TO USE OR NOT TO USE MODEL STELLAR SPECTRA TO STUDY INTEGRATED STELLAR POPULATIONS?

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RESUMEN

Las librerías de espectros estelares son esenciales para los modelos de poblaciones estelares. Estas pueden ser empíricas o teóricas, cada una con sus propias ventajas y desventajas. Aquí discutimos los resultados obtenidos al estudiar el impacto de los espectros estelares modelados en los modelos de poblaciones estelares y hacemos una aplicación a la luz integrada de cúmulos globulares. Concluimos que los modelos de poblaciones estelares construidos con espectros estelares modelados compiten con, y a menudo superan, a los modelos basados en espectros empíricos.

ABSTRACT

Spectral stellar libraries are essential to stellar population models. They can be empirical or theoretical, each with its own advantages and disadvantages. Here, we discuss the results obtained by studying the impact of model stellar spectra on stellar population models and make an application to integrate light of globular clusters. We conclude that stellar population models built with model stellar spectra rival and often outperform models based on empirical spectra.

Key Words: stellar atmospheres — stellar population models

1. CONTEXT

The field of stellar population studies sits at the frontier between stellar and extragalactic astrophysics. It uses our knowledge of the evolution of stars and gas to predict the light evolution of galaxies (Tinsley 1980). The field was born with Baade (1944), who observed stars in M31 and satellites, noting similarities with Galactic stellar systems. When individual stars cannot be resolved (the vast majority of the universe), we need to use integrated light models to simulate the observables of stellar populations (e.g. Bruzual & Charlot 2003).

The starlight, coming from libraries of stellar spectra, is a central ingredient. While some models eschew isochrones and initial mass function assumptions (e.g. Martins et al. 2019), the selection of a stellar flux library remains unavoidable. These libraries comprise homogeneous compilations of stellar spectra, each tagged with characteristics like effective temperature, surface gravities, and abundances.

The literature features over a hundred such libraries, which are also used for automatic determinations of stellar parameters (e.g. Dias et al. 2015), studies of exoplanets via radial velocities measurements (e.g. Spring et al. 2022), and photometric calibration in surveys (Almeida-Fernandes et al. 2022).

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2. A PROBLEM AND AN EXPERIMENT

A spectral stellar library can be empirical (based on observations, e.g. Sánchez-Blázquez et al. 2006) or theoretical (relying on atmosphere models and radiative transfer codes; e.g. Coelho 2014).

Empirical libraries have relatively sparse coverage of the Hertzsprung-Russell (HR) diagram, constrained by the star formation and chemical histories of the observed stars. This limitation prompted the use of stellar population models based solely on theoretical stellar spectra in some cases (e.g. Leitherer et al. 1999; Coelho et al. 2007). Theoretical libraries offer optimal HR diagram coverage but may contain inaccuracies in certain spectral regions or parameter space due to opacities or implemented physics (e.g. Martins & Coelho 2007).

Stellar population models will inherit errors and uncertainties from the chosen library. In the absence of a library with both optimal coverage of stellar parameters and excellent reproduction of spectral line profiles, which should we favour, better parameter coverage (model stellar spectra) or superior spectra on a star-by-star basis (empirical stellar spectra)?

The work by Coelho et al. (2020, hereafter CBC20) attempts to answer that question. The authors modelled Simple Stellar Population (SSP) models with fixed initial mass function and isochrones and three different stellar flux libraries: the empirical MILES (Sánchez-Blázquez et al. 2006),

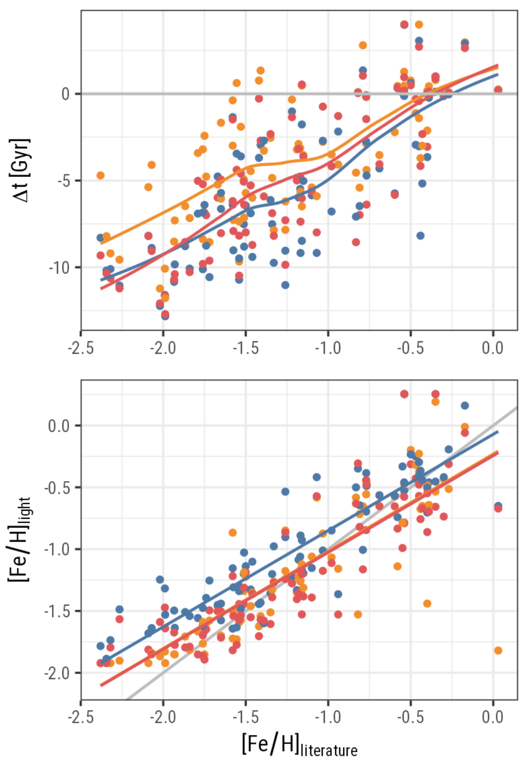

Fig. 1. Results are shown comparing the integrated light properties of galactic globular clusters, inferred from spectral fitting. The top panel shows the difference in age between the integrated light and those derived from isochrones (Δt) as a function of iron abundance [Fe/H]. The bottom panel depicts integrated light [Fe/H] versus abundances derived from high-resolution spectral analysis. Orange symbols are results obtained from SSP models based on theoretical libraries, blue symbols correspond to models based on empirical libraries, and red symbols correspond to models based on theoretical libraries with a coverage of the HR equal to that of the empirical library. Lines are fitted to the data for visualization purposes, with a LOESS fit in the top panel and a linear fit in the bottom panel.

the theoretical from Coelho (2014) and a synthetic library with the same (sparser) coverage of the HR as the empirical library. They isolate two effects: the "coverage effect" which pertains to the impact of a sparse HR diagram coverage on SSPs, and the "synthetic effect", which relates to uncertainties in model stellar spectra.

3. DISCUSSION

CBC20 investigates the impact of different stellar libraries on SSP model predictions and on inferred parameters of a sample of bulges. However, stellar clusters serve as better benchmarks, as we can compare the integrated light parameters with ages derived from isochrone fitting and high-resolution metallicities obtained for resolved stars

Gonçalves et al. (2020, hereafter, G20) analysed integrated spectra of stellar clusters (Usher et al. 2017) using the spectral fitting code STARLIGHT (Cid Fernandes et al. 2005) and models by Vazdekis et al. (2015). The integrated light parameters reproduced the reference values from the literature reasonably well for high metallicity objects. However, for low-metallicity clusters, ages were significantly underestimated (see their Fig. 11), a phenomenon traditionally attributed to blue horizontal branch stars.

Here we replicate the analysis conducted by G20 using the SSP models provided by CBC20 (figure 1). The top panel, akin to Fig 11 in G20, still exhibits a notable age discrepancy. Yet, the results based on model stellar spectra (orange, with optimal coverage of the HR) are about 2 Gyr closer to the literature values than the ones based on an empirical library (blue, sparser coverage). Concerning metallicities (bottom panel), those obtained from SSPs based on a theoretical library are, on average, closer to the literature values than those obtained from SSPs based on an empirical library (Δ[Fe/H] = 0.02 vs. 0.20).

4. CONCLUSIONS

The conventional wisdom has held that SSPs based on model stellar spectra are valuable for systems with chemical patterns differing from the solar neighbourhood and very young systems, while models based on empirical stellar spectra should be favoured otherwise. However, the findings of CBC20 and those presented here paint a different picture: modern theoretical libraries not only compete with but, in some instances, outperform models based on empirical libraries (see as well Martins et al. 2019). Through the study of the integrated light of stellar clusters, we note that the coverage effect can explain up to 25% of the "blue-light excess" of metal-poor star clusters, thus mimicking the presence of blue horizontal branch stars. Additionally, model stars, on average, better reproduce iron abundances from literature. Further work is underway, including stellar clusters from the Magellanic Clouds (Asad, Coelho et al., in preparation).

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