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THE NATURE OF DWARF ELLIPTICAL GALAXIES: AN OBSERVING PROJECT FOR OSIRIS

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RESUMEN

Aunque las galaxias elípticas enanas constituyen la población de galaxias dominante en cúmulos cercanos, su origen y naturaleza son aún un misterio. El objetivo principal de este proyecto es comparar las propiedades dinámicas y las historias de la formación estelar de una muestra de elípticas enanas en el cúmulo de Virgo con las de las galaxias elípticas clásicas. En particular, la espectroscopía profunda con rendija larga que se obtendrá con OSIRIS permitirá: i) medir hasta qué grado estos esferoides están soportados por rotación para comprobar si pueden representar una extensión de las elípticas clásicas hacia luminosidades más bajas, y ii) analizar sus gradientes de poblaciones estelares en términos de gradientes en edad promedio, metalicidad, función inicial de masas e historia de la formación estelar. Estos datos nos suministrarán importantes pistas para comprobar si las galaxias elípticas enanas pueden ser miembros primordiales de los cúmulos o si, por el contrario, son el resultado de efectos de interacción con el medio.

ABSTRACT

Although dwarf elliptical galaxies are the dominant galaxy population in nearby clusters, their origin and nature remain a mystery. The main aim of this project is to compare the dynamical properties and star formation histories of a sample of dwarf ellipticals in the Virgo cluster with those of the classical elliptical galaxies. In particular, deep long slit spectroscopic data to be obtained with OSIRIS will allow us to: i) measure the degree at which these spheroids are rotationally supported to check if they could represent the low luminosity extension of the classical ellipticals; and ii) analyze their stellar populations gradients in terms of mean age, metallicity, initial mass function, and star formation histories. These data will provide important clues to understanding whether the dwarf ellipticals are primordial cluster members or, on the contrary, whether they are the result of environmental effects.

Key Words: **GALAXIES: DWARF — GALAXIES: ELLIPTICAL AND LENTICULAR, CD — GALAXIES: KINEMATICS AND DYNAMICS — GALAXIES: EVOLUTION**

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1. INTRODUCTION

Dwarf early-type galaxies constitute the dominant galaxy population in nearby clusters and are the most common galaxies in the local Universe. Furthermore, in the hierarchical models scenario, dwarfs are thought to be the building blocks of more massive galaxies. Even though dwarf galaxies may hold the key to our understanding of the processes involved in the formation and evolution of galaxies, their origin and true nature remain a mystery.

The main question in the debate about the nature of dwarf elliptical galaxies (dEs) is whether they represent the extension of the "classical" ellipticals (Es) to lower luminosities, or, on the contrary, whether they are completely different objects, being the result of distinct formation and evolution processes. Early observational work clearly implied a dichotomy in the structural properties of both kinds of galaxy families: i) dEs and Es follow opposite trends in the absolute magnitude versus central surface brightness plane (Kormendy 1985), and ii) dEs exhibit exponential luminosity profiles (Binggeli & Cameron 1991), in contrast with the $r^{1/4}$ de Vaucouleurs law followed by Es. However, this dichotomy contrasts with the remarkable similarity in some global properties of their stellar populations. In particular, the color–magnitude relation, as well as the correlation between the Mg_2 index and velocity dispersion, is apparently universal for both galaxy families (Caldwell 1983; Bender et al. 1993). More recently, Binggeli & Jerjen (1998) have shown the apparent structural differences, which were the crux of the dichotomy between the two galaxy types, tp disappear completely when a Sersic law, $\mu(r) = \mu_0 + C\log(r/r_0)^n$, is used to fit the luminosity profiles of Es and dEs. They

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noted that, when excluding the more central regions, dEs and classical Es follow a sequence in which the shape parameter, n, and central surface brightness, μ_0, change smoothly with absolute magnitude (see also Durrell 1997). These results have reanimated the open question of whether dwarf and classical ellipticals may share a common origin.

Most of the previous work in this field has aimed to understand the origin of the dominant dE population in clusters of galaxies. Basically, there are two main competing scenarios. In the first, dEs would be genuinely old primordial galaxies formed early in the protocluster formation (e.g., White & Frenk 1991). In the second, dEs evolve from spirals accreted into the cluster via stripping and "harassment" processes (e.g., Moore et al. 1998). In order to discriminate between these two scenarios, previous workers have mainly concentrated on comparing the flattening distributions (e.g., Ryden & Terndrup 1994) and clustering properties (e.g., Conselice et al. 2001) of classical Es and dEs. Two critical issues, not fully exploited so far, that should provide important clues are the search for possible dichotomies in the rotational properties and the stellar populations.

