces fits of comparable quality to the one at which Σ^2 is minimum. For instance, for model 4, Σ^2(13 Gyr)=1.88, and Σ^2(9 Gyr)=2, which are still better fits according to the Σ^2 criterion than the best fits provided by models 3, 5, and 6.

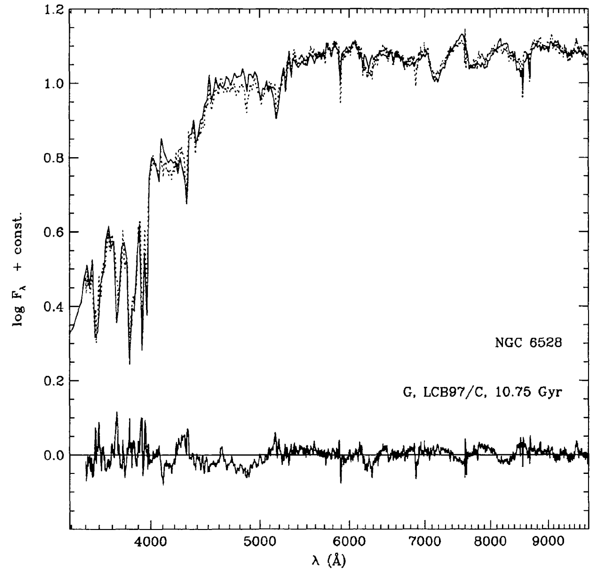

FIG. 1. Best fit to the integrated spectrum of NGC 6528 (dotted line) in the range $\lambda\lambda$ 3500–9800 Å for model 4 in Table 1 (solid line). The best fit occurs at 10.75 Gyr. The residuals of the fit, $\log F_\lambda$(observed) $-\log F_\lambda$(model), are shown as a function of wavelength.

Figure 3(a) shows the intrinsic *HST VI* CMD of NGC 6528 together with the isochrones corresponding to the models in Table 1. It is apparent from this figure that the isochrones for models 3 and 4 provide the best representation of the cluster population in this CMD, especially the position of the turnoff and the base of the asymptotic giant branch (AGB). We note that both NGC 6528 and NGC 6553 show a double turnoff, the upper one being due to contamination from the field star main sequence. The appropriate TO location would be around that indicated by the 11, 12, and 13 Gyr isochrones. Despite the fact that models 1 and 2 provide better fits to the SED of this cluster than models 5 and 6, the isochrones from the latter reproduce more closely the CMD diagram than models 1 and 2. Figure 3(b) compares the *VI* CMD of NGC 6528 with different isochrones derived from model 3.

From these results we conclude that:

(1) The $\lambda=3500-9800$ Å SED for $E(B-V)=0.62$ and the *VI* CMD of NGC 6528 are well reproduced by $Z=Z_\odot$ models at an age from 11 to 14 Gyr.

(2) The age derived from the fit to the observed SED of NGC 6528 is extremely sensitive to the assumed $E(B-V)$. Using $E(B-V)=0.59$ instead of 0.62, increases the best-fitting ages by 2 to 3 Gyr, since the observed SED is then intrinsically redder. On the other hand, if $E(B-V)=0.66$, the observed SED is intrinsically bluer and the derived ages are 2 to 3 Gyr younger than for $E(B-V)=0.62$. However, inspecting the isochrones in the CMD, the ages derived for $E(B-V)=0.62$ listed in Table 1, seem the most appropriate.

