The Spectral Energy Distribution of Galaxies
Proceedings IAU Symposium No. 284, 2011
R.J. Tuffs & C.C. Popescu, eds.

doi:10.1017/S1743921312008617

Effects of Non-Solar Abundance Ratios on Star Spectra: Observations versus Models

Anne E. Sansom[1], **André de Castro Milone**[2], **Alexandre Vazdekis**[3] **and Patricia Sánchez-Blázquez**[4]

[1]Jeremiah Horrocks Institute, University of Central Lancashire, Preston, Lancs PR1 2HE, UK

[2]Divisão de Astrofísica, Instituto Nacional de Pesquisas Espaciais, Av. dos Astronautas 1758, São José dos Campos, SP 12227-010, Brazil

[3]Instituto de Astrofísica de Canarias, La Laguna, E-38200 Tenerife, Spain

[4]Departamento de Física Teórica, Universidad Autónoma de Madrid, 28409, Spain

email: aesansom@uclan.ac.uk

Abstract. Element abundance ratios hold important clues to understanding the evolution of stellar populations, through the varying timescales of different nucleosynthetic contributors. Newly measured and compiled [Mg/Fe] ratios in the MILES stellar library are used to confront models of star spectra. Such models have been used in recent years to provide estimates of differential changes in spectral line strengths, due to enhancements in [α/Fe]. In this paper we test one widely used set of theoretical element response functions. Using magnesium as a proxy for all alpha elements we test the reliability of these theoretical response functions against empirical observations, and thus the reliability of current methods of measuring element abundance ratios in the stellar populations.

Keywords. stars: atmospheres, stars: abundances, techniques: spectroscopic.

1. Why are Abundance Ratios Important?

In individual stars element abundance patterns are useful for understanding the initial composition, evolution and photospheric structural and dynamical processes. In samples of stars abundance patterns are used to determine which components the stars are associated with and to constrain the history of how those populations formed. In unresolved stellar populations, the ratio of α-capture elements to iron-peak elements [α/Fe] can tell us about the timescale of star formation, since different enrichment sources contribute to the inter-stellar medium at different rates and with different patterns of heavy element abundances. Therefore it is important to be able to accurately measure abundance ratios so that a coherent picture of the data on stellar populations can be achieved, against which models of galaxy evolution and chemical feedback can be tested.

The importance of abundance ratios in understanding stellar populations is highlighted by the large number of publications in which attempts are made to measure abundance ratios in integrated stellar populations (recent examples include: Annibali *et al.* 2011, Thomas *et al.* 2011). Many of these studies are based on the use of element response functions. We use such response functions in studying different types of galaxies (e.g. Sansom & Northeast 2008). Response functions are tables of how line strengths change in theoretical spectra, due to different atmospheric abundances of elements. They can be used to make differential corrections to theoretically or empirically derived simple stellar populations (SSPs), to account for effects of non-solar abundance ratios on predicted line-strength, such as the widely used Lick indices. The most extensively used response functions are those of Korn *et al.* (2005) (hereafter K05) and it is those that we test in this current work.

2. New Measurements

The empirical data that we use to test the K05 response functions became available from our recent careful study of stars in the MILES spectral library (Sánchez-Blázquez *et al.* 2006). Our catalogue of [Mg/Fe] measurements for MILES stars is published in Milone, Sansom & Sánchez-Blázquez (2011). See also Milone *et al.* in this volume. We use [Mg/Fe] as a proxy for the α-elements in general, therefore we can assign [α/Fe] and [Fe/H] values for many of the stars in the MILES library. Response functions are applied in a differential way. Therefore we can use MILES stars that have the same effective temperature and surface gravity as the models of K05 (within observational errors) and form the ratio of line-strengths at specific abundances ([α/Fe],[Fe/H]) to line-strengths of MILES stars at solar abundances ([α/Fe] and [Fe/H] = 0.0). This relies on having a suitable star with the base abundance (0,0), which we have, within observational errors. For the corresponding predictions from theoretical response functions this is done in a two-stage process; first to correct to a specific metallicity, then to a specific [α/Fe]. This latter step is done by taking into account changes due to the α-elements only. Both MILES observations and K05 models have Lick indices measured at the Lick resolutions.

3. Comparisons with Theoretical Models

3.1. *Line-Strength Indices*

For strong lines, ratios of line-strengths are compared, however, some of the Lick indices take positive and negative equivalent width values (e.g. for H_γ and H_δ features), therefore differences rather than ratios are compared for those cases. In these comparisons of normalised observations versus normalised theoretical predictions, the data points will lie on a one-to-one line if the predictions using response functions match the observations. Below we show an example for some of the Lick indices.