2. ROTATIONAL PROPERTIES

From the work of Davies et al. (1983), it is well known that low luminosity E galaxies, in contrast to giant Es, are supported by rotation. If dEs were the extension to even lower luminosities of the classical Es, one should expect to find relatively high rotational velocities along the major axis of these objects. The observational data in this subject require high signal-to-noise spectra at faint levels of surface brightnesses and are therefore very scarce. Until recently, rotation curves had only been measured for six dEs: two dwarfs in Virgo (VCC 351 and IC 794, Bender & Nieto 1990), the three dwarfs companions of M31 (e.g., Bender et al. 1991) and the Fornax dE (Mateo et al. 1991). In all these cases, dEs were found to rotate too slowly to be consistent with an oblate isotropic body flattened by rotation. Very recently, new data have been added to these sparse statistics. On the one hand, Geha et al. (2001) have presented kinematical data for a sample of four Virgo dEs (based on Keck spectroscopy) and find that, in agreement with the previous results, they are slow rotators. On the other hand, using the VLT, De Ricke et al. (2001) have obtained deep spectroscopic data of the dE FS76 and shows that the galaxy is rotating as fast as predicted by the isotropic models. We have also obtained new kinematical data for six Virgo dwarfs (four dEs and two dS0s, Pedraz et al. 2002). The main results, which are presented in Figure 1 together with those of previous studies, clearly show that rotation in dEs is not rare (three out of the four dEs are fast rotators). To add further support to this result we must note that one of our galaxies (IC 794, the one with $\varepsilon = 0.24$) is also in the samples of Bender & Nieto (1990) and Geha et al. (2001), and that the agreement between the three measurements is excellent. Concerning interpretation, these results could be compatible with the diversity of rotational properties predicted by the harassment scenario of Moore et al. (1998). However, more data are clearly needed to understand the driving parameters governing the dynamical properties of dEs, as well as the possible correlation of rotation with luminosity profiles, core properties (nucleated versus non-nucleated), and stellar populations.

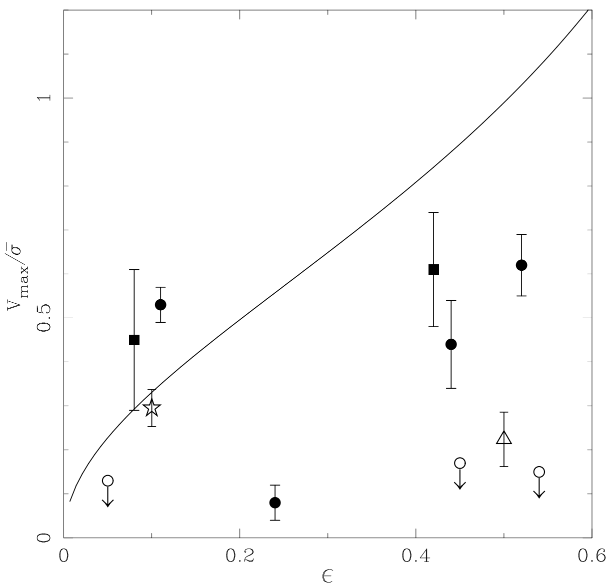

Fig. 1. The ratio of the maximum rotational velocity to mean velocity dispersion for a sample of dwarf early-type galaxies. Filled points are the new data from Pedraz et al. (2002) (circles: dEs; squares: dS0s). Open circles, the triangle and the star show respectively data from Geha et al. (2001), Bender & Nieto (1990), and De Ricke et al. (2001). The solid line represents the prediction for oblate galaxies flattened by rotation (Binney 1978).

