On Age and Metallicity of Evolved Stellar Populations

E. Bertone [(1)], M. Chavez [(1)], L.H. Rodriguez-Merino [(2)], A. Buzzoni [(3)]

(1) INAOE, Mexico, (2) Johns Hopkins University, USA, (3) INAF – Osservatorio Astronomico di Bologna, Italy

ABSTRACT. We explore the applicability of updated stellar libraries and synthesis codes in determining the age and chemical composition of evolved populations from their integrated UV spectra. In this poster paper we present preliminary results of comparing the UV spectra of two fundamental calibration objects, the Sun and M32, with a grid of synthetic spectra of Single Stellar Populations (SSP) calculated using the stellar library UVBLUE in Buzzoni's synthesis code. While the results for these two objects are highly encouraging, there is still to be analyzed if the method is robust enough to be applied to the analysis of any old population.

INTRODUCTION. Evolutionary single stellar population (SSP) models are proved to be a relevant and effective tool for the interpretation of the integrated spectra of quiescent stellar aggregates (e.g., among many, Buzzoni 1989, Bressan et al. 1994). In particular, they can provide estimates of fundamental parameters, such as the age and the metallicity, of the stellar populations which build up the system.

The improvement of telescopes and instrumentation now allows to have good quality observations of faint objects. Spectra of high-redshift galaxies (z >1) can now "easily" reach (rest frame) resolutions of FWHM < 10 Å (Cimatti et al. 2002, Abraham et al. 2004). This makes compulsory to match the population synthesis codes with extended stellar spectral libraries, either empirical or theoretical, of equal or better quality, to create models that can fully exploit the observational data.

We have computed a large grid of high-resolution synthetic stellar spectra which cover the electromagnetic spectrum from UV (with the UVBLUE library; Rodriguez-Merino et al. 2005) to red (BLUERED; Bertone et al. 2004a) wavelengths.

This set of spectra has been implemented in the Buzzoni's code (1989) to produce 2 Å FWHM integrated spectral energy distributions (SED) of SSPs. They span an age interval from 2 to 15 Gyr at six different metallicities [Z=0.0001, 0.001, 0.01, 0.017 (solar), 0.03, and 0.1]. In this work we use models which assume a Salpeter Initial Mass Function (s=2.35) and a red morphology of the horizontal branch.

We focus our attention on the analysis of the mid-UV regime, between 2000 and 3200 Å. This wavelength interval is suitable to investigate the integrated emission of "red" galaxies at 1<z<2 (the "redshift desert"), as it can be observed from ground-based large optical telescopes. The determination of the age and metallicity of the stars of these distant objects can provide stringent constraints on the galaxy formation epoch and early evolution.

Note: the UVBLUE library is public and can be downloaded at:
http://www.inaoep.mx/~modelos/uvblue/uvblue.html
http://www.bo.astro.it/~eps/uvblue/uvblue.html

AGE AND METALLICITY DETERMINATION. The age and the metallicity (Z) of the population which dominates the mid-UV emission of a stellar system can be provided by identifying the best match between the observed spectrum and a grid of SSP SEDs.

The first mandatory step to validate the method and check the suitability of the models is to apply it on target objects whose parameters are already well established. In this poster we show the results that we have obtained for the nearby dwarf elliptical galaxy M32 and for our nearest star, the Sun.

THE SUN. If we assume that the mid-UV emission of a SSP is dominated by turn-off stars, we should obtain an age which correspond to the life time that those stars have spent on the main sequence. For the Sun we can assume a value of 10.5 Gyr (Jorgensen 1991).

The mid-UV solar spectrum was extracted from the UARS/SUSIM archive (http://daac.gsfc.nasa.gov/data/dataset/UARS/SUSIM), averaging 769 observations from September 1991 to February 1993. The spectrum is shown in Fig. 1.

We have selected the interval between 2000 and 3200 Å. However, we have excluded the interval from 2610 to 2750 Å, as the observed bump included between these limits is not accurately reproduced by the synthetic stellar spectra. Some opacity is missing in the stellar model atmospheres, but there is still not a common agreement about its nature (Peterson et al. 2001).

We compare the template spectrum with the grid of SSP spectra, broadened to the same spectral resolution (FWHM=13 Å) and normalized to the same flux integral, and compute the reduced chi-square χ_ν^2.

For each metallicity, the chi-square points as a function of the age are interpolated by means of a cubic spline curve. The abscissa of the minimum of the curve determines a corresponding "best" fiducial age. A 1-sigma uncertainty of the age is provided by performing a single-tail F-test (Bertone et al. 2004b).

The results are shown in Fig. 2 and reported in Table 1.