(3) The SED and CMD of this cluster are consistent with those expected for a $Z=Z_\odot$ population at an age of $\approx$12–13 Gyr, if overshooting occurs in the convective core of stars down to $1M_\odot$ (P tracks, model 3 in Table 1). If overshooting

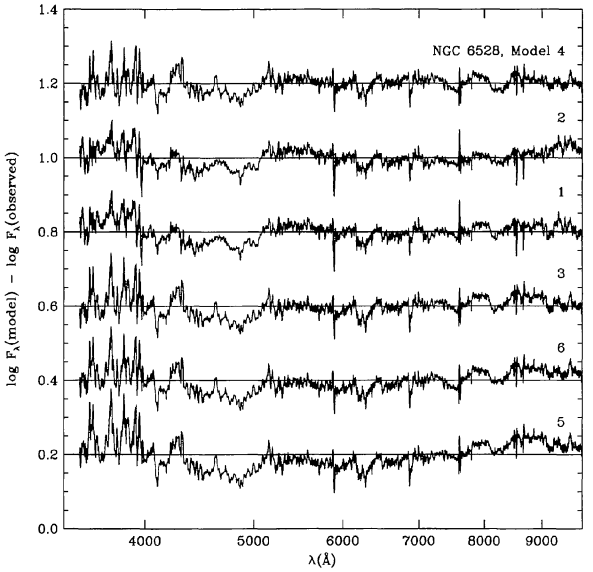

FIG. 2. Residuals log F_λ(observed) − log F_λ(model) of the fit of different models to the integrated spectrum of NGC 6528 (Table 1) as a function of wavelength. The lines have been shifted arbitrarily in the vertical direction and are shown in increasing order of $\Sigma^2_{\min}$ (top to bottom).

stops at $1.5 M_\odot$, as in the G-tracks, this age is reduced to ≈ 10–11 Gyr (model 4 in Table 1).

(4) For the same spectral library, the ages derived from the P tracks are older than the ones derived from the G tracks. This is due to the fact that the P tracks include overshooting in the convective core of stars more massive than $1 M_\odot$, whereas the G tracks stop overshooting at $1.5 M_\odot$. Thus, stars in this mass range require more time in the P tracks to leave the main sequence than in the G tracks.

(5) For the same set of evolutionary tracks, the corrected LCB97 library seems to provide a better fit to the CMD than the EGS atlas [Fig. 3(a)]. Interpolation in the finer LCB97 grid of models produces smoother isochrones than in the coarser EGS atlas. We attribute this to the fact that M stars are very sparse in the EGS atlas. Furthermore, the temperature scale becomes problematic for these stars in the EGS atlas. In the LCB97 library, the temperature scale for giants relies on measurements of angular diameters and fluxes, which enter directly in the definition of effective temperature. For dwarfs, the temperature scale is more difficult to define, as discussed in LCB97b.

(6) Noticeable differences exist in the isochrones computed for both sets of LCB97 libraries [Fig. 3(a)]. The differences are more pronounced for the M giants of $(V-I)_0 > 1.6$, and $(J-K)_0 > 1$, corresponding to a temperature of $T_e \leq 4000$ K, and for the cool dwarfs of $(V-I)_0 > 1$, corresponding to a temperature of $T_e \leq 4700$ K. There are very few of these stars in the CMD of NGC 6528 to favor a particular choice of library. However, the corrected library produces better fits to the observed SED. We attribute this fact to the relative importance of the luminosity of M giants.

(7) In general the LCB97 corrections redden the stellar SEDs in the optical range, producing redder SSP models at an earlier age. As a consequence, the ages derived in Table 1 for the LCB97-C library are younger than the ones derived

