Chapter 14
Using Evolution Strategies to Perform Stellar Population Synthesis for Galaxy Spectra from SDSS

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ABSTRACT
In this work, the authors employ Evolution Strategies (ES) to automatically extract a set of physical parameters, corresponding to stellar population synthesis, from a sample of galaxy spectra taken from the Sloan Digital Sky Survey (SDSS). This parameter extraction is presented as an optimization problem and being solved using ES. The idea is to reconstruct each galaxy spectrum by means of a linear combination of three different theoretical models for stellar population synthesis. This combination produces a model spectrum that is compared with the original spectrum using a simple difference function. The goal is to find a model that minimizes this difference, using ES as the algorithm to explore the parameter space. This paper presents experimental results using a set of 100 spectra from SDSS Data Release 2 that show that ES are very well suited to extract stellar population parameters from galaxy spectra. Additionally, in order to better understand the performance of ES in this problem, a comparison with two well known stochastic search algorithms, Genetic Algorithms (GA) and Simulated Annealing (SA), is presented.

INTRODUCTION
Evolution Strategy (ES) (Back, Hammel, & Schwefel, 1997; Rechenberg, 1973) is a very flexible and effective optimization algorithm (Ashlock, 2005), suitable to be employed in many areas and subjects such as mechanical design (Giraud-Moreau & Lafon, 2002), optics (Vazquez-Montiel, Sanchez-Escobar, & Fuentes, 2002) and control engineering (Fernandez, Munoz, Sanchez, & Mayol, 1997). In this paper we introduce a novel application of this method to a very interesting problem in astronomy: the fitting
of galaxy spectra with models of stellar population synthesis; a problem that has been attacked following traditional approaches like $\chi^2$ minimization (Wolf, Drory, Gebhardt, & Hill, 2007) or stochastic methods such as Simulated Annealing (SA) (Fernandes, Mateus, Sodré, Statinska, & Gomes, 2005). However, these methods have some problems because they tend to be computationally expensive in terms of time, like $\chi^2$, and sometimes converge to non-global optima, like SA.

Astronomy faces today an important set of difficult tasks that need to be tackled by sophisticated algorithms. Basically there are two types of problems in modern computational astronomy: problems with great computational complexity (e.g., n-body and cosmological simulations) (Gomez, Athanassoula, Fuentes, & Bosma, 2004) and problems where huge amounts of information must be analyzed (e.g., sky surveys, Abazajian et al., 2004). The problem presented here belongs to the second category.

Tasks where a huge amount of data have to be analyzed need to be performed automatically using reliable and efficient algorithms, as manual analysis is practically impossible because of the great amount of time required. In particular, the Sloan Digital Sky Survey (SDSS) (Abazajian et al., 2004) contains terabytes of information from galaxy images and spectra that need to be processed in order to extract important scientific knowledge. This massive amount of high quality data has the potential to enable enormous progress in our understanding of galaxies and the universe in general.

Galaxy spectra encode information about age and metallicity distributions of the constituent stars, which in turn reflect the star formation and chemical histories of the galaxies (Karttunen, Kroger, Oja, Poutanen, & Donner, 2000). Extracting such information from observational data in a reliable way is crucial for a deeper understanding of galaxy formation, composition, and evolution. In order to extract knowledge from SDSS spectra, a methodology must be set up to go from observed spectra to the physical properties of galaxies, including reddening, age, metallicity, and contribution of each stellar population.

The main goal in this paper is to present a method based on ES for extracting parameter information about the stellar components of a given observed galaxy spectrum from SDSS, presented as an image. The idea is to do it by fitting, efficiently and automatically, the observed spectrum with a linear combination of simple theoretical stellar populations computed with evolutionary synthesis models at the same spectral resolution as that of the SDSS. ES works as an optimization algorithm by exploring the space of feasible parameters, trying to find the ones that produce the model that best matches the original galaxy spectrum image.

In this paper we have obtained results for a set of 100 spectra from SDSS Data Release 2 as a first approach to the use of ES in this problem, proving ES are very well suited to extract stellar population parameters from galaxy spectra automatically and efficiently. The rest of the document is structured by presenting a brief description of galaxy spectra and the information we can extract from them and describes the data from SDSS. Next, we detail the implementation of ES to solve the problem and then results are presented followed by a conclusion.

**GALAXY SPECTRA**

The light of a star can be dispersed into a spectrum by means of a prism or a diffraction grating. In this way we obtain the *stellar spectrum*, which is the distribution of the energy flux density over frequency. A stellar spectrum is made up by a continuum and by absorption and emission lines, which are produced by the different chemical elements present in the star (Karttunen, Kroger, Oja, Poutanen, & Donner, 2000). Each line is a fingerprint of some chemical element that is excited or ionized.
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