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Element abundance ratios in stellar population modelling

Daniel Thomas

Institute of Cosmology and Gravitation, University of Portsmouth, Dennis Sciama Building, Burnaby Road, Portsmouth, PO1 3FX, UK. email: daniel.thomas@port.ac.uk
SEPnet, South East Physics Network, (www.sepnet.ac.uk)

Abstract. I review the implementation of the effects from varying chemical element abundance ratios in stellar population modelling. Recent highlights include the adoption of new flux calibrated libraries, the inclusion of a wide range of chemical elements, the calculation of error estimates on the model, and the consideration of element variation effects on full spectra. Some key results on the element ratios measured in early-type galaxies are discussed.

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The spectra of galaxies and globular clusters carry a wealth of information about gas and stellar population properties. A number of absorption features in a spectrum allow to dissect 'metallicity' into individual element abundances (Greggio 1997; Tantalo et al. 1998; Trager et al. 2000; Thomas *et al.* 2003a) that set valuable constraints on the chemical enrichment history of a galaxy (Thomas *et al.* 1999). The inclusion of the these effects in stellar modelling has produced a major step forward in the field of stellar population modelling and has led to key progress in the interpretation of galaxy data. In the following I will discuss some of the recent developments.

1. New stellar libraries and model errors

The advent of new flux-calibrated libraries has made it possible to produce models that are now flux calibrated and at higher spectral resolution. This is essential for the interpretation of galaxy spectra where calibration stars are not available, such as large galaxy redshift surveys or other high-redshift observations. Johansson *et al.* (2010) produced new empirical fitting functions based on the MILES library (Sánchez-Blázquez *et al.* 2006) that relate absorption line strength with stellar parameters, that are adopted in the Thomas *et al.* (2011) models. These models can directly be applied to SDSS data with minimal correction for spectral resolution (Beifiori *et al.* 2011).

A particular feature of the Thomas *et al.* (2011) models is that model errors are calculated for the first time. This is possible thanks to the use of absorption line strengths in combination with fitting functions. The major strength of fitting functions lies in the fact that they allow for interpolation between well-populated regions of stellar parameter space which increases the accuracy of the model in stellar parameter space that is only sparsely sampled by empirical stellar libraries. Moreover, each absorption index or spectral feature is represented by an individual fitting function, which is optimised to best reproduce its behaviour in stellar parameter space.

2. Full spectral response

An alternative to the approach of Thomas *et al.* (2003a) has been presented in the recent literature. Conroy *et al.* (2014) follow their method in that they use response functions from model atmosphere calculations to assess the relative effect of element abundance variations, while the basic stellar population model is footed on empirical stellar libraries. Rather than using response functions for key absorption features, though, they calculate wavelength-dependent spectral response functions and apply those to the full model spectrum. This approach is very powerful, while somewhat more affected by uncertainties in line lists and continuum uncertainties, hence may be considered well complementary to the use of absorption index features.

3. Galaxy data

Element ratio sensitive stellar population models provide the opportunity to derive the abundance ratios for a variety of chemical elements of unresolved stellar populations. Graves & Schiavon (2008) and Johansson et al. (2012) developed codes that fit iteratively a set of absorption line indices resulting in the derivation of the abundance ratios of the elements best accessible through strong absorption features including C, N, Mg, Ca, Ti, and Fe. The abundance of oxygen cannot be derived directly from absorption features, but can be estimated through its role as dominating element among the light α-elements (Johansson et al. 2012). Conroy *et al.* (2014) recently extended this procedure to full spectral fits adding the element Si.

A key result seen in all these studies consistently is that the light-element to Fe-peak abundance ratios [C/Fe], [N/Fe], [O/Fe], [Mg/Fe], and [Si/Fe] increase with galaxy velocity dispersion and mass (Smith *et al.* 2009; Johansson et al. 2012; Conroy *et al.* 2014), leading to significantly super-solar ratios in massive galaxies. The heavier elements Ca and Ti deviate from this trend. [Ca/Fe] is close to solar across all galaxy masses and may only increase slightly (if at all) with galaxy mass. This has also been interpreted as Calcium under-abundance in massive galaxies (Thomas *et al.* 2003b). The best explanation is that the relevance of Type Ia enrichment increases with element mass, which implies that Ca and Ti are suppressed because they get partially enriched by the delayed Type Ia supernovae. However, Ti, even though being heavier than Ca, appears to show somewhat higher enhancement than Ca in massive galaxies, which seems contrived within this picture. The optical spectrum used in these studies only is moderately sensitive to Ti abundance, though, and further work on this, potentially including the near-IR part of the spectrum, will be very valuable.

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