The absolute chi-square minimum is found on the solar metallicity curve and provides an age of 10.1 Gyr, with an error of more than 1 Gyr. This result is perfectly compatible with the commonly accepted value of 10.5 Gyr.

SUN

Z	Age (Gyr)	χ_ν^2
0.0001	9.575	4347.0
0.001	15.000	2542.6
0.010	15.000	82.6
0.017	$10.115^{+1.620}_{-1.255}$	8.9
0.03	$7.465^{+1.210}_{-0.995}$	9.9
0.1	6.000	57.6

Table1. The results of the comparison of the Sun and the SSP spectra. The "best" fiducial age is reported for each metallicity. It is singled out by the abscissa of the minimum of each metallicity curve of Fig. 2. The 1-sigma errors are only reported for those cases where a well established minimum was present inside the age range spanned by the SSP models.

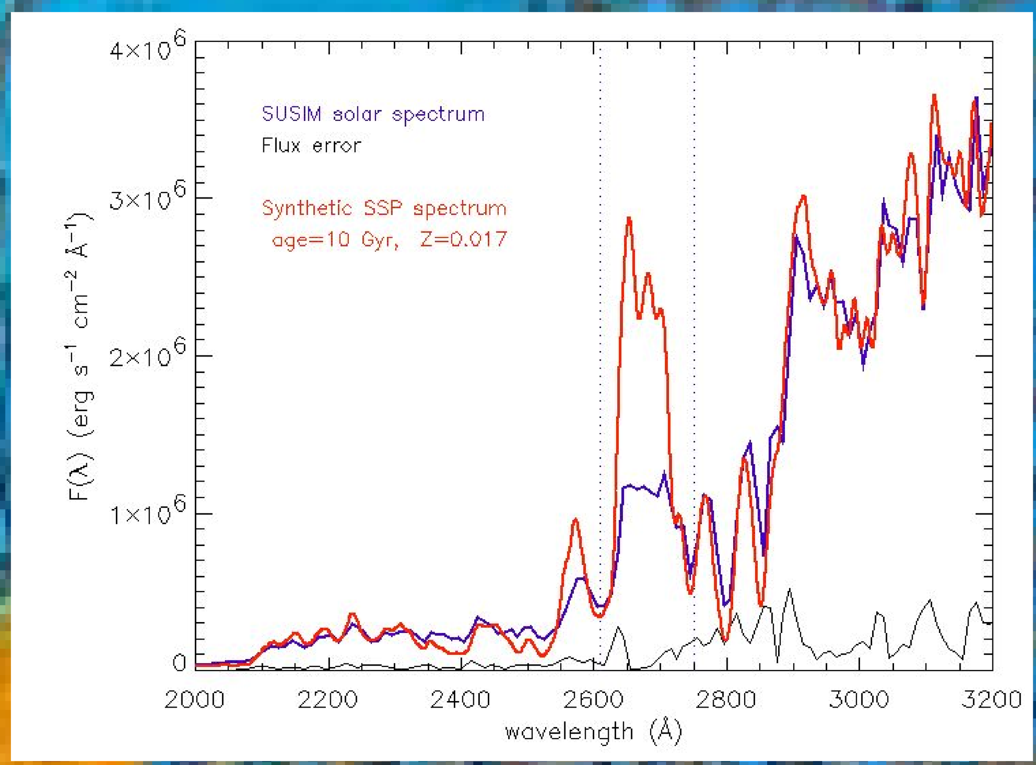

Figure 1. The observed solar spectrum (blue line) is shown, along with its corresponding flux error (black) and the theoretical integrated spectrum of the SSP model which provided the minimum χ_ν^2: age=10 Gyr, Z=0.017 (solar). The dotted lines defines the border of interval excluded from the comparison.