3. STELLAR POPULATIONS

The study of stellar populations is of vital importance to discriminating between the different formation and evolution models for dEs. If cluster dEs were primordial cluster members, they should be roughly coeval and old. On the other hand, if they were formed by other processes, such as harassment of accreted spirals, they should exhibit a significant range of mean ages with traces of significant intermediate or young stellar populations. Previous studies devoted to comparing the stellar populations of dE and E galaxies are very scarce and have led to ambiguous results so far. Although photometric studies (Caldwell 1983; Rakos et al. 2001) have provided some evidence of intermediate stellar populations, the results are uncertain because of the difficulty of breaking the age–metallicity degeneracy. Spectroscopic studies so far have been limited to very small samples or are affected by large observational errors. Thus, although some of them have found traces of younger-looking stellar populations as compared to Es (Held & Mould 1994), the general trend is for dEs to follow the galactic globular cluster locus in the color–line strength diagrams, but with a large scatter (Brodie & Huchra 1991; Held & Mould 1994). In Gorgas et al. (1997) we presented deep spectroscopic data for six Virgo dwarfs. Although we found evidence of a dichotomy between the stellar populations of dEs and Es (dEs exhibit solar abundance [Mg/Fe] ratios, substantially lower metallicities, a range of mean ages, and shallower Mg_2 gradients), the conclusions about differences in the star formation histories were unclear. Recently, Drinkwater et al. (2001) have presented a spectroscopic survey of dEs in the Fornax cluster in which they detect a population of star forming dwarfs in the outer cluster region, in agreement with Rakos et al. (2001) and the qualitative predictions of the harassment scenario. Also, Poggianti et al. (2001) have included a large number of dEs in their spectroscopic survey of the Coma cluster. Except for a possible trend towards lower ages and metallicities for the faintest galaxies, the observational random errors for the dEs are so large that it is difficult to extract any conclusion about their stellar populations. Finally, in Figure 2 we show our own measurements of line strength indices in the central regions of a sample of Virgo dEs (see also Pedraz et al. 2001). The observations were performed at the 4.2 m William Herschel Telescope with the WYFFOS spectrograph. The error bars are again too large to extract reliable conclusions about their stellar populations, even in the central regions.

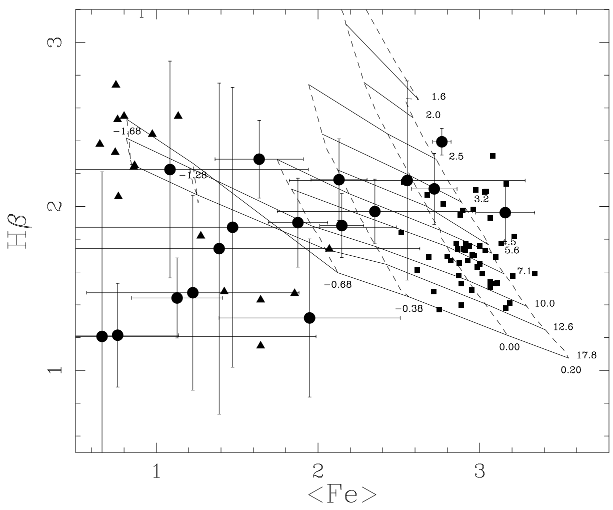

Fig. 2. Hβ–⟨Fe⟩ diagram for galactic globular clusters (triangles), classical E galaxies (squares) and dEs (circles) from Pedraz et al. (2001). Predictions from the single-burst stellar population models of Vazdekis (1999) are shown as dashed lines (for fixed metallicities) and solid lines (for fixed ages).

4. THE PROJECT

In the previous sections, we have shown that, because of the observational challenges involved in obtaining high signal-to-noise (S/N) spectra at the faint surface brightness levels outside the nuclei of dEs, the basic data needed to investigate the nature of dwarf ellipticals are simply missing. Although previous studies have tried to untangle their dynamical and evolutionary status, we remain with conjectures. Very relevant aspects, such as the possible differences between nucleated dEs, non-nucleated dEs, and dS0s have not been addressed. The possible existence of a dichotomy within the dE family (Ryden et al. 1999), similar to that found for the Es (in isophote shapes, rotation, core properties, and stellar populations) needs also to be investigated. The importance of not restricting the studies to the central regions of the dEs (the only targets of most previous studies) needs to be emphasized. The core regions can be affected by particular processes, and their properties do not represent those of the galaxies as a whole. In contrast, the gradients in stellar populations and velocity dispersions, together with the rotation curves, are crucial discriminants of galaxy formation scenarios.

The overall objective of this project, then, is to obtain high signal-to-noise spectra along the radius of a selected sample of dEs to investigate their kinematical and stellar population properties. In particular:

1. We will measure velