Stellar Populations as Building Blocks of Galaxies
Proceedings IAU Symposium No. 241, 2006
A. Vazdekis & R. F. Peletier, eds.

doi:10.1017/S1743921307008599

The use of [Mg/Fe] to trace truncated star formation in elliptical galaxies

Ignacio G. de la Rosa[1,2], **Reinaldo R. de Carvalho**[3], **Alexandre Vazdekis**[1] **and Beatriz Barbuy**[2]

[1]Instituto de Astrofísica de Canarias, E-38200 La Laguna, Tenerife, Spain
email: irosa@iac.es, vazdekis@iac.es

[2]Instituto Astronômico e Geofísico - USP, 04301-904 São Paulo, Brazil
email: barbuy@astro.iag.usp.br

[3]Instituto Nacional de Pesquisas Espaciais - INPE, DAS, São José dos Campos - SP - Brazil
email:reinaldo@das.inpe.br

Abstract. The present study tries to identify the mechanism responsible for the hostility to star formation (SF) found in galaxies of dense environments. Among the several candidate mechanisms, the gas-rich merger of galaxies stands as a plausible option since the realisation that the AGN-feedback, which follows the merger, can deplete the gas and truncate the SF of the resulting spheroid. Our strategy is to look for traces of SF truncation in the elliptical galaxies of Hickson compact groups (HCGs), because these are the ideal environments for mergers to occur. The stellar populations of 22 elliptical galaxies in HCGs and 12 in the field are compared using three different SSP models and two different emission correction procedures. Along the study, an extensive use of the [Mg/Fe] abundance ratio is made, because it contains useful information on the timescale of the SF history of the galaxies. Systematic differences of [Mg/Fe] and [Z/H] between both galaxy subsamples (field and HCGs) suggest that SF truncation events have affected the intermediate-mass galaxies of the HCGs. Our interpretation is that when a field galaxy enters the dense HCG environment it merges with another galaxy and ends up as a passive elliptical with traces of SF truncation.

Keywords. Galaxies: elliptical and lenticular, evolution, interactions, stellar content

1. Introduction

The global decay of the star formation (SF) rate density since redshift 1-2 (e.g. Hopkins & Beacom (2006)) suggests that an unknown mechanism is quenching the SF in galaxies. In terms of the bimodal distribution of galaxies (e.g. Baldry *et al.* (2004)), this means that galaxies are systematically migrating from the blue sequence, where the SF is active to the red sequence, formed by passive galaxies without SF. Although the responsible mechanism is still unknown, there are some hints on its attributes. The mechanism must be fast in order to preserve the observed separation between the red and blue sequences. It must also involve AGN activity, as Mateus *et al.* (2006) show that the galaxies filling the gap between both color sequences are mainly AGN hosts. It acts in dense environments, although extreme densities are not needed, because Lewis *et al.* (2002) and Gómez *et al.* (2003) found that the SF truncation mechanism operates well beyond the virialized cluster cores, in the region where galaxy groups are infalling. Although there is no lack of candidate mechanisms, the majority of them do not match the mentioned attributes. Unexpectedly, the gas-rich galaxy mergers seem to exhibit the right profile for SF truncation, despite the well established belief that mergers are a source of SF enhancement. The hydrodynamical simulations of gas-rich galaxy mergers by Di Matteo *et al.* (2005), which take the feedback from supermassive black holes into account, show that the SF enhancement is just a transient phase of a longer process, which ends up depleting the gas and quenching both star formation and nuclear activity. A short time (~ 0.5 Gyr) after the merger event, the remnant has evolved to a dead spheroid. In order to check the merger-truncation link, we have searched for traces of SF truncation on galaxies located in the most favorable environments for mergers, i.e. the compact groups of galaxies, which combine high spatial densities with low velocity dispersions. In the present study, we compare the stellar populations of elliptical galaxies in HCGs with those of their counterparts in the field.

2. Observations and Reduction

Our sample consists of 34 early-type galaxies, 22 of them located in HCGs and the remainder in the field. Long-slit spectra were obtained at the KPNO 2.1 m telescope with the GoldCam CCD spectrometer, with an intermediate 4.25 Å FWHM spectral resolution and a median Signal-to-Noise Ratio of 55. Details about the sample and basic reduction were published in de la Rosa *et al.* (2001a). For the present study, $R_{eff}/8$ and $R_{eff}/2$ apertures were extracted.

In the present work we have tried to avoid the potential bias introduced by the stellar population models and reduction methods by using three alternative stellar population analyses. (i) A standard Lick-IDS approach, with the Single Stellar Population (SSP) models developed by Thomas *et al.* (2003), which include abundance ratio effects. (ii) A similar approach, which uses the SSP models based on synthetic stellar spectra published in Mendes de Oliveira *et al.* (2005) and (iii) the SSP models and the strategy proposed by Vazdekis (1999), which leaves the original spectral resolution of the data untouched.

We have also carried out a careful decontamination of the emission, by combining the results of two independent methods, one proposed by González (1993) and the other one by Caldwell *et al.* (2003).

Both the details of the stellar population analysis and of the results are extensively explained in de la Rosa *et al.* (2007).

3. Results

Our results for the stellar population parameters are an average of the individual values given by the three approaches, after they have been converted to a common frame. The chosen frame is that of Thomas *et al.* (2003) in order to make the comparison with the literature easier. Figure 1 shows the correlation of the age, metallicity and abundance ratio in $R_{eff}/8$ with $\log(\sigma_0)$, where σ_0 is a proxy for the galaxy mass. The behavior of elliptical galaxies in the FIELD (right-hand panels) is compared with their counterparts in Hickson Compact Groups (HCG) (left-hand panels). Data from the literature (open symbols) have been superimposed to assess our results. They were taken from Thomas *et al.* (2005) (T05), Trager *et al.* (2000) (T00) and Mendes de Oliveira *et al.* (2005) (MCGB05), previously converted to our same reference frame. Least-squares fits (dotted lines) for all the field galaxies are displayed in figures (b), (d) and (f) and repeated in the group galaxy panels (c) and (e). Dashed lines in figures (a) and (b) show the median value of our data, while panels (c) and (e) show the least-squares fit (dashed) to all the objects, excluding the galaxy HCG37e, with $\log\sigma_0$=1.93. The *anomalous* galaxies (see text below) are tagged with a circle and the average error bars of our data are plotted in the low-right corner of each panel. The following trends have been found in the results.

(i) *On average, galaxies in HCGs are 1.6 Gyrs older and more metal poor, in 0.11 dex, than their counterparts in the field.* Qualitatively similar results has been already

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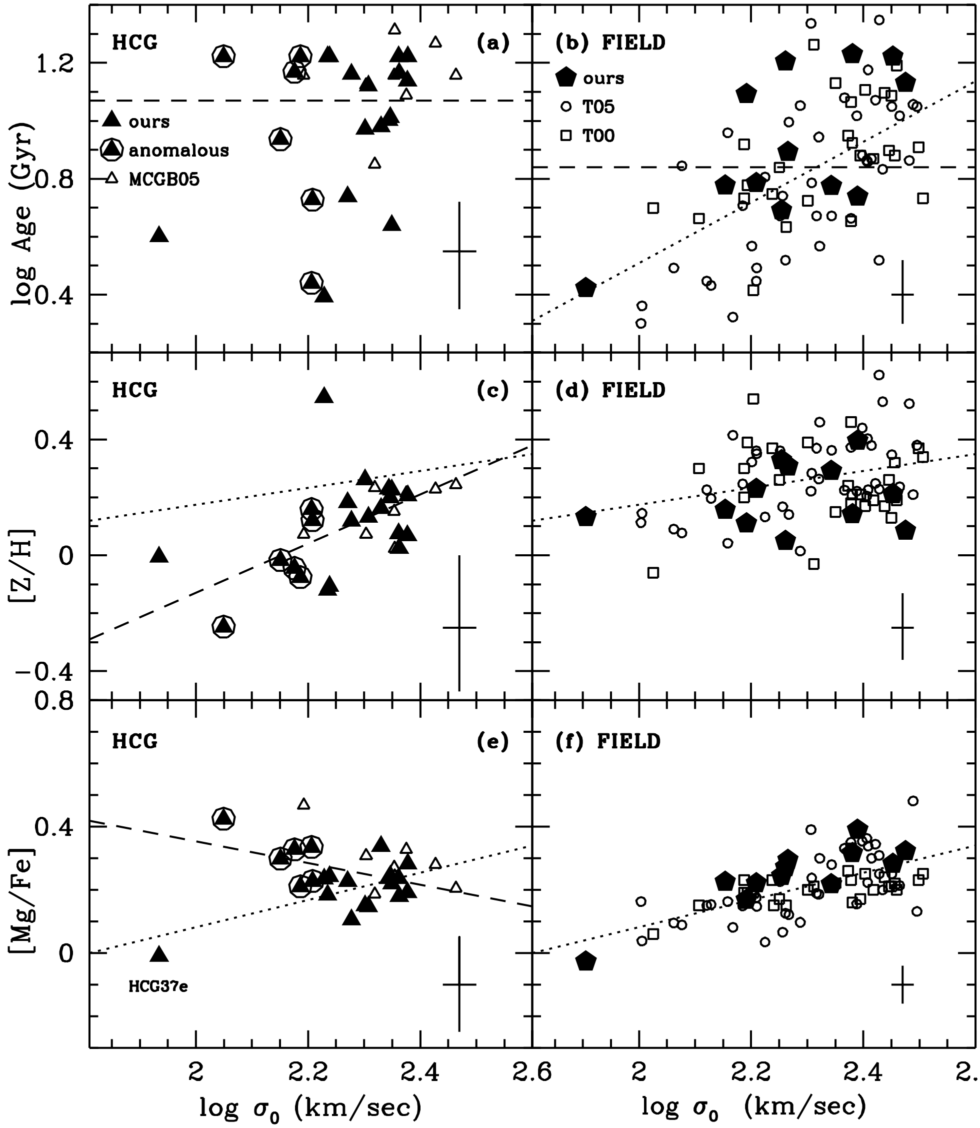

Figure 1. The correlation of the stellar population parameters: age, [Z/H] and [Mg/Fe] with log(σ_0) for galaxies in compact groups (left panels) and in the field (right panels). See text for details.

reported in the literature (de la Rosa *et al.* (2001b); Proctor *et al.* (2004); Mendes de Oliveira *et al.* (2005)).

(ii) *The [Mg/Fe] abundance ratio increases with log(σ_0) for the field galaxies.* In agreement with the literature, this result is interpreted as a *downsizing*, in which low-mass galaxies display more extended SF histories. The abundance ratio [Mg/Fe] is related to the SF history of the galaxies, because it depends on the relative importance of Type II and Type Ia supernovae, which show different timescales. Qualitatively, large [Mg/Fe] means a short SF history, while low [Mg/Fe] means an extended SF history.

(iii) *Low-mass galaxies in HCGs show an anomalous trend in [Mg/Fe] vs log* σ_0. This result, evident from Figure 1e, is a novel finding of this study. Encircled points represent the *anomalous* galaxies, which combine larger than average [Mg/Fe] with lower than average [Z/H] values. This anomaly refers only to their discrepancy with the corresponding field galaxies.

4. Discussion

The anomalous behaviour of the low-mass galaxies in HCGs is interpreted as a result of a *merger + SF truncation* process. Similar galaxies in the field, living an unperturbed and extended SF history, would see their [Mg/Fe] and [Z/H] parameters steadily converging to the solar values. On the contrary, galaxies whose SF history has been truncated would end up with an enhanced [Mg/Fe] and a depleted [Z/H], as observed in the *anomalous* galaxies of our HCG subsample. A plausible scenario is that gas-rich galaxies from the field, still in the middle of their extended SF history, merge with other galaxy after entering the dense compact group environment. Soon after the merge, the SF is truncated and the galaxy becomes *anomalous* in the sense of the present work. The massive galaxies would be exceptions to the SF truncation process, because, according to the downsizing, they have completed their SF by z $\approx$ 1 and nothing remains to be truncated after the merger.

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Discussion

KROUPA Is there evidence for supermassive black holes actually shutting-down star formation in HCGs?

DE LA ROSA I am not aware of any direct evidence, but the short timescale of the process probably prevents a direct observation of the phenomenon. However, indirect evidence is steadily accumulating. Our result, for instance, is a preliminary evidence that the process is acting in HCGs. Large-scale galactic winds have also been detected in active galaxies, suggesting AGN-feedback (see the review by Veilleux *et al.* 2005).

https://doi.org/10.1017/S1743921307008599 Published online by Cambridge University Press

Geisler Perhaps you might expect [Mg/Fe] to show a small increase during and just after the merger, when SFR is strongly increased and then subsequently show the decrease you observe.

de la Rosa I agree. There is an ambiguity that arises from the fact that we are not able to measure the SF history of the galaxy, but the luminosity-weighted properties of its stellar population. Both a truncated SF history and a short starburst would leave an enhanced [Mg/Fe]. Incidentally, the two phenomena take place during galaxy mergers and our interpretation stands unaltered.

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