

Stellar Population gradients in early-type galaxies

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Abstract. Long-slit spectra have been obtained with the Keck telescope for a sample of 11 early-type galaxies covering a range in luminosity. Rotation velocity and velocity dispersions, together with 20 Lick line-strength gradients have been measured to two effective radius. We transform line-strength gradients into age, metallicity and α/Fe . Galaxies show very shallow age gradients, strong metallicity gradients, and both positive and negative α/Fe gradients, which cannot be explained with simple outside-in scenarios of galaxy formation. We explore the correlation of the gradients with other global parameters of the galaxies, finding different behaviour for the two families of galaxies, luminous (boxy, core inner profile) and less luminous (disky, cuspy inner profile) galaxies.

Keywords. galaxies: elliptical and lenticular, cD, galaxies: formation, galaxies: stellar content

1. Introduction

While monolithic collapse models of galaxy formation account naturally for the old apparent ages of spheroidal stars, for their high densities and for the weak evolution in their properties with time, it is less successful at explaining the detailed luminosity dependence of their dynamical properties. More luminous galaxies are slowly rotating, the shape of their isophotes is preferentially boxy, and their inner surface brightness profile is coreless while less luminous ones are supported by rotation, they preferentially show a cuspy inner profile core and disk isophotes. Numerical simulations of merger of galaxies suggest that these properties (in particular the shape of the isophotes and the degree of rotation) can be explained with a variation of the degree of dissipation during the formation of the galaxies (e.g. Bekki & Shioya 1997). Dissipation can also explain the power-law inner profile of the less luminous elliptical galaxies, while the dense core may be explained in a model of an orbital decay of a black hole binary system (Faber *et al.* 1997).

One way to test this idea is to study the gradients of stellar population of early-type galaxies, as the amount of dissipation modify their final shape. Gaseous mergers with a strong degree of dissipation produce steeper metallicity gradient. If these mergers trigger star formation (Mihos & Hernquist 1994), an age gradient may be also present. On the other hand, mergers of pure stellar systems would tend to dilute the original gradients (White 1980).

We use the Keck telescope to observe a sample of 11 early-type galaxies (10 E and 1 S0) covering a wide range in luminosity. To derive gradients we added spectra along the

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radio to get a minimum signal-to-noise per Å of 55. We reach $2 r_{\text{eff}}$ in all the galaxies. We derived ages metallicities and α -element abundances † using the χ^2 method described in Proctor & Sansom (2002) with 19 Lick indices and Thomas, Maraston & Bender (2003) models. The details of the procedure can be found in Sánchez-Blázquez *et al.* (2007).

2. Results

In agreement with other studies, we found that line-strength gradients in our galaxies are mainly due to variations in metallicity. Metallicity gradients range from $\text{grad}[Z/H] = -0.466$ to -0.135 . Only 2 galaxies in our sample show age gradients significantly different from zero, NGC 2865 and NGC 1700. Both galaxies have a mean young population in their centers. We also found that galaxies show both, positive and negative $[\alpha/\text{Fe}]$ gradients, contrary to what it is expected in a simple monolithic collapse or in an scenario where the galactic winds were the only mechanism to shape the gradients (e.g. Martinelli *et al.* 1998; Pipino *et al.* 2006). Under this scenario positive α/Fe gradients are expected due to the delayed onset of the galactic winds in the internal parts with respect to the external parts. We studied the correlation between the gradients and other parameters of the galaxies. We found a correlation between the metallicity gradient and the shape of the isophotes and the degree of rotation (see Fig. 1). These relations are difficult to explain under models of monolithic collapse, but they appear naturally in models of mergers between galaxies with different degree of dissipation (see, e.g. Bekki & Shioya 1999; Naab, Khochfar & Burkert 2006), where a larger amount degree of dissipation produce both, steeper metallicity gradients and higher values of a_4 .

We also examined the relation between the strength of the stellar population gradients and the central values and found that, for galaxies with a mean central age lower than 10 Gyr, those showing a lower central mean age also show steeper metallicity gradients. This relation suggests that central secondary burst of star formation in some ellipticals are responsible for both, the mean young ages and the strength of the gradient as suggested in other studies (e.g. Kuntschner *et al.* 2006; Sánchez-Blázquez *et al.* 2006b). The relation of the metallicity gradient with both, the shape of the isophotes and the central age, suggests that major mergers are responsible for triggering these secondary bursts of star formation. Other aspect that has been debated in the literature is if luminous and less luminous elliptical galaxies form a continuous sequence or if there exists a dichotomy in their properties. Signs of dichotomy has been found in the shape of the inner profile of elliptical galaxies (Faber *et al.* 1997), although this claim remains controversial (see Ferrarese *et al.* 2006 for another point of view). In the right panel of Fig. 1, we appreciate a relation between the gradient and the central value of the $[\text{E}/\text{Fe}]$. We have separated, with different symbols, galaxies showing a core and power-law inner profile. It also obvious that galaxies showing a core profile lay above the relation, i.e, it seems to exist a dichotomy between galaxies with different inner profiles, although this claim is very adventurous given the small number of galaxies in our sample. The dichotomy, if it is confirmed, may be indicating fundamental differences in the formation process of these galaxies.

