Stellar populations as bulding blocks of galaxies
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Stellar Population SEDs at 2.3Å

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Abstract. We present a new spectral library for old and intermediate-aged single-age, single-metallicity stellar populations for a wide metallicity range. The major ingredient of these models is a new empirical stellar library composed of 985 stars, whose main characteristic is its unprecedented stellar atmospheric parameters coverage. The model SEDs cover the spectral range 3540-7410A at 2.3A (FWHM). We present some advantages and applications of these models.

Keywords. stars: fundamental parameters, galaxies: abundances, galaxies: elliptical and lenticular, cD, galaxies: evolution, galaxies: stellar content

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1. Introduction

Relevant stellar population parameters of unresolved stellar systems are estimated with the aid of the so called stellar population synthesis models. The method consists in comparying observed colors and/or absorption line-strengths to the predictions of these models. The most popular approach so far consists in comparing the data to single-age, single-metallicity stellar population models (SSPs). Therefore applying this method we obtain mean luminosity weighted ages and metallicities, which are heavily biased toward most recent star formation episodes. Under this assumption we cannot retrieve the true Star Formation History. However we can constrain it if we combine this piece of information with the abundance ratio of various key elements, such as [Mg/Fe], which provides strong hints on how fast the bulk of the stars formed at the earliest stages of galaxy formation (e.g., Trager et al. 2000; Vazdekis *et al.* 2001).

The studies of absorption line-strengths have experienced a great development in the last two decades, allowing us to alleviate the effects of the age/metallicity degeneracy affecting the integrated light of the stellar systems (Worthey 1994). Most of the results were obtained on the basis of the indices of the Lick/IDS system at low resolution (FWHM > 8Å) (Worthey *et al.* 1994; Worthey & Ottaviani 1997). Most of the stellar population

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synthesis models employed to obtain these results, implement Lick/IDS based empirical fitting functions that relate the index strengths to the stellar temperature, gravity and metallicity, to predict the integrated line-strengths (Worthey *et al.* 1994).

More recently, the appearance of new flux-calibrated stellar spectral libraries have allowed us to predict stellar population SEDs at higher spectral resolutions, rather than just a limited number of line-strengths at low resolution (e.g., Vazdekis 1999; Bruzual & Charlot 2003). These models open new abilties to pursue the stellar populations studies. In the following sections we present a new stellar library in the optical range and the associated SSP model SEDs at 2.3Å (FWHM), and show some applications that allow us to improve stellar population studies.

2. MILES: a new stellar spectral library

The key ingredient of our stellar population synthesis models is a new empirical stellar spectral library, which is presented in Sánchez-Blázquez *et al.* (2006) for the whole optical range $\lambda\lambda$ 3525-7500Å. This library, named MILES, overcomes many limitations of the previous ones. MILES, at spectral resolution of 2.3 (FWHM)], contains 985 stars with metallicities ranging from [Fe/H] -2.7 to +1.0 and a wide coverage of temperatures and gravities. The stellar spectra, with fluxcalibrated response curve, were obtained at the INT 2.5m telescope (Observatorio del Roque de Los Muchachos, La Palma).

To be able to properly flux calibrate the stellar spectra, we observed several spectrophotometric standards along each night at different air-masses and to avoid the selective flux losses due to the differential refraction all stars were also observed through a 6-arcsec slit. The comparison of the synthetic (B - V) colours derived from our library spectra with the corresponding colours extracted from the Lausanne photometric data base provide very small residuals (<0.02 mag). Final stellar spectra were also corrected for telluric absorptions by the standard technique of dividing into a reference, telluric spectrum.

One of the most important advantages of MILES over previous libraries is its stellar parameter coverage, as the necesary stars for population synthesis are represented in the library stars. The atmospheric parameters were taken from the literature, but to construct a homogeneous data set of parameters, we used a subsample of stars of Soubiran, Katz & Cayrel (1998) with very well determined fundamental parameters as the standard reference system for our field stars, and have calibrated and bootstrapped the available parameters from other papers against it. The method and final parameters are presented in Cenarro *et al.* (2007). The parameters of the cluster stars have been updated on the basis of recent metallicity scales, colour-temperature relations and improved set of isochrones.

We are in the process to complete a new set of fitting functions, which describe the empirical behavior of the line-strength indices of the Lick indices with the atmospheric stellar parameters (Martín-Hernández *et al.*, this volume). These functions should replace the standard Lick/IDS ones on a flux-calibrated response curve. To compute these fitting functions we have designed a new method consisting in fitting local polynomials in a narrow temperature interval, which is moved to scan the whole range of temperatures covered in the library, rather than choosing a number of fixed boxes as it has been done in previous works (e.g., Cenarro *et al.* 2002). Though preliminary the resulting fitting functions show significant differences with respect to the standard Lick/IDS ones. We also will add the velocity dispersion as a fourth parameter to compute the new fitting functions. For further details see (Martín-Hernández *et al.*, this volume).