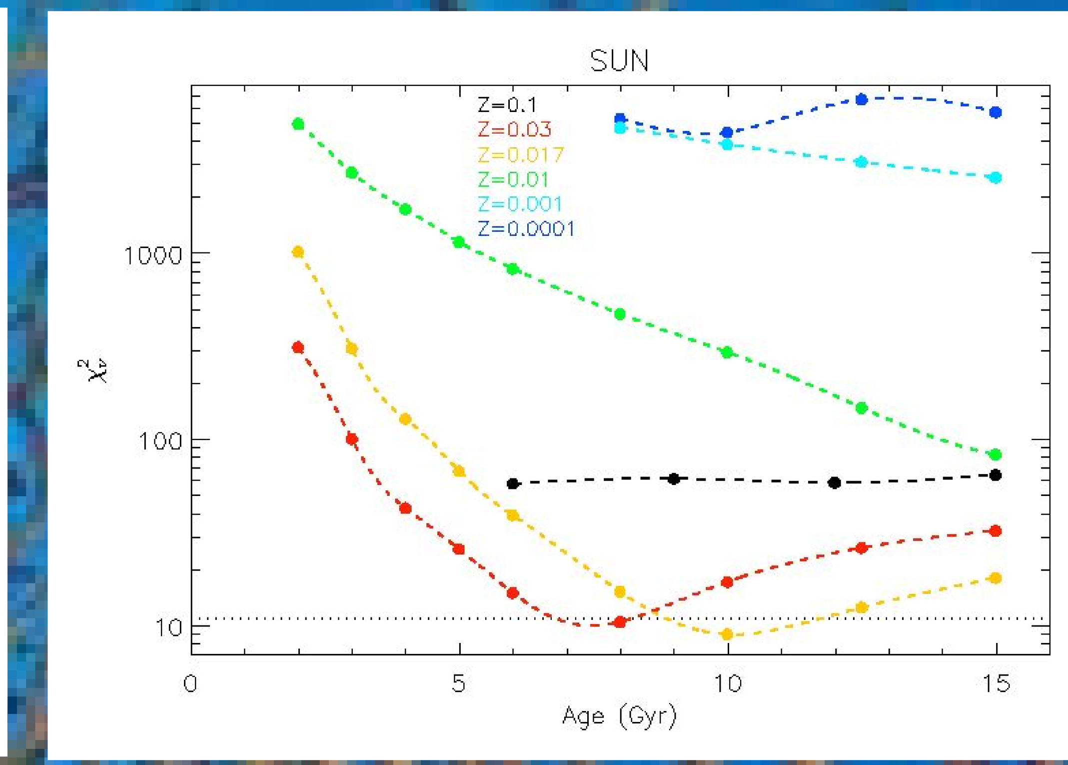

Figure 2. The distribution of the χ_ν^2 vs. age at different metallicities (color coded as indicated in the panel). The data points are interpolated with a cubic spline curve (dashed lines). The intersections of the horizontal dotted line, whose value was provided by an F-test, with the solar metallicity line (yellow) determine the age uncertainty. Note that we use a logarithmic y-axis, due to the very large difference of χ_ν^2 values.

M32. The spectrum, shown in Fig. 3, of the central part of the nearby dwarf elliptical galaxy M32 was taken with the Faint Object Spectrograph (FOS) onboard the Hubble Space Telescope (programme 1D=6636; PI: M. Gregg). In this case, the comparison with the SSP spectra is performed over the 2200-3200 A range, due to lower wavelength limit of the observation. The same procedure adopted for the Sun is used here and the results are shown in Fig. 4 and reported in Table 2.

We found a "best" fiducial age for the stellar population of the central region of M32 of 3.640 Gyr, at solar metallicity. This result well agree with the generally accepted age of 3-4 Gyr at solar (or slightly super solar) metallicity (see, e.g, Worthey 1994, Schiavon et al. 2004).

It is important to note that the best chi-squares for Z=0.01, solar, and 0.03 are quite similar. However, the small difference in the metal content between Z=0.01 and 0.017 produces a tremendous shift in the age of about 10 Gyr. This points out that the age-metallicity degeneration is clearly present in UV spectra of stellar systems.

M32

Z	Age (Gyr)	χ_ν^2
0.0001	10.000	153.9
0.001	15.000	84.7
0.010	13.040	19.5
0.017	$3.640^{+0.725}_{-0.440}$	14.3
0.03	$2.790^{+0.515}_{-0.545}$	15.1
0.1	6.000	82.2

Table 2. Same as Table 1, but for M32.