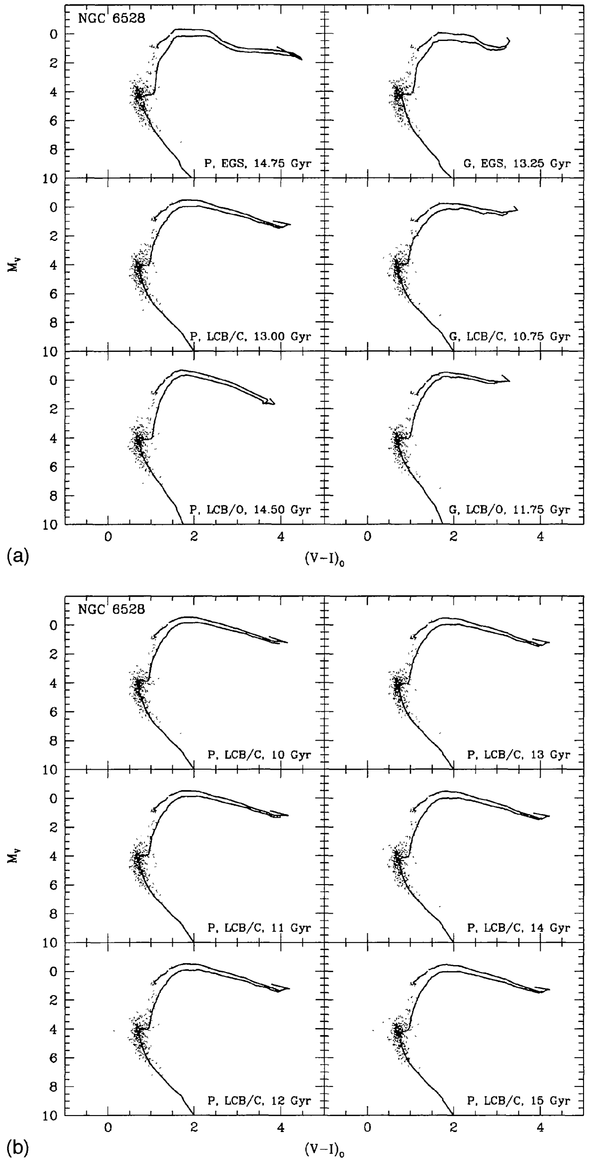

FIG. 3. Intrinsic M_V vs $(V-I)_0$ CMD of NGC 6528 shown together with (a) theoretical isochrones for the $Z=Z_\odot$ models listed in Table 1; and (b) theoretical isochrones for model 3 from 10 to 15 Gyr in 1 Gyr steps.

from the LCB97-O library for the same set of tracks.

(8) We have adopted $Z=Z_\odot$ for this cluster. However, for a slightly lower value of Z, the derived age would be older.

4.2 NGC 6553

We do not have available a SED of NGC 6553 of signal-to-noise ratio comparable to that of NGC 6528. Due to the similarity of the CMDs of both clusters, we will compare the CMD of NGC 6553 with the same isochrones considered above for NGC 6528. Figure 4 shows the isochrones of Fig. 3 together with the intrinsic CMD of NGC 6553 in M_V vs $(V-I)_0$, while Fig. 5 shows the isochrones from Table 1 for M_K vs $(J-K)_0$.

From these figures we see that:

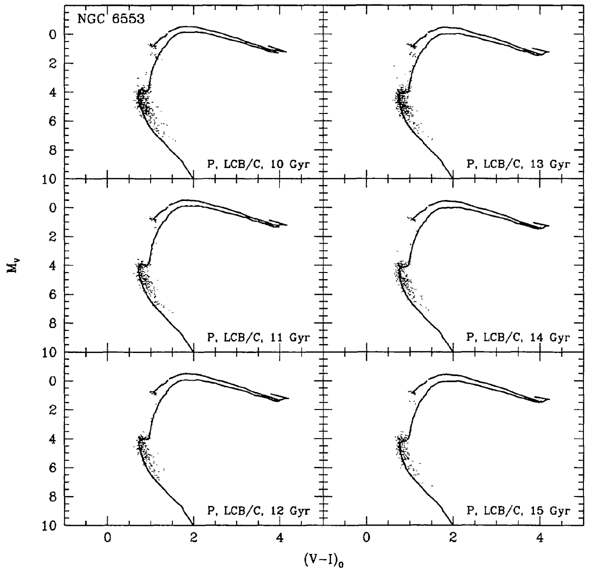

FIG. 4. Intrinsic M_V vs $(V-I)_0$ CMD of NGC 6553 shown together with the theoretical isochrones for model 3 of Table 1 from 10 to 15 Gyr in 1 Gyr steps.

(1) The 13 Gyr isochrone (model 3 in Table 1) provides a good fit to the M_V vs $(V-I)_0$ CMD in Fig. 4, in agreement with the discussion by Ortolani *et al.* (1995).