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3. SSP models

We have implemented MILES in our stellar population synthesis model to extend the spectral coverage in the optical range (Vazdekis *et al.* 2007, in preparation). The details about the code are extensively described in Vazdekis *et al.* (1996), Vazdekis (1999) and Vazdekis *et al.* (2003). The nominal spectral resolution of the new models is 2.3Å (FWHM). Accurate SSP SEDs for a larger range of ages and metallicities are now possible thanks to the stellar parameter coverage of MILES. For example, we provide SSP SEDs for lower metallicities, and in particular we overcome the well known limitation of predicting metal-poor stellar populations of ages smaller than say 10 Gyr for [Fe/H]<-1 (e.g., Worthey 1994; Vazdekis 1999), as we specifically included a representative set of metal-poor dwarfs with temperatures above 6000 K in the MILES library. These metal-poor SSP SEDs are particularly interesting for studying globular cluster systems. The new models also provide accurate SEDs for supersolar metallicities as MILES includes a large number of such stars, which were lacking in previous stellar libraries.

To implement MILES in the models we have identified all the spectroscopic binaries, peculiar stars and stars with anomalous signatures of variability. Then we either removed them from the sample or decreased their weights when computing the required stars for synthesizing the SSP SEDs. To synthesize a stellar spectrum of a given set of parameters we use the algorithm described in Vazdekis *et al.* (2003), which takes into account the typical uncertainties in different parametric regions, the assymetries in the distribution of stars around that point and the signal-to-noise of the selected stellar spectra. We tested each star of MILES by removing it from the sample and synthesizing a spectrum of identical set of parameters on the basis of the other MILES stars. This test also served to discard a number of stars, which provided high residuals.

The comparison of the resulting SSP spectra based on MILES with those of Vazdekis (1999), based on the stellar library of Jones (1999), smoothed to match the lower resolution of MILES, i.e. from 1.8Å to 2.3Å (FWHM), provides excellent agreement for SSPs of solar metallicity. However for lower metallicities non negligible differences in the line-strength measurements were found, showing how important is to employ a library with excellent coverage of stellar parameters. As it concerns to the spectrum shape, this test has shown that there are significant residuals for all metallicities, which are attributed to the limitation of the fluxcalibration quality of the Jones (1999) stellar spectra employed in Vazdekis (1999).

These models, and in general those models providing SEDs at high enough resolution, introduce a new methodology for analyzing stellar cluster and galaxy spectra. The method consists in adjusting the resolution and dispersion of the model SEDs to match the instrumental setup of the observations. Then these models are smoothed to match measured galaxy velocity dispersion σ. Finally, the synthetic spectra can either be compared to the whole spectrum (or part of it) or the comparison can be made on the basis of selected line-strengths, which are measured in both the observed and synthetic spectra.

4. New analysis tools

The SSP SEDs allow us to explore new indicators or optimize previous index definitions to increase their sensitivities to relevant stellar population parameters such as age and metallicity. This is performed by shifting and varying the widths of the pseudcontinua and feature passbands of the proposed index definition and then measure it on the SSP spectral library. In addition the new indices can be tunned to minimize for example the signal–to–noise, to decrease their sensitivity to the spectral resolution and σ or to

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the wavelength shifts due to rotation or redshift. Following this method we have defined a new age indicator, named Hβ_o, which is virtually insensitive to metallicity. Interestingly, spectra of similar qualities to those needed to obtain the standard Lick/IDS index definition for this feature are sufficient for measuring Hβ_o (i.e. S/N$\sim$40).

When Hβ_o is plotted versus different metallicity indicators it provides almost orthogonal model grids to separate the age and metallicity. See for details Cervantes *et al.* (this volume). Furthermore, the metallicities inferred from these grids can be used to determine deviations of the abundance ratios with respect to the scaled-solar element partition in a relative scale. This approach is fully appropriate for studying stellar populations with non scaled-solar abundance ratios, such as giant ellipticals, and disentangle relative abundance patterns among galaxies. Note that this approach is different to the one proposed by, e.g. Tantalo *et al.* (1998), Trager *et al.* (2000), Thomas *et al.* (2003), which specifically implement the index responses to abundance ratio variations as derived from stellar atmospheric computations, such as those of Tripicco & Bell (1995).

The new model SEDs also allow us to introduce an innovative approach for studying stellar populations by means of photometric filters, rather than the more expensive spectroscopy. In fact we are developing a new set of indices specifically designed to exploit the unique capabilities of the Tunable Filters of OSIRIS, a Day One instrument of GTC 10.4m telescope. These filters, which reach high enough resolutions to be able to measure the absorption features, can be positioned on a particular feature and on selected pseudocontinua to define an index. An additional advantage of this method is that we obtain a much larger FOV than with current IFU facilities (e.g. SAURON – WHT 4.2m). These indicators provide larger sensitivities to the ages and metallicities than their Lick/IDS spectroscopic counterparts (Cervantes *et al.*, in preparation).

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Discussion

PRUGNIEL: This is a comment about coverage of the parameters space. You should compare with ELODIE 3 (2004) rather than with ELODIE 1 (2001). Its coverage is quite comparable with MILES and allows a good comparison. We find some differences of ages of SSP between the libraries, amounting to 10-30% on 10Gyr, they may be due to differences in the temperature scale of the giants by (3-4%) or evolutionary tracks. Do you have idea on how to solve this question?. .

VAZDEKIS: Thanks for pointing this out. Concerning your question, I think this is the well know model zero point problem. Stellar tracks and librarires should cause these differences. This issue will be discussed in the stellar population challenge.

PETERSON: What coverage does MILES have of stars with enhanced [α/Fe] near solar metallicity?.

VAZDEKIS: We did not check that but it should be similar to, e.g. Edvardsson *et al.* (1993). This work has to be done.

The speaker (right) with Reynier Peletier.

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