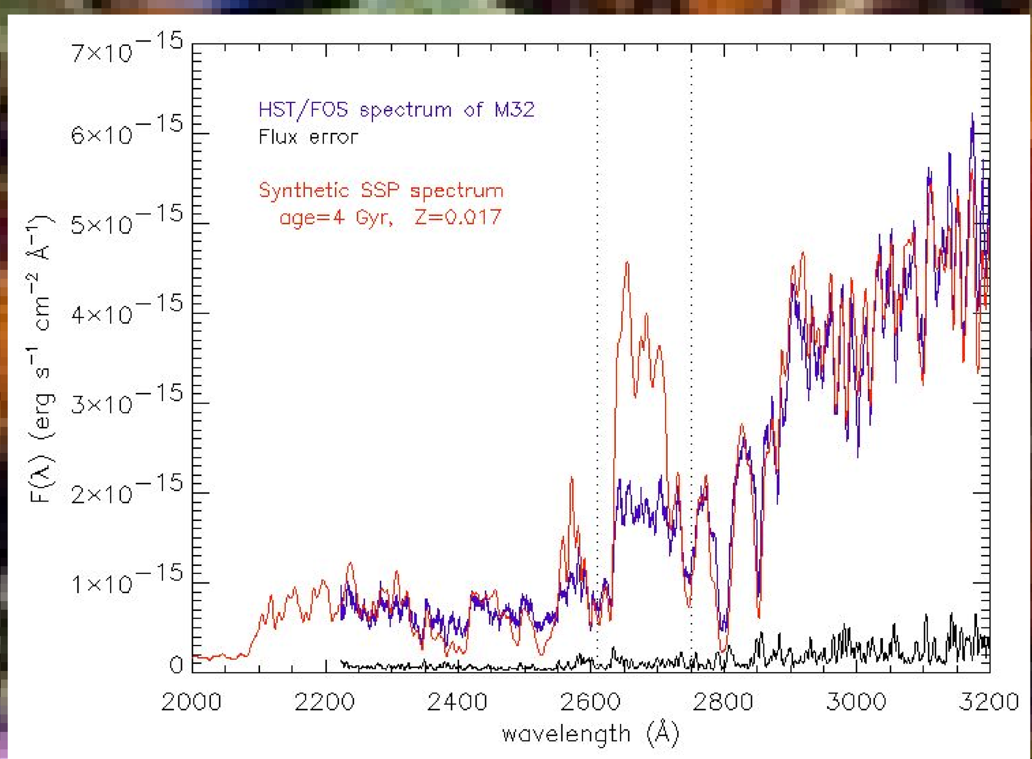

Figure 3. Same as Fig. 1, but for M32. In this case, the SSP model has an age of 4 Gyr and solar metallicity.

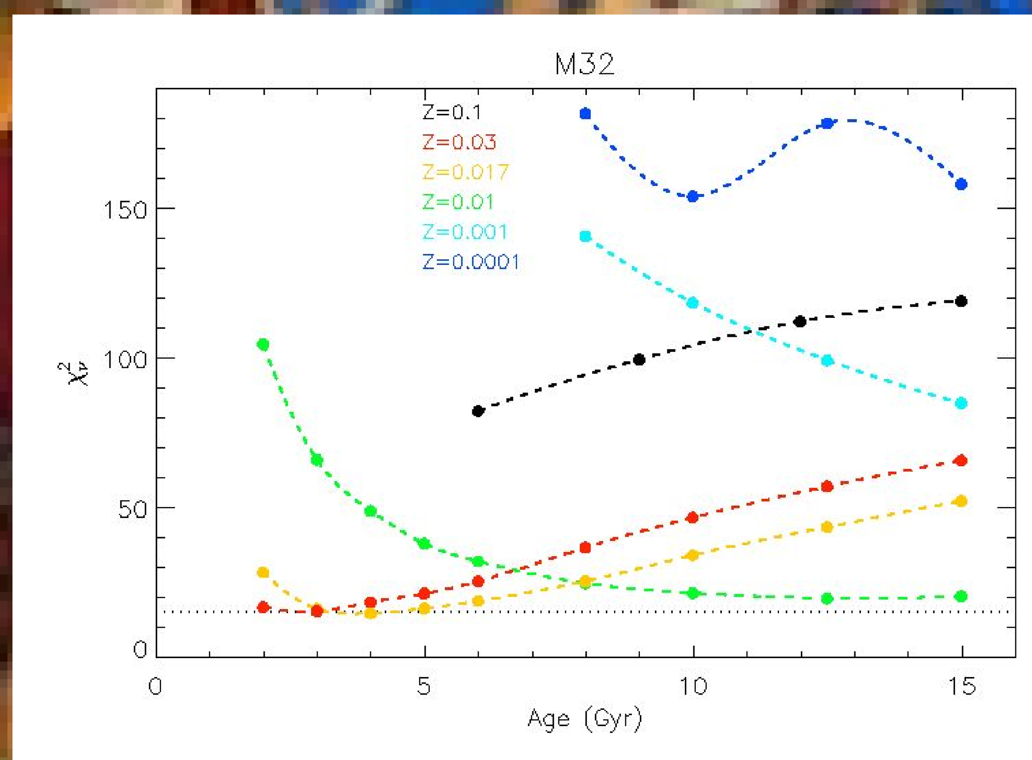

Figure 4. Same as Fig. 2, but for M32. A linear y-axis is used in this case.

FUTURE WORK. The results that we obtained for the Sun and M32 are encouraging. We are planning to apply the same procedure to a variety of stellar systems: galactic and extragalactic globular clusters, local elliptical galaxies, and eventually high redshift red galaxies.

We will concentrate in two main aspects: (1) analysis of the robustness of the method when applied to different objects and when using spectra of low S/N, and (2) determine the extent to which UVBLUE spectra are suitable for the analysis of old stellar systems.

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