Fig. 1 shows that the Lick $H_{\delta A}$ and $H_{\gamma A}$ indices are not well matched between observations and models, whereas Fe5270 and Fe5335 are. Other Fe sensitive features also behave as predicted from the response functions. The lack of agreement that we find for higher order Balmer indices may be due to a problem with our assumption of [Mg/Fe] tracking [α/Fe] in the observed stars; an anomaly in the normalising stars used; or a problem with the predictions from response functions for specific indices. The higher order Balmer lines are located in a region of the spectrum that shows a rapid change with wavelength and a stronger dependence on abundance ratios. Features in the side bands may systematically affect response function predictions in such rapidly changing regions in the blue part of the spectrum, where there are a lot of atomic and molecular line contributions.

New and alternative band definitions need to be explored, together with tests of the theoretical model spectra, in order to find more robust measures for abundance ratios in unresolved stellar populations. This also affects measurements of ages and metallicities since all indices have some sensitivity to each of these parameters.

3.2. *Spectra*

To test for the effect of abundance ratios across a stellar spectrum we form the ratio of observed spectra at enhanced versus solar [α/Fe] ratios. An example is illustrated in Fig. 2, which shows the ratio of two spectra of stars in the MILES library. The stars were chosen to have the same overall metallicity, based on inferred [O/H] abundances via

https://doi.org/10.1017/S1743921312008617 Published online by Cambridge University Press

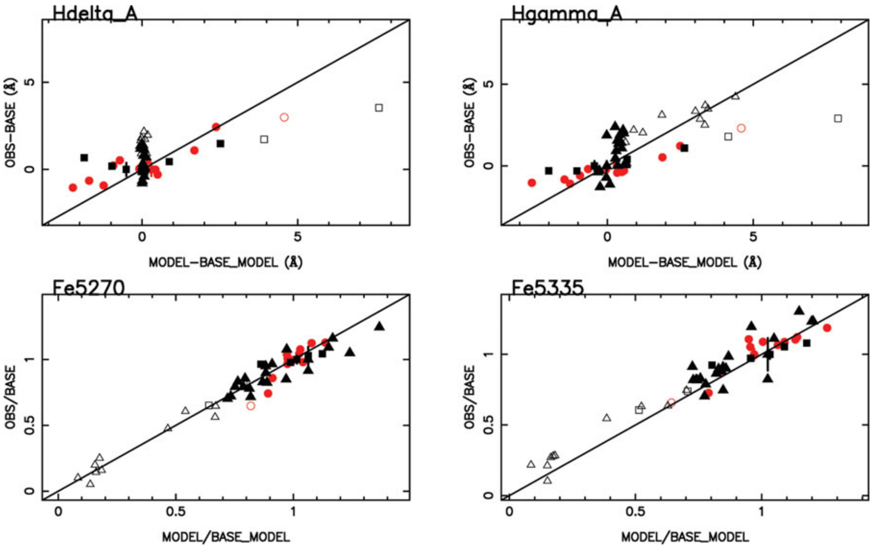

Figure 1. Comparison of empirical observations for MILES stars with theoretical predictions obtained from the K05 response functions, for $H_{\delta A}$, $H_{\gamma A}$, Fe5270 and Fe5335 Lick indices. Model values are normalised in the same way as the observations in these plots. BASE refers to indices for stars with solar abundances. Data points are stars covering abundance ranges: $-2.86<$[Fe/H]$<+0.41$ and $-0.40<[\alpha$/Fe]$<+0.53$. The diagonal line shows the one-to-one relation. Circles are cool giant stars (T_{eff} ~4255K, log(g)~1.9), triangles are turn-off stars for a 5 Gyr old population (T_{eff} ~6200K, log(g)~4.1) and squares are cool dwarf stars (T_{eff} ~4575K, log(g)~4.6) matching the T_{eff} and log(g) values of three theoretical models with tabulated response functions in K05. Open symbols correspond to larger extrapolations from the base models at solar abundance (i.e. stars with [Fe/H]<-0.4).

the correlation of Bensby, Feltzing & Lundström (2004). This figure shows that the blue to UV part of the spectrum, below about 450nm, is increasingly affected by changes in [α/Fe]. Qualitatively similar patterns are found for ratios of theoretical spectra, as shown at the top of Fig. 2. This is similar to the earlier work of Cassisi *et al.* (2004) (their figure 2), based on ATLAS 9 models. There are several identifiable features in the blue region of the spectrum that may be worth further study for their sensitivity to abundance patterns. This very blue part of the spectrum has been little observed or modelled to date. This is because there are many uncertain predictions of lines particularly affecting the blue region of the spectrum, therefore attempts to model the flux levels there have required corrections for these uncertain contributions.

