High Resolution Spectral Synthesis: 2 Å Mapping of UV-Optical Emission of Stellar Populations

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ABSTRACT

We explore, from the theoretical point of view, the spectral properties of SSPs in the ultraviolet wavelength range. Our models rely on a new stellar library of high-resolution synthetic spectra (based upon ATLAS9 and SYNTHE codes developed by R. L. Kurucz), coupled with Buzzoni's population synthesis code to follow the evolution of the main UV features below 4000 Å in the integrated SED of SSPs. Properties of UV features are compared to those of the spectral region where the Mg2 index is defined. In this poster paper we present the first results of a project aimed at singling out spectral properties that better track separately the age and metallicity in stellar aggregates.

INTRODUCTION

The analysis of the UV spectra of early-type galaxies has gained particular attention over the past two decades, manly due to the availability of ultraviolet spectral observations of enhanced quality primarily conducted by the International Ultraviolet Explorer (IUE) for over 17 years and, more recently, by the Goddard High Resolution Spectrograph (GHRS) and the Space Telescope Imaging Spectrograph (STIS) on board the Hubble Space Telescope.

While the vast majority of synthesis work devoted to old systems have concentrated on predicting the properties of the underlying hot population giving rise to the so-called UVX phenomenon (Dorman, O'Connell & Rood 1995), efforts have extended to the Mid-UV (1900–3500 Å) in search for new diagnostics that allow us to separate the effects of age from the effects of chemical composition (e.g. Worthey 1994). The age-metallicity degeneracy present in the spectral properties of galaxies makes the spectral energy distribution of a relatively young metal-rich population to be almost indistinguishable from that of a metal-poor much older aggregate. Several investigations have demostrated that the Mid-UV might be a promising spectral band to explore the effects of age and metallicity (see Dorman, O'Connell & Rood 2003 and references therein), since in old populations (older than 1 Gyr) these wavelengths map mainly HB and main sequence stars at the turn-off (TO).

Most works dealing with Mid-UV have implemented Kurucz theoretical stellar fluxes to cope with the deficiency of empirical libraries in covering the parameter space at sub solar metallicity regimes. It has been found that these theoretical fluxes well represent some of the Mid-UV features such as the Mg-Fe blend at 2538 Å and the slope between 2600–3100 Å (Lotz, Ferguson & Bohlin 2000). However is has also been claimed that some of the limitations of Kurucz grid of model fluxes (more importantly the spectral resolution!) might well be part of the reasons of the discrepant results when dating elliptical galaxies at high redshift (Nolan et al. 2003).

We are currently developing a project aimed at constructing a large data base at increased resolution for population synthesis studies. In this poster paper we present the first preliminary results of applying our high resolution stellar library within Buzzoni's synthesis code (Buzzoni 1989) and explore the behavior of features in two spectral bands of the Mid-UV (2275–2575 Å) and the wavelength interval defining the Mg2 index. This work complements the broad band analysis conducted by Buzzoni (2002).

THE GRID OF STELLAR SPECTRA

The full wavelength interval (850–7000 Å) for our models is covered by two distinct grids of synthetic spectra (one centered on the ultraviolet range and the other tuned in the optical window). The UV and optical grids were computed separately and mainly differ in the spectral resolution, which is R=50000 in the UV and R=500000 in the optical. The main characteristics of the combined grid are summarized in **Table 1**.

Both grids used as input the Kurucz ATLAS9 model atmospheres (Kurucz 1995). The high-resolution spectra were computed using the SYNTHE series of codes by Kurucz (1993). Line opacity derives from the huge database of Kurucz (1992), that includes all atomic elements at different ionization states and several diatomic molecules (namely, C2, CN, CO, CH, NH, OH, MgH SiH, H2, and SiO).

As a major improvement, in our spectra we also accounted in some detail for the TiO contribution, relying on the updated work by Schwenke (1998). This new line database provides a more accurate description of the band absorption in the optical range. Quite importantly, the TiO can strongly affect the continuum region around the 5170 Mg feature in M and late-K stars. This has a direct impact when computing Lick spectrophotometric indices, such as Mg2, from theoretical spectra.