(2) The M_K vs $(J-K)_0$ CMD (Fig. 5) shows satisfactory fits, but it is not possible to infer an age from these diagrams, since the turnoff is not reached at the limiting M_K.

(3) The LCB97 corrections improve the M giant colors in both CMDs, and for the dwarfs in the *VI* CMD, where the NGC 6553 observations reach the main sequence. The isochrones in the *JK* CMD are similar for both libraries, except for the red giant branch tip stars, where the corrected library seems to provide a closer fit to the data.

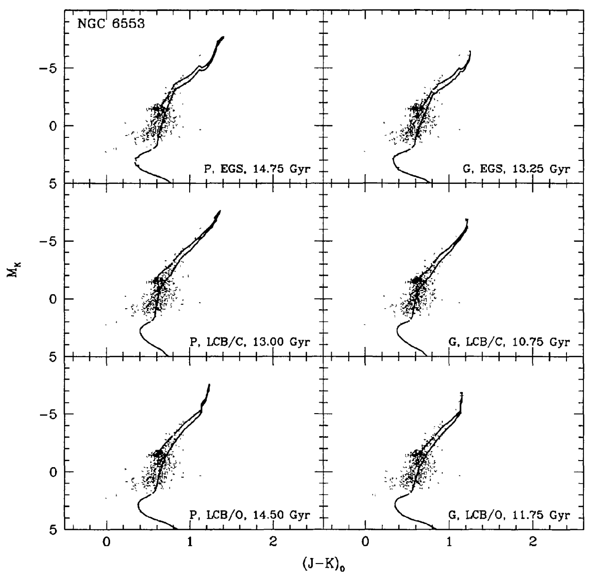

FIG. 5. Intrinsic M_K vs $(J-K)_0$ CMD of NGC 6553 shown together with the theoretical isochrones for the $Z=Z_\odot$ models listed in Table 1.

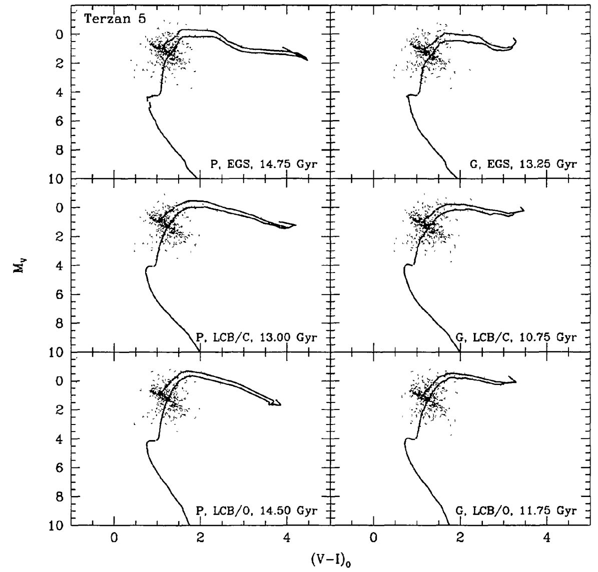

FIG. 6. Intrinsic M_V vs $(V-I)_0$ CMD of Terzan 5 shown together with the theoretical isochrones for the $Z=Z_\odot$ models listed in Table 1.

4.3 *Terzan 5*

Figure 6 shows the same isochrones discussed so far, together with the intrinsic M_V vs $(V-I)_0$ CMD of Terzan 5. The fits are quite satisfactory for the solar metallicity adopted. Again, it is not possible to infer an age from these diagrams since the turnoff is not reached at the limiting M_V.

4.4 *47 Tuc*

Figure 7 shows the best fit to the 2000–9800 Å integrated spectrum of 47 Tuc (Bica *et al.* 1994), accomplished with a $Z=0.004$, [Fe/H]-0.65, SSP at an age of 14.5 Gyr, using the LCB97-C library. The isochrone computed for this age and metallicity shows good agreement with a revised high quality CMD of 47 Tuc, that will be provided by Desidera & Ortolani (1997). This age is in agreement with the determinations by Hesser *et al.* (1987), Jimenez *et al.* (1996), Richer *et al.* (1996), and VandenBerg (1997) where an age of about 14 Gyr is indicated for 47 Tuc. Chaboyer *et al.* (1996) give a range of possible ages, which can be considered consistent with our value. Since 47 Tuc is a template cluster, our fit to its SED serves as a consistency check of our models. The value of the age quoted above depends on the exact metallicity of the cluster. It is premature at this point to consider significant the difference between this age and the one derived for NGC 6528.

5. CONCLUSIONS

We have used the BC97 code to study the stellar population of metal-rich globular clusters. In particular, we compare non-blanketing-corrected and blanketing-corrected isochrones and SEDs to observed CMDs of NGC 6528, NGC 6553, and Terzan 5, and integrated spectra of NGC 6528 and

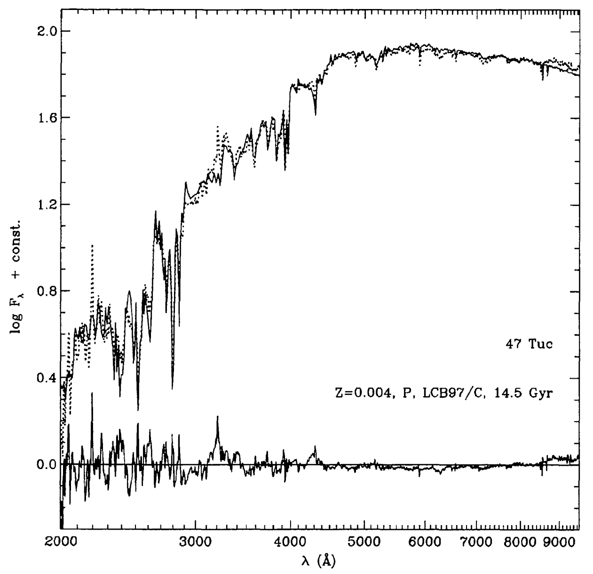

FIG. 7. Best fit to the integrated spectrum of 47 Tuc (dotted line) in the range λλ 2000–9800 Å. A SSP model for $Z=0.004$ built with the LCB97-C library was used in the fit (solid line). The best fit occurs at 14.5 Gyr. The residuals of the fit, $\log F_\lambda(\mathrm{observed}) - \log F_\lambda(\mathrm{model})$, are shown as a function of wavelength.

47 Tuc, respectively. The comparison between models and observed CMDs and integrated spectra indicate that:

The semi-empirical flux corrections applied by LCB97 to existing grids of synthetic spectra improve the agreement between population model predictions and observations, at least for $Z=Z_\odot$. For this metallicity, the LCB97-C library provides the best match to the observations, improving significantly over that obtained with the empirical EGS atlas.

(b) The reddening and distance moduli used for NGC 6553, NGC 6528, and Terzan 5, appear to be well determined, since the theoretical isochrones fit rather well the observed CMDs.

(c) From the P tracks and the LCB97-C spectral library, we estimate that the age of NGC 6553 and NGC 6528 must be $\approx 12\pm 2$ Gyr. The same set of models imply an age of $\approx 14\pm 2$ Gyr for 47 Tuc, consistent with previous estimates. We think it is premature at this point, due, in particular, to uncertainties in the reddening of the bulge clusters, to consider significant the age difference between NGC 6528 and NGC 6553 relative to 47 Tuc.

(d) The adopted overall metallicity $Z\approx Z_\odot$ seems adequate for NGC 6553, NGC 6528, and Terzan 5. The former two clusters show [Fe/H]$=-0.35$ and enhancement of α-elements, derived from high dispersion spectroscopy, which results in Z close to the solar value.

(e) The evolutionary tracks used reproduce well the observed properties of these SSPs. Tracks with a finer resolution in Z will improve our estimates of cluster ages and metallicities.

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