4. Interpretation and Future Work

We find that, whilst some of the Lick indices are correctly modelled for element abundance ratios, through the use of the Korn *et al.* 2005 response functions, other indices are not. In particular the iron sensitive Lick indices are quite well modelled, whereas the higher order Balmer line indices show discrepancies, when observations are compared with models of star spectra. The sense of these discrepancies is different in cool and warm stars. Therefore it is not easy to predict how these discrepancies will affect SSPs. We are currently extending the MILES empirical spectral database to encompass a wider range of stars with known abundance ratios.

Further tests of spectra, indices and response functions are ongoing and will be presented in a future paper. From the initial spectral ratios given here, future work on the

https://doi.org/10.1017/S1743921312008617 Published online by Cambridge University Press

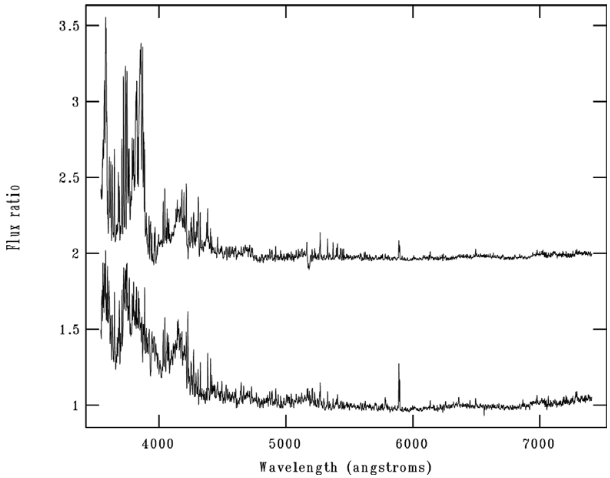

Figure 2. The lower curve shows the ratio between an observed (MILES) spectrum of a giant star with $[\alpha/\text{Fe}] = +0.4$ to that of a star with $[\alpha/\text{Fe}] = 0.0$, both at solar [Z/H], $T_{eff} = 4500$ and $\log(g) = 2.0$. The upper curve shows this same ratio for theoretical spectra from Coelho *et al.* (2007). The curves are separated by one in the vertical axis of relative flux ratio, to avoid overlapping. The effects of abundance ratios are strongest in the U and B bands, at <4500Å.

sensitivity of features in the blue part of the spectrum shows promise for highlighting features sensitive to varying abundance ratios. This will be an important new direction to explore, since accurate measurements of abundance ratios are vital for interpreting star formation histories in galaxies. Uncovering and accurately calibrating sensitive new $[\alpha/\text{Fe}]$ indicators would help with such measurements.

References

Annibali, F., Grützbauch R., Rampazzo R., *et al.* 2011, *A&A*, 528, 19
Bensby, T., Feltzing, S., & Lundström, I. 2004, *A&A*, 415, 155
Cassisi, S., Salaris, M., Castelli, F., & Pietrinferni, A. 2004, *ApJ*, 616, 498
Coelho, P., Bruzual, G., Charlot, S., *et al.* 2007, *MNRAS*, 382, 498
Korn, A. J., Maraston, C., & Thomas, D. 2005, *A&A*, 438, 685
Milone, A. de C., Sansom, A. E., & Sánchez-Blázquez, P. 2011, *MNRAS*, 414, 1227
Sánchez-Blázquez, P., Peletier, R. F., Jiménez-Vicente, J., *et al.* 2006, *MNRAS*, 371, 703
Sansom, A. E. & Northeast, M. S. 2008, *MNRAS*, 387, 331
Thomas, D., Johansson, J., & Maraston, C. 2011, *MNRAS*, 412, 2199

Discussion

Ferreras: Concerning the "blue excess", would it appear if treating both [Fe/H] & $[\alpha/\text{Fe}]$ as free parameters? Concerning the H_γ and H_δ mismatch, could this be related to "nearby" features like CN in H_δ or G-band in H_γ? Are there any better indices?

Sansom: The spectral ratios plotted show specific examples of stars with known [Fe/H] & $[\alpha/\text{Fe}]$. These are not fitted parameters. The stars chosen have the same overall metallicity, and different $[\alpha/\text{Fe}]$ ratios. Concerning the indices, indeed band and side band definitions are important and we will explore further definitions in the literature for the H_γ and H_δ features.

https://doi.org/10.1017/S1743921312008617 Published online by Cambridge University Press