The Epochs of Early-Type Galaxy Formation in Clusters and in the Field

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Abstract. Using our models of absorption line indices that account for variable abundance ratios, we derive ages, total metallicities, and element abundance ratios of 126 early-type galaxies in various environments. The data are analyzed by comparison with mock galaxy samples created through Monte Carlo simulations taking the typical average observational errors into account, in order to eliminate artifacts caused by correlated errors. We find that all three parameters age, metallicity, and α/Fe ratio are correlated with velocity dispersion. We further find evidence for an influence of the environment on the stellar population properties. Massive early-type galaxies in low-density environments appear on average several Gyrs younger and ~ 0.1 dex more metal-rich than their counterparts in clusters. No offsets in the α/Fe ratios, instead, are detected. With the aid of a simple chemical evolution model, we translate the derived ages and α/Fe ratios into star formation histories. We show that most star formation activity in early-type galaxies is expected to have happened between redshifts ~ 3 and 5 in high density and between redshifts 2 and 3 in low density environments.

1 Introduction

The most direct way to constrain the formation and evolution of galaxies certainly is to trace back their evolution with redshift [1,3,40,14,38,27]. The price to be paid, however, is that high-redshift data naturally have lower quality and are therefore more difficult to interpret. A clear complication is the so-called progenitor bias, which implies that galaxies observed at low and high redshift are not necessarily drawn from the same sample [38]. The alternative approach is the detailed analysis of the stellar populations in local galaxies. By determining their average ages and element ratios, it is possible to unravel their (star) formation histories and to constrain the main epoch of galaxy formation. The confrontation with predictions from models of galaxy formation is certainly most meaningful, when the two approaches, the archeology of local galaxies and the mining of the high-redshift universe set consistent constraints.

In this paper we follow the former approach and analyze a homogeneous, high-quality data sample of early-type galaxies in various environmental densities. With our new stellar population models ([34], hereafter TMB03) we determine, besides ages and total metallicities, α/Fe ratios from absorption line indices. The main aim is to reveal possible correlations of these parameters with velocity dispersion, hence, galactic mass, and to derive star formation histories as a function of redshift, in order to constrain the main epochs of early-type galaxy formation.

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2 Data and Models

We analyze a sample of 126 early-type galaxies, 71 of which are field and 55 cluster objects, containing roughly equal fractions of elliptical and lenticular (S0) galaxies. The sample is constructed from the following sources: 41 Virgo cluster and field galaxies [11], 32 Coma cluster galaxies [22,23], and 53 mostly field galaxies (highest quality data from [5]) selected from the ESO–LV catalog [17]. In the latter sample, objects with a local galaxy surface density $NG_T > 9$ are assumed to be cluster galaxies. NG_T is given in [17] and is the number of galaxies per square degree inside a radius of one degree around the considered galaxy. Line indices are measured as functions of galaxy radius. We adopt the central indices determined within 1/10 of the effective radius, so that the analysis presented here is free from aperture effects. The average $1-\sigma$ errors in Hβ, Mg b, and ⟨Fe⟩ are 0.09, 0.06, 0.07 Å, respectively.

In TMB03 new stellar population models with different chemical mixtures and element abundance ratios are presented. All optical Lick indices from CN_1 to TiO_2 [39] in the wavelength range 4000 Å $\leq \lambda \leq$ 6500 Å are computed for various chemical mixtures modifying the abundance ratios between α-elements (i.e. O, Mg, Ca, Na, Si, Ti), and iron-peak elements (Fe, Cr). The models are based on the evolutionary population synthesis of [19,20]. The impact from element ratio changes is computed with the help of the [37] model atmosphere calculations, using an extension of the method introduced by [35]. We refer to TMB03 for more details. These models are used here to derive the stellar population parameters age, metallicity, and α/Fe ratio from the line indices Hβ, Mg b, and ⟨Fe⟩.

3 Results

An uncomfortable effect of the degeneracy between age and metallicity, is that the errors of these stellar population parameters are not independent. A possibility to get a handle on correlated errors is the performance of Monte Carlo simulations taking into account the observational uncertainties of the line indices from which the stellar population parameters are derived [36,16]. In this paper we extend the approach of [16] to a 3-dimensional parameter space including also α/Fe ratios besides age and total metallicity. We produce artificial samples of galaxies with given ages, metallicities, and α/Fe ratios, from which we compute through our stellar population models the line indices Hβ, Mg b, and ⟨Fe⟩. By means of Monte Carlo simulations we perturb these 'exact' values with the $1-\sigma$ errors of the observational sample, assuming a Gaussian error distribution. The outcome is then compared with the observational data.

The result is shown in Fig. 1, in which the α/Fe-independent index [MgFe]$'$ (see TMB03) vs. the Balmer line index Hβ is plotted. Grey symbols are the observational data, while the filled symbols are the Monte Carlo realizations. Left and right panels refer to high and low density environments, respectively. The sample splits in two subclasses divided by the Balmer absorption index at H$\beta \approx 2$ Å. The main part of the data ($\sim$ 75 per cent) is centered around