Astronomical Data Analysis Software and Systems XXV
ASP Conference Series, Vol. 512
Nuria P. F. Lorente, Keith Shortridge, and Randall Wayth, eds.

Stellar Atmosphere Interpolator for Empirical and Synthetic Spectra

Nikolay Podorvanyuk,[1] Igor Chilingarian,[2,1] and Ivan Katkov[1]

[1]*Lomonosov Moscow State University, Sternberg Astronomical Institute, 13 Universitetsky prospect, Moscow, Russia, 119991;* `nicola@sai.msu.ru`

[2]*Smithsonian Astrophysical Observatory, 50 Garden St. MS98, Cambridge, MA 02138, USA*

Abstract. We present a new stellar atmosphere interpolator which we will use to compute stellar population models based on empirical and/or synthetic spectra. We combined observed and synthetic stellar spectra in order to achieve more or less uniform coverage of the (T_{eff}, $\log g$, $[Fe/H]$) parameter space. We validated our semi-empirical stellar population models by fitting spectra of early-type galaxies from the SDSS survey.

1. Motivation

Empirical stellar spectra (e.g. the stellar libraries ELODIE (Prugniel & Soubiran 2004) and MILES (Sánchez-Blázquez et al. 2006)) are broadly used in stellar population synthesis codes, however they do not cover the temperature–gravity–metallicity parameter space (T_{eff}, $\log g$, $[Fe/H]$) uniformly, which requires extrapolation in the parameter space and leads to artefacts in stellar population models computed with empirical stellar libraries. Those gaps can be filled using synthetic stellar atmospheres (e.g., PHOENIX Husser et al. 2013 and BT-Settl[1]). However, using fully synthetic grids for stellar population synthesis is not recommended because they suffer from incomplete line lists and do not reproduce observed integrated light spectra well enough.

2. Implementation

We propose a new interpolation procedure that is based on a non-parametric smoothing of fluxes from stellar spectra in the (T_{eff}, $\log g$, $[Fe/H]$) parameter space. We apply our interpolation procedure at every spectral pixel. Before we run our procedure, we normalize all spectra to unity at the wavelength 5500Å.

First, we combine libraries of empirical and synthetic stellar spectra. This is done by analyzing the distribution of observed stars in a 3-dimensional parameter space and creating a concave hull around them. A concave hull is similar to a convex hull, a uniquely defined convex polyhedron that can be constructed for any distribution of points in a multidimensional space and will contain all the points while all its vertices

---

[1] `https://phoenix.ens-lyon.fr/Grids/BT-Settl/`

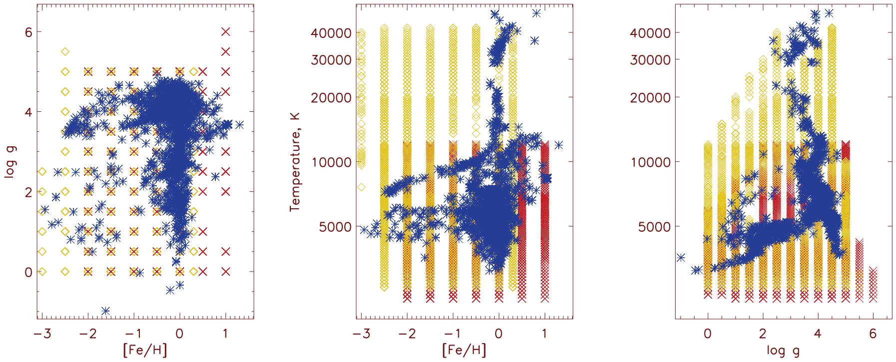

Figure 1. The parameter space for empirical (ELODIE - blue points) and synthetic (PHOENIX - red and BT-Settl - yellow) stellar libraries: (a) $T_{eff} - [Fe/H]$, (b) $[Fe/H] - \log g$, (c) $\log g - T_{eff}$. These three libraries cover the full range of parameters required by stellar population fitting codes.

will also be the points from the same set. A concave hull is a non-convex polyhedron that possesses the same properties regarding the inclusion but excludes "cavities" in the space that do not contain any points from the original distribution. The maximal characteristic size of those cavities is defined by an additional parameter.

