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SOME EFFECTS OF THE LARGE-SCALE ENVIRONMENT ON THE STELLAR CONTENT AND ON THE INTERNAL DYNAMICS OF EARLY-TYPE GALAXIES

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Валери Голев, Деница Кирилова. НЯКОИ ЕФЕКТИ НА ЕДРОМАЩАБНОТО ОБКРЪЖЕНИЕ ВЪРХУ ЗВЕЗДНОТО СЪДЪРЖАНИЕ И ВЪТРЕШНАТА ДИНАМИКА НА ГАЛАКТИКИТЕ ОТ РАНЕН ТИП

Изследвана е зависимостта популация–плътност в слабо населено обкръжение, от бедни купове до изолирани галактики. Намираме, че галактиките от ранен тип с младо звездно население предпочитат обкръжение с най-ниска плътност. Анализирали сме връзката между остатъците към Фундаменталната равнина и плътността на обкръжението. Намираме, че "негативните отклонения" характеризиращи ниска металичност или наличието на младо звездно население, се асоциират с обкръжение с ниска плътност. Това може да отразява възможни вариации в историята на звездообразуването на галактиките от ранен тип, което е довело до различната им морфология.

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We have studied the population-density relation in very sparse environments, from poor clusters to isolated galaxies, and we find that early-type galaxies with a young stellar population are preferably found in the lowest density environments. We have analysed the relation between the residuals to the Fundamental Plane and the density of the environment. We found that "negative departures", characterizing a low metallicity or the presence of young stellar population, are preferentially associated with low-density environment. The residuals may reflect the possible variations in the star-forming history of the early-type galaxies under the circumstances of the different environment, leading to different morfology of these galaxies.

Keywords: galaxies: general – galaxies: elliptical and lenticular – galaxies: fundamental parameters – galaxies: star formation history

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1. INTRODUCTION

It is generally accepted that the rate of star formation in early-type galaxies is enhanced in low-density environments [1–4]. It results in a population – density relation: The metallic features in the spectra (e.g. Mg_2) are weaker and the Balmer lines stronger in low-density regions.

A recent analysis of the population-density relation in low-density environments (isolated galaxies to poor clusters) shows that the early-type galaxies which are likely to contain a young sub-population are mostly found in the sparsest environments [5]. The approach used to diagnostic this effect is to study the Mg_2–σ_0 and the Fundamental Plane (hereafter FP) relations. Indeed, although both relations are sensitive to the dynamics and to the stellar content, departures resulting from one or the other origin will have opposite signs. One the one hand, if a galaxy is found below the Mg_2–σ_0 relation, it may have either an unusually low velocity dispersion (see Fig. 1) or a high Mg_2 index (Fig. 2). On the other hand, a galaxy below the FP relation has either a low velocity dispersion or contains a young population.

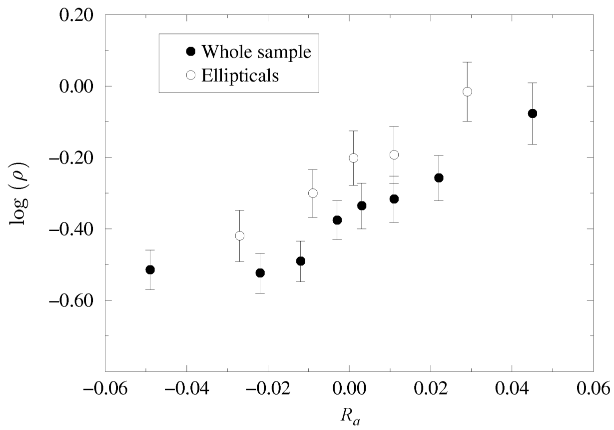

Fig. 1. Mean density of the environment ($\log \rho$) vs residuals of the Mg_2–σ_0 relation for the whole sample (filled symbols, 80 objects in a point) and *bona-fied* ellipticals only (open symbols, 40 objects in a point) The error bars are 1σ uncertainties

Our analysis of the residuals shows that the environment has primarily a visible effect on the stellar content (not on the dynamics).

2. DYNAMICAL EVOLUTION

It is not a surprise that an enhancement of the young population is detected: A relatively small fraction of young stars is sufficient to significantly modify the broad-band colors and the line strength indices.

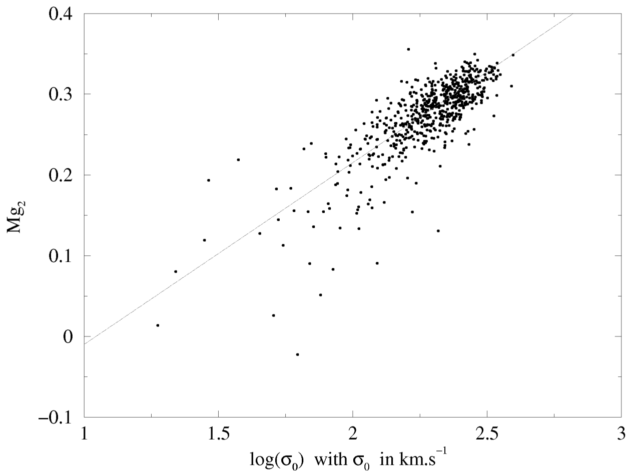

Fig. 2. The Mg_2–σ_0 diagram of our sample with the classical relation
$Mg_2 = 0.225 \log(\sigma_0) - 0.235$

However, the enhancement of the stellar formation should have a long term effect on the dynamics of the galaxies. This delayed star formation in early-type galaxies is mostly occurring in the central regions and hence modifies the mass balance in these galaxies.

Unfortunately, when we into account the stellar population effect as deduced from the residuals to the Mg_2–σ relation, no more environmental effect persist in the FP analysis. We cannot find any dynamical evolution with this analysis. However, the FP analysis mostly diagnoses the equilibrium status of the galaxies, and this long term evolution is not expected to significantly disturb the equilibrium. However, the FP analysis is also sensitive to the details of the dynamics and of the structure.

3. RESIDUALS TO THE FUNDAMENTAL PLANE

We performed a fit of the FP using the subsample of 291 *bona-fide* elliptical galaxies (17 galaxies were excluded from the 308 galaxies sample because of the lack of reliable photometry):

$$R_f = 2\log\sigma_0 + 0.2(1+2\beta)M_B + 0.2\mu_e + \eta. \tag{1}$$

Here R_f is the residual to the FP, σ_0 is the central velocity dispersion (in km sec^{-1}), M_B and μ_e are respectively the asymptotic magnitude and mean surface brightness within the effective aperture in the B band, β and η are the free parameters. Their best fit values are: $\beta = 0.20 \pm 0.02$, $\eta = -3.2 \pm 0.2$, similar to the values previously reported in [12].

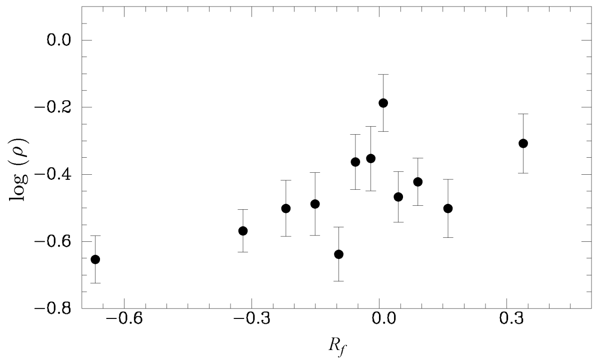

Fig 3. The main relative density of the environment $\log(\rho)$ plotted as a function of the residuals R_f to the Fundamental Plane. Each point corresponds to a bin of 40 galaxies, the error bars are the $1-\sigma$ uncertainty on the position of the points

Note that we fitted the classical FP, i.e., we did not include the additional terms accounting for the stellar population, the rotational support and the non-homology of the spatial structure (see [12]). Since we precisely want to use the residuals to the fundamental plane as a parameterisation of the stellar population, we did not include the first scaling relation in the FP equation. Including the two latter would have dramatically reduced the size of the sample and is not useful to the present goal.

In Fig. 3 we present the average of $\log(\rho)$ as a function of R_f. Each point on the figure represents 40 galaxies. There is a (somewhat marginal) tendency for the galaxies with the more negative residuals to be found in lower density environments.

Splitting the sample in two parts, we find for $R_f < -0.1$, $\log(\rho) = -0.35$ (154 galaxies), and for $R_f < -0.1$, $\log(\rho) = -0.19$ (264 galaxies). The uncertainty on the mean $\log(\rho)$ being about 0.06, the difference is significant at the 3 σ level.

Repeating this on arbitrary extracted subsamples of half the total size produce the same result. Therefore, we conclude that the trend is significant. Since there is no reason why the measurement errors could be connected with the environment, we conclude that the relation is physically significant.

Combining the results from the R_a and R_f analyses, we confirm the existence of a population segregation, and extend it to the low-density environments.

4. THE ORIGIN OF THE POPULATION SEGREGATION

Our result fits in the frame of the current paradigm suggesting a reduced rate of star formation in high density environments. The morphology-density relation, the HI deficiency of cluster spirals or the relative isolation of shell galaxies are classically interpreted as the result of past gravitational interactions which both stimulated the star formation earlier in the life of the galaxies and stripped the dense gas, prohibiting present-epoch star formation.

We will now try to extract the fraction of the population segregation due to recent merging or accretion of a gas-rich companion, which cannot be accounted for by the morphological segregation.

Apart the violent cases of star forming galaxies often associated with strong interactions or mergers, the "weak" interactions have also been related with the presence of a young stellar component. In particular, Schweizer & Seitzer [6] found clear correlations between the anomalies on the colors, Mg_2, $H\beta$ and CN, and the fine structure index Σ (indicating the amount of shells, ripples, boxiness, etc.). Gregg [7] showed that the Σ-index is also correlated with the residuals to the FP (*peculiar velocities* in his terminology). To summarize, the presence of a "young" sub-population is clearly associated with merging events or gravitational encounters. Hence, this population effect is expected to depend on the environment.

Indeed, Guzmán et al. [2] found a difference between the galaxies located in the outer and inner regions of the Coma cluster. The former have negative residuals (i.e. they are younger or less metallic). It was found a difference between the Coma and Virgo clusters, but this could also be an observational effect due to the difference in the projected slit sizes. Recently Jørgensen & Jønch-Sørensen [8] showed that the colors and the absorption-line indices of E and S0 galaxies belonging to the poor cluster S 639 indicate that the stellar populations in these galaxies are probably younger (or less metallic) than those in rich clusters. This is in agreement with the results by De Carvalho & Djorgovski [1] and Bernardi et al. [4].

It is important to note that these previous works searched for mean-age differences as a function of the environment. For instance, Bernardi et al. [4] found a zero-point difference on the Mg_2–σ_0 relation of $\delta(Mg_2) = 0.007$ between cluster and field ellipticals, compatible with our comparison between the high- and low-density subsamples. Assuming a single-burst population model [9], this corresponds to an age difference of $\sim$ 1 Gyr.

In the present work, we found a much stronger difference when grouping the galaxies according the R_a or R_f residuals. The galaxies containing a younger stellar population are clearly found in lowest-density environment, but, in any environment, the majority of the early-type galaxies have only an old population. The rare galaxies containing young stars form the tail of negative residuals. This same skewness is also apparent in the distribution of the color-magnitude diagrams. It is also reminiscent of the population of blue galaxies in clusters (Butcher-Oemler effect). If we compare the median of R_a, less sensitive to the skewness, instead of the average, the difference between the high- and low-density subsamples vanishs.

We also tried to connect the residuals with the small-scale density of the environment by weighting the galaxies according to their separation on the sky when computing the density, with the scope of defining a "strength of the tidal field". We experimented different weightings, but failed to find evidence for an effect related with the "tidal" field. Only the large scale environment correlates with the stellar content. The population segregation may still be contaminated by the morphological segregation. For example, Kuntschner & Davies [10] and Mehlert et al. [11] find the ellipticals to be coeval in Coma and Fornax, and detect the presence of residual star formation in lenticulars only.

5. SUBTRACTING THE MORPHOLOGICAL SEGREGATION

If the morphological segregation results from the morphological segregation, R_a should also correlate with any other parameter dependent on the morphological type. Such parameter could be the signature of a disk, as detected from image analysis or from the rotational support ($V_{\max}/\sigma_0$, where $V_{\max}$ is the observed maximum rotational velocity). Both of these parameters are affected by projection effects and are available only for a restricted subsample. We will use $V_{\max}/\sigma_0$, taken from HYPERLEDA.

In our sample, $V_{\max}/\sigma_0$ is available for 272 galaxies: 157 ellipticals and 115 lenticulars, the mean values are respectively: $< V_{\max}/\sigma_0 >= 0.27 \pm 0.02$ and 0.43 ± 0.04 (The corresponding mean $\log(\rho)$ are: -0.46 ± 0.04 and -0.50 ± 0.04). The difference is clear and shows that $V_{\max}/\sigma_0$ is fairly correlated with the morphology, but the morphology-density relation is here very marginal.

Because of the smaller statistics the $\log(\rho)$–R_a correlation is much noisier than in Fig. 1, but the effect is still marginally observed in the subsample: The mean $\log(\rho)$ for $R_a < 0$ is -0.50 ± 0.03 (162 galaxies) and -0.44 ± 0.04 for $R_a \geq 0$ (114 galaxies). The corresponding mean $V_{\max}/\sigma_0$ are: 0.328 ± 0.023 and 0.288 ± 0.025. The difference is marginally significant 0.040 ± 0.035

The $V_{\max}/\sigma_0$–$\log(\rho)$ correlation represents the morphology–density relation and it is fitted as $\log(\rho) \approx -0.25 V_{\max}/\sigma_0$. It predicts a difference in $\log(\rho)$ between the two subsamples ($R_a < 0$ and $R_a > 0$) of 0.010 ± 0.015. This is about 1/4 of the observed effect. However, taking into account the large uncertainties, it is not possible to reject the possibility that the totality of the stellar population segregation may be due to the morphology–density relation.

Repeating the analysis on R_f reproduces the dynamical effect found by Prugniel & Simien [12] and does not help to understand the origin of the population segregation.

6. CONCLUSIONS

Analyzing the residuals to the Mg_2–σ_0 and FP relations as a function of the large scale density of the environment, we find a segregation of the stellar population. The early-type galaxies with a line-strength index Mg_2 weaker than expected from their value of σ_0 are preferentially found in low-density regions. These galaxies are likely to contain an excess of young stars, presumably formed after a gravitational encounter or merging event that occurred in the last few Gys.

However, we cannot rule out that this effect is a by-product of the morphological segregation. Indeed, our sample of bona-fide ellipticals may still be contaminated by some lenticular galaxies seen almost face-on or with a weak disk, and the observed segregation could be due to residual star formation in these galaxies expected to be found mostly in low-density regions.

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