2.1. Star formation Histories along the radius

If the star formation history (SFH) of the galaxies analysed was more complicated than a single, instantaneous burst, the ages and metallicities derived with Single Stellar Population (SSP) models are mean ages, metallicities and chemical abundances weighted with

† We use the term $[\text{E}/\text{Fe}]$ instead of $[\alpha/\text{Fe}]$ to denote the abundance of α elements with respect to Fe as, in the models, some other elements apart from the α are enhanced

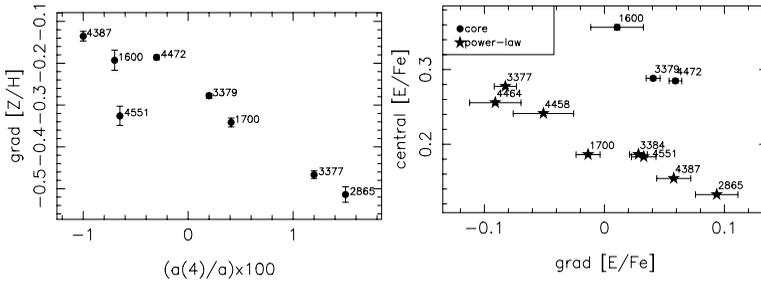


Figure 1. Left panel: Relation between the metallicity gradient and the shape of the isophotes parametrized by the a_4 parameter, extracted from Bender (1989). Right panel: Relation between the $[E/Fe]$ gradient and the central value. Galaxies with σ higher and lower than 200 km/s, which also separate galaxies with a core inner profile and a power law inner profile respectively are marked with different symbols, as indicated in the inset. For the galaxy NGC 2865 we could not find in any reference the shape of its inner profile but its central velocity dispersion is lower than 200 km/s. The inner profile shape has been extracted from Faber *et al.* (1997).

the light of the individual stars. In this context, a small percentage of young stars are able to bias the final mean age toward very low values. Furthermore, the stars that are in the region of the HR diagram sensitive to age variations are different to the ones in the region of this diagram sensitive to metallicity variations, and, therefore, the ages and metallicities we are measuring with SSP are not necessarily the mean values of the same population of stars.

In order to explore the possible SFHs compatible with the observed spectra, we have used STECKMAP (Ocvirk *et al.* 2006a,b) † to derive star formation histories along the radius of the galaxies using Vazdekis *et al.* (2007) models. This method reconstructs the stellar age distribution, the age-metallicity relation and the line of sight velocity distribution (LOSVD) of a galaxy from an integrated spectra in a non-parametric way, i.e., no previous shape of the star formation or the LOSVD is assumed. The only a priori that is imposed is that the solution is smooth with age. The continuum of the model spectra is corrected to match the galaxies (i.e., we do not use the information in the continuum for the fit). This method works very well in recovering the star formation history of galaxies (see the contribution of S. Trager to this volume).

Figure 2 shows the mass fraction of stars formed at different ages, in the center, and at $r \sim 2 r_{\text{eff}}$ for the galaxies NGC 1600 and NGC 2865. As can be seen, while NGC 1600 seem to have formed all their stars at an early epoch, NGC 2865 show evidence of late star formation in the center (though the exact shape of the mass distribution is not reliable), while SFH at $2 r_{\text{eff}}$ is compatible with an early formation and a passive evolution after that. The exact shape of the mass distribution is not reliable, as would show the analysis of the mass distribution with different SSP models, but they give us an indication of when the majority of the stars were formed in the galaxies.

3. Conclusions

- The relation of the gradients with a_4 seems to indicate that elliptical galaxies formed through mergers with a systematic decrease, with mass, of the degree of dissipation during these interactions.
- The relation between the stellar population parameters in the center and along the radius suggests that the relative recent episode of star formation that have been observed

† STECKMAP is available at <http://astro.u-strasbg.fr/ocvirk/>

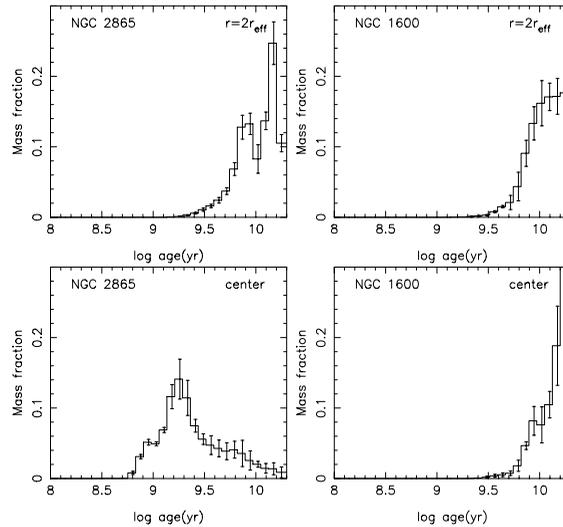


Figure 2. Mass fraction of stars formed at different ages at the center and at $r \sim 2 r_{\text{eff}}$ for the galaxies NGC 1600 and NGC 2865. The errors bars are the standard deviation of the mean values obtained in 20 Monte Carlo Simulations.

in the center of a large fraction of E galaxies (González 1993; Caldwell *et al.* 2003; Trager *et al.* 2000; Sánchez-Blázquez *et al.* 2006) have been triggered by mergers.

- Our data show indications of a dichotomy in the $\text{grad}[E/Fe]$ vs. $[E/Fe]$ plane between core and power-law galaxies.
- The results presented here need to be confirmed with larger samples of galaxies.

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