For observed Milky Way stars in the stellar atmosphere parameter space, there is a pronounced cavity at high temperatures, low metallicities and low surface gravities (see Fig. 1). We take synthetic stars outside the concave hull constructed around empirical stellar spectra and add them to our dataset in order to avoid extrapolation when computing interpolated stellar spectra. We do this, because we do not want the situation when synthetic atmospheres dominate in the region of the parameter space where observed spectra are available.

Then, we use smoothing splines (basic splines or *b*-splines) on T_{eff} and a low-order two-dimensional polynomial fitting surface on $\log g$ and $[Fe/H]$ to approximate the distribution of fluxes from corresponding stellar spectra normalized to unity at the wavelength 5500Å. The use of the smoothing function is essential because: (i) there are uncertainties in the stellar atmosphere parameter determinations for real stars; (ii) there are physical star-to-star variations in the chemical composition that cause spectra of several stars having very close values of atmosphere parameters to differ from each other.

The obtained parametrization is then evaluated at every point of the parameter space of the output [regular] stellar atmosphere grid. Since our goal is to compute stellar population models with the PEGASE.HR evolutionary synthesis code, we use the same grid of atmosphere parameters as the one taken by the code. We obtain the flux re-normalization values for our spectra by measuring them at $\lambda = 5000$ Å in one of the synthetic stellar atmosphere grids provided within the PEGASE.HR package.

We also evaluate the parametrization at every point of the input stellar atmosphere grid in order to check the interpolation quality and detect possible systematics. In Fig. 2 we show the standard deviation of the residuals between the input stellar spectra and interpolated spectra at the same positions of the parameter space.

The use of *b*-splines helps us to resolve a long standing issue in the stellar population modelling regarding a mathematically correct way of stellar atmosphere interpolation that does not cause discontinuities in resulting stellar population models, which hampers stellar population analysis in real galaxies and star clusters.

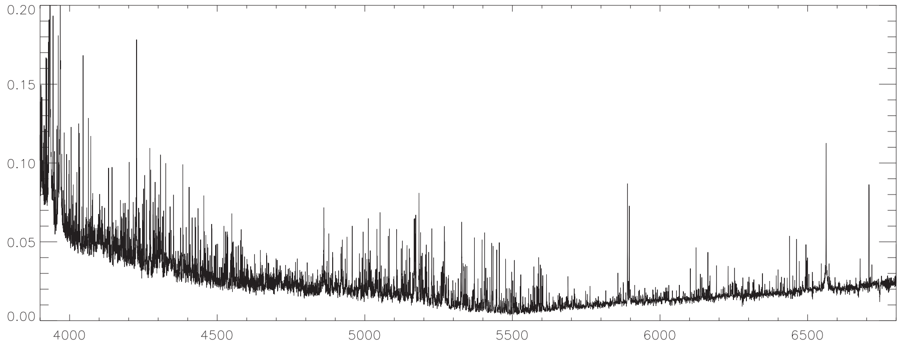

Figure 2. Standard deviation of the difference between interpolated and original spectra at every point in wavelength range.

3. Results

We computed a grid of stellar population models by feeding our interpolated semi-empirical stellar atmosphere grid to the PEGASE.HR population synthesis code (Le Borgne et al. 2004). We tested the new grid of models by fitting spectra of galaxies from the SDSS survey (Abazajian et al. 2009).

In Fig. 3 we show an example of the spectral fitting for the galaxy 51913-0394-625. We fitted its spectrum with a new technique for the determination of the initial mass function in unresolved stellar populations (Podorvanyuk et al. 2013). We see that the fitting residuals are similar compared to the results obtained by fitting the same galaxy using the original NBURSTS code (Chilingarian et al. 2007a,b) with ELODIE-based stellar population models (Fig. 4).

We analysed spectral data for 3000 giant elliptical galaxies from the SDSS survey and other galaxies using our full spectrum fitting technique. The detailed comparison of our results (ages, metallicities) for different grids of stellar population models will be provided in a separate paper (Katkov et al. in prep.)

Acknowledgments. This work is supported by a grant of the President of the Russian Federation MD-7355.2015.2, and Russian Foundation for Basic Research grants 15-52-15050 and 15-32-21062.

References

Abazajian, K. N., et al. 2009, ApJS, 182, 543

Chilingarian, I., et al. 2007a, in Stellar Populations as Building Blocks of Galaxies, edited by A. Vazdekis, & R. R. Peletier (Cambridge, UK: Cambridge University Press), vol. 241 of IAU Symposium, 175

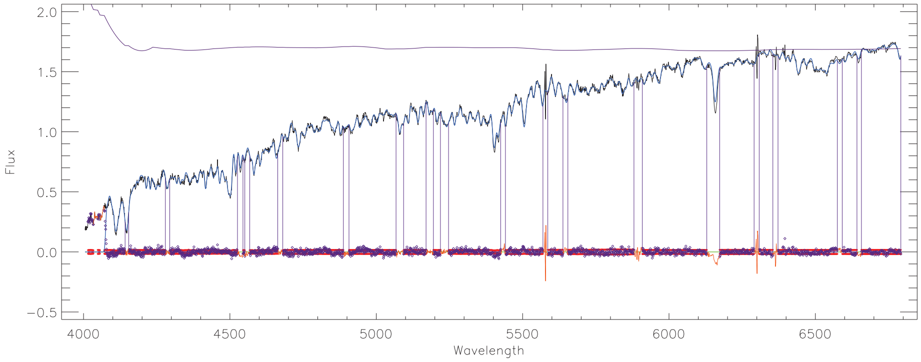

Figure 3. Galaxy 51913-0394-625 from SDSS survey, fitted by semi-empirical stellar population models using ELODIE and PHOENIX stellar libraries. Upper line shows the continuum shape. Several regions (e.g., night-sky emission lines and NaI D) were excluded from the fitting.

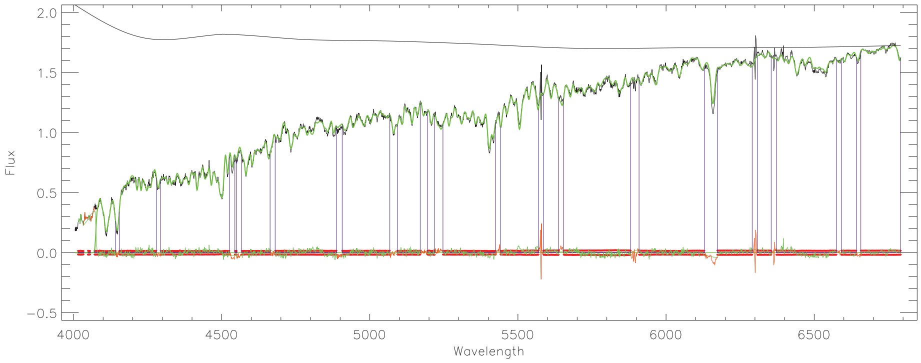

Figure 4. Galaxy 51913-0394-625 from SDSS survey, fitted using ELODIE based PEGASE.HR stellar population models. Upper line shows the continuum shape.

Chilingarian, I. V., et al. 2007b, MNRAS, 376, 1033
Husser, T.-O., et al. 2013, A&A, 553, A6
Le Borgne, D., et al. 2004, A&A, 425, 881
Podorvanyuk, N. Y., Chilingarian, I. V., & Katkov, I. Y. 2013, MNRAS, 432, 2632
Prugniel, P., & Soubiran, C. 2004. ArXiv:astro-ph/0409214, `astro-ph/0409214`
Sánchez-Blázquez, P., et al. 2006, MNRAS, 371, 703