Stellar Populations as Building Blocks of Galaxies
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A High Resolution α-enhanced stellar Library for Evolutionary Population Synthesis

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Abstract. One of the main ingredients of current stellar population models is a library of stellar spectra. Both empirical and theoretical libraries are used for this purpose, and the question about which one to use is still being debated in the literature. Empirical and theoretical libraries are improving significantly over the years, and many libraries have become available lately. It is not clear what are the advantages of using each of these new libraries, and how far behind are models compared to observations. Here we compare in detail some of the modern theoretical libraries availabe in the literature against empirical libraries attempting to detect their weaknesses and strengths. The aim is to be able to compute in the short future a new synthetic stellar library that combines the best qualities of the current available ones, while improving considerably their weaknesses.

Keywords. stellar library, stellar spectra

1. Introduction

Evolutionary population synthesis models that describe the chemical and spectral evolution of stellar systems in detail are fundamental tools in the analysis of observations of both nearby and distant galaxies. They are needed to determine the stellar populations in a variety of systems, spanning a wide range of metallicities, from early type galaxies and spiral bulges to star forming galaxies at different redshifts. Libraries of stellar spectra are one of the main ingredients of stellar population synthesis models and both empirical and theoretical libraries have improved dramatically in recent years, allowing the construction of more detailed models. Observations are also becoming increasingly better and each time demanding more from the modeling point of view. To keep up with this evolution, the quality of empirical libraries have been refined along the years and recently, many new libraries are becoming available. The first stellar library that provided flux calibrated spectra was Jones' library (Jones 1998). From then on, many other libraries have appeared (Elodie: Prugniel & Soubiran 2001, Stelib: Le borgne *et al.* 2003, Indo-US: Valdes *et al.* 2004, Miles: Sanchéz-Blásquez *et al.* 2004). Amongst the synthetic libraries, perhaps the most widely used is the low resolution flux distributions by the BASEL library (Lejeune *et al.* 1997). Resolution ceased to be a limitation recently, with many high-resolution theoretical libraries appearing in the literature (Chavez *et al.* 1997, Murphy & Meiksin 2004, Rodrigues-Merino *et al.* 2005, Munari *et al.* 2005, Martins *et al.* 2005, Coelho *et al.* 2005).

2. Are More Libraries Needed?

The choice of using either an empirical or a synthetic library in stellar population models is a subject of debate. One disadvantage of synthetic libraries is that they rely on model atmospheres, which are subject to systematic uncertainties. Besides, computing a reliable high-resolution spectral library for a large range of stellar parameters and in a wide spectral region is a very challenging task, since it requires building an extensive list of atomic and molecular line opacities which are needed for an accurate reproduction of real stars. On the other hand, synthetical libraries overcome limitations of empirical libraries, like their inability to cover the whole space in atmospheric parameters or extrapolate to abundance patterns that differ from that of the library stars, which are mostly from the solar neighborhood. *Therefore, it is impossible, to reproduce the integrated spectra of systems that have undergone star formation histories that differ from that of local systems with models based on empirical libraries.*

But, how good are the models? Where do they fail? To understand this we have to compare models with observations in detail. Here we do an extensive study with libraries available, in search of what needs to be improved on the models. We measured spectral indices in empirical and theoretical libraries, and compared them. For the comparison, we used the theoretical libraries by Martins *et al.* 2004, Munari *et al.* 2005 and Coelho *et al.* 2005. We only used solar abundances at this point. We compared these theoretical libraries with the empirical libraries Indo-US, MILES and Elodie.

We measured all Lick/IDS indices (Tragger *et al.* 1998 and references therein) and some of the indices of Serven *et al.* (2005). Figures 1 and 2 show the comparison between two of these indices. The figures for the remaining indices are presented in Martins & Coelho (2007). The way this was done was to take each star in the empirical library and find the closest model in Teff and log g for each theoretical library. The black line in each plot shows where is the one to one relation. If all observations were perfectly represented by the models, all points would be along this line. For the empirical libraries, we calculated a median value for each temperature and gravity bin. The dispersion of this median is shown as the error bars presented in the plots. A point with no error bar means that there was only one star for that temperature and gravity. We divided the stars into three ranges of temperatures, using different shades and symbols: light gray squares are stars with Teff $>$ 7000K, dark gray diamonds are stars with 4500K $<$ Teff $\leqslant$ 7000K and black circles are stars with Teff $\leqslant$ 4500K. The crosses are stars with Teff $<$ 3500 K, but they are really rare.

First thing to notice is that the error bars are non-negligible, specially for the lower temperature stars. That is probably a consequence of the difficulties in deriving accurate atmospheric parameters for these stars. Metallic lines are very intense and numerous, making the determination of these parameters a real challenge. For the high temperature stars the spread between the points is very small for most of the indices. This is somewhat expected, since there are very few metallic lines as you go up in temperature, so many of these indices will give almost no information about these hot stars.

Even though a lot of information can be extracted from these type of figures, the interpretation of the plots is not always straightfoward. It is clear that models and observations do not agree completely, but is that because models just fail to reproduce observations? One example of how these comparisons can be dangerous is for indices sensible to calcium abundances. Bensby *et al.* (2005) studied the abundances of F and G dwarfs of our galaxy and found that the [Ca/Fe] tends to be supersolar for the stars with solar [Fe/H]. This shows how complicated it can be to compare models that have solar abundance pattern with real stars, that not necessarily follow this pattern. This

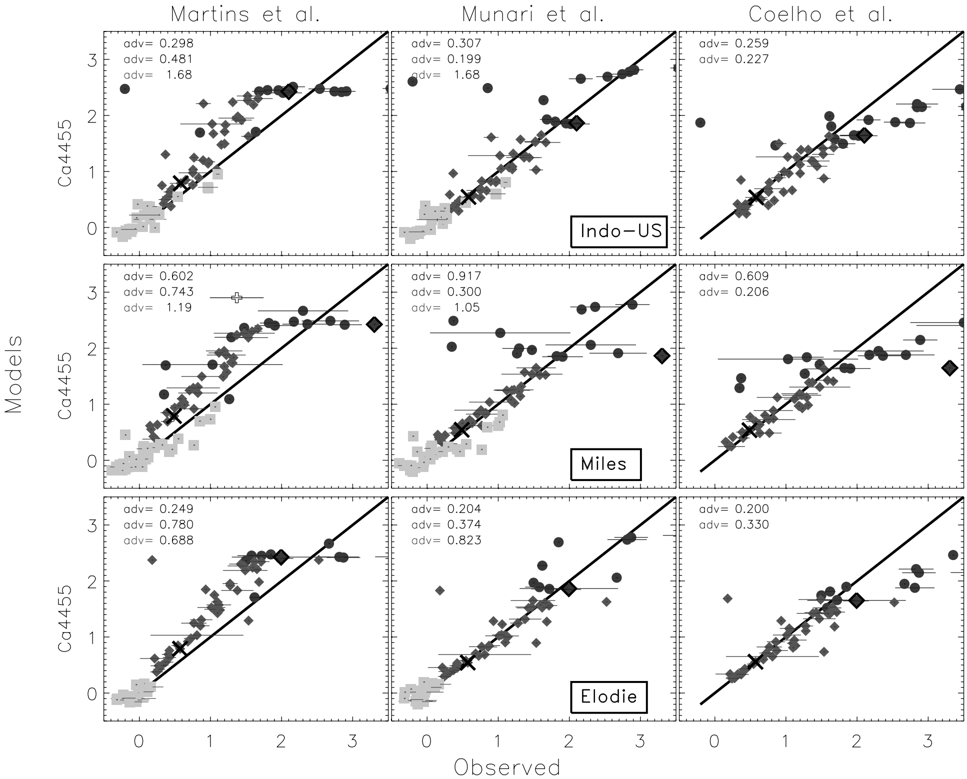

Figure 1. Comparison of the index Ca4450 measured in the empirical and theoretical libraries. Different symbols represent three bins of temperature: light gray squares mean Teff < 7000K, dark gray diamonds mean 5000K < Teff ⩽ 7000K and black circles mean Teff ⩽ 5000K. The crosses are stars with Teff < 3500 K. The line is the one to one relation.

does not mean this kind of comparison is useless. Something that shows how models can be improved are the Fe and Mg indices. The line lists for these two elements were extensively calibrated by Coelho *et al.* and references therein, and the results are clearly shown in the plots (e.g. Figure 2). Althought the line lists are not the sole important parameter when building theoretical libraries, it is one that can yet be perfected, and impact in significant way in the results.

3. Conclusions

The tests show that the models still have a lot of room for improvement. We will start with this work an extensive study in search of this improvement, comparing in detail models and stars with very well determined parameters, and calibrating the line and molecular lists, not only for the Sun and Arcturus (as done in previous works), but colder and hotter stars too. We will search for the best codes available in the literature, and test them for every range of paramters we want to cover. With that we aim at creating a theoretical library suitable for all kinds of stellar population modeling (young and old, metal rich and metal poor, etc.), including not only α-enhancement, but also chemical patterns characteristics of different star formation histories.