In order to account for the effects of stars cooler than 4000 K, we have included a collection of model fluxes extracted from the NextGen spectral library (Hauschildt et al. 1999a, 1999b) down to 2000 K.

POPULATION SYNTHESIS

We have used Buzzoni's (1989) synthesis code to calculate the integrated spectra for simple stellar populations (SSP) of solar chemical composition. We remind the reader that these codes include all important evolutionary phase: main sequence (MS), sub-giant branch (SGB), red giant branch (RGB), horizontal branch (HB), asymptotic giant branch (AGB), and post-asymptotic giant branch (PAGB). For the calculation we have considered nine ages: 2, 3, 4, 5, 6, 8, 10, 12.5 and 15 Gyr, three different slopes of the initial mass function (IMF): s = 2.35 (Salpeter), 1.35 and 3.35 and two mass-loss efficiencies given by the Reimers' parameter η = 0.30 and 0.50. Additionally, Buzzoni's code includes three different HB morphologies: intermediate (I-HB), red (R-HB) and blue (B-HB) (see Buzzoni 1989 for details). For the calculations we have applied a Gaussian filter of FWHM=2 A to the full stellar grid.

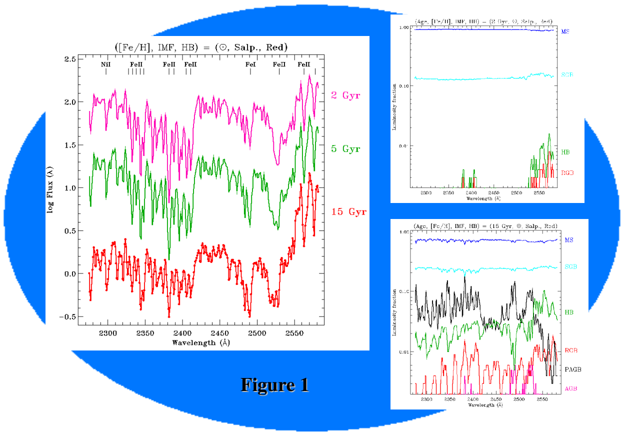

Figure 1

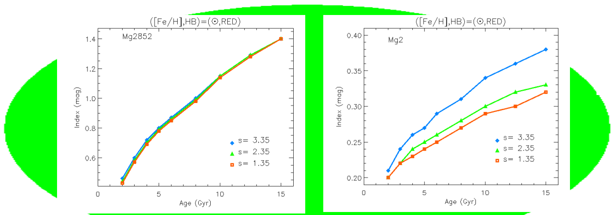

Figure 4

TABLE 1: *The main properties of the theoretical stellar library*

	UV-Blue grid	Optical grid
Wavelength range	850 → 4750 Å	3500 → 7000 Å
R = $\lambda / \Delta\lambda$	50 000	500 000
T_{eff}	3000 → 50000 K	4000 → 50000 K
log g	0.0 → 5.0	0.0 → 5.0
[M/H]	−2.0 → +0.5	−3.0 → +0.3

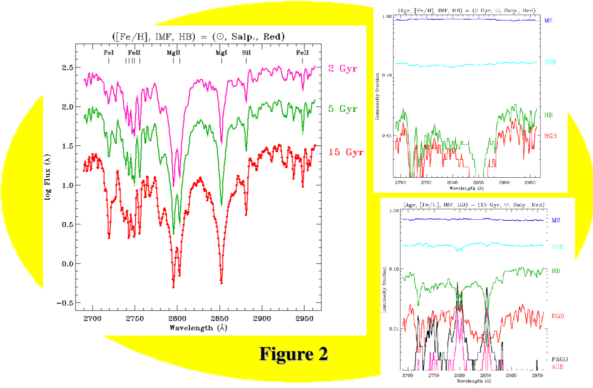

Figure 2

PRELIMINARY RESULTS

The figures show some of the results obtained so far. We illustrate the behavior in terms of age of several integrated spectral features in three wave bands: two in the Mid-UV (2275–2575 Å and 2690–2960 Å) and one in the optical (4880–5390 Å). In all cases we have considered a red horizontal branch (R-HB) morphology, a Salpeter IMF (s = 2.35), solar chemical composition, and η = 0.30. In the **larger panels of Figs. 1-3** we plot the evolution of the integrated spectra at three different ages (2, 5 and 15 Gyr). At the top we indicate some of the most prominent spectral lines present in each interval. In the two **smaller panels** we present the relative contributions of the different evolutionary phases to the total luminosity of the population, at 2 and 15 Gyr, as indicated at the right margin of the figures.

It is interesting to note that, with the parameter choice adopted here, the main sequence stars are in all cases the main contributor, even if its dominance lowers at longer wavelengths and older ages. The evolved He-burning stars do not account for a large flux fraction, but in models (not shown here) which include hotter HB components, they turn out to provide almost 99% of the flux at 15 Gyr at the shorter wavelengths.

In **Figure 4** we display the age dependence of two spectral indices which primarily measure the intensity of the of Mg I features at 2852 and 5170 Å (Fanelli et al. 1990 and Trager et al. 1998, respectively). In the figure we have included the indices measured from the population calculations with three prescriptions for the IMF: s = 1.35, 2.35, 3.35. All populations, as above, are of solar composition and R-HB morphology. Two main distinctive characteristics can be readily distinguished from these figures: a) the fact that the variation of the Mg2852 index is twice as large as that of the Mg2 index (about a factor of 3.5 and 1.6 respectively for s = 2.35) over the whole age interval; b) that the UV features have a negligible dependence on the original distribution of stars along the main sequence.

We would like to stress that the material presented here is based on a purely theoretical approach. A detailed comparison of the stellar grid with a homogeneous set of UV-optical data is underway. We are also currently conducting the calculation of SSPs over the entire wavelength interval (850–7000 Å), adopting different HB morphologies and metallicities.

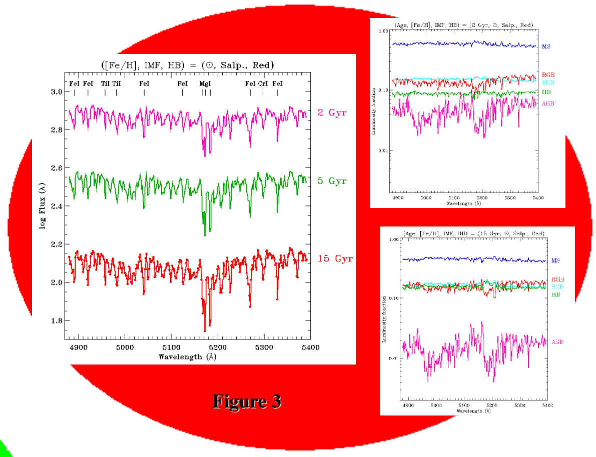

Figure 3

References

Bertone E. 2002, Ph.D. Thesis, University of Milan
Buzzoni A. 1989, ApJS, 71, 817
Buzzoni A. 2002, AJ, 123, 1188
Dorman B., O'Connell R.W., Rood R.T. 1995, ApJ, 442, 105
Dorman B., O'Connell R.W., Rood R.T. 2003, ApJ, 591, 878
Fanelli M.N., O’Connell R.W., Burstein D., Wu C.-C. 1990, ApJ, 364, 272
Hauschildt P.H., Allard F., Baron E. 1999a, ApJ, 512, 377
Hauschildt P.H., Allard F., Ferguson J., Baron E., Alexander D.R. 1999b, ApJ, 525, 871
Kurucz R.L. 1992, RMxAA, 23, 45
Kurucz R.L. 1993, CDROM No.18, SYNTHE spectrum synthesis programs and line data
Kurucz R.L. 1995, CDROM No.13, revised
Lotz M.J., Ferguson H.C., Bohlin R.C. 2000, ApJ, 532, 830
Nolan L.A., Dunlop J.S., Jimenez R., Heavens A.F. 2003, MNRAS, 341, 464
Schwenke D.W. 1998, Faraday Discuss., 109, 321
Trager S.C., Worthey G., Faber S.M., Burstein D., González J.J. 1998, ApJS, 116, 1
Worthey G. 1994, ApJS, 95, 107