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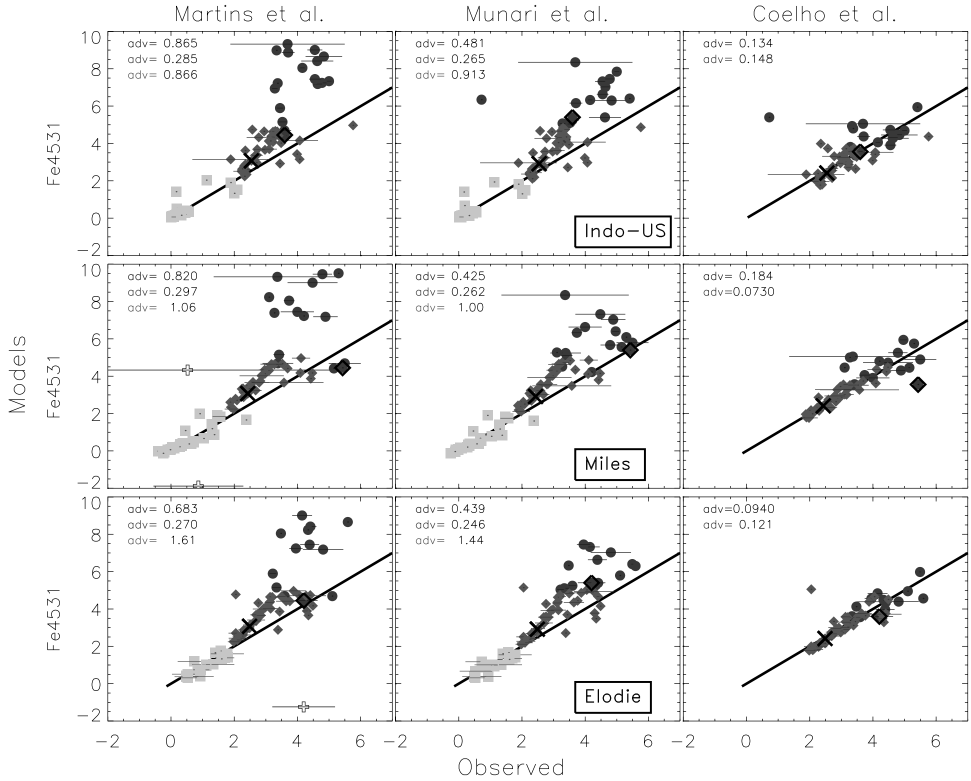

Figure 2. Comparison of the index Feλ4531 measured in the empirical and theoretical libraries. Symbols are the same as in Figure 1.

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References

Bensby, T., Feltzing, S., Lundström & Ilyin, I. 2005, *A&A*, 433, 185
Chavez, K., Malagnini, M.L., & Morossi, C. 1997, *A&AS*, 126, 267
Coelho, P., Barbuy, B., Meléndez, J., Schiavon, R.P. & Castilho, B.V. 2005, *A&A*, 443, 735
Jones, L.A. 1998, *PhD Thesis, University of North Carolina, Chapel Hill*
Le Borne, J.-F., *et al.* 2003, *A&A*, 402, 433
Lejeune, T.,Cuisinier, F., & Buser, R. 1997, *A&AS*, 125, 229
Martins, L. & Coelho, P. 2007, *submitted to MNRAS*
Martins, L., González, R.M., Leitherer, C., Cerviño, M., & Hauschildt, P. 2005, *MNRAS*, 358, 49
Munari, U., Castelli, F. & Zwitter, T. 2005, *A&A*, 442, 1127
Murphy, T. & Meiksin, A. 2004, *MNRAS*, 351, 1430
Prugniel, & Soubiran 2004, *astro-ph/0409214*
RodrigueMerino, L.H., Chavez, M. & Bertone, A. 2005, *ApJ*, 626, 411
Sanchéz-Blasquez, P., *et al.* 2006, *MNRAS*, 371, 703
Serven, J., Worthey, G. & Briley, M.M. 2005 *ApJ*, 627, 754
Tragger, S.C., Worthey, G., Faber, S.M., Burstein, D., & González, J.J. 1998, *ApJS*, 116, 1
Valdes, F., Gupta, R., Rose, J., Singh, H. & Bell, D. 2004, *ApJS*, 152, 251

Discussion

Meixner: To obtain a good empirical stellar atmosphere spectra, ideally you want to measure the same star from UV to far-IR at least 20μm (100μm would be great). Is there any effort in this community to coordinate efforts to use all the observatories required to achieve this work?

Martins: Ideally, you would like the star observed through the same instrument, for homogeneity, from UV to IR. This is of course impossible. There are libraries that go from near UV (300Å) to near-IR (9000Å), but that is about the maximum effort in this sense. I think it would be really hard to have an homogeneous sample of spectra from UV to IR, and I do not know about anybody trying that, but it would be extremely interesting to have that.

From left: Alan Alves-Brito, Ignacio Garcia de la Rosa, Paula Coelho and the speaker.

Scott Trager, presenting the results of the Stellar Population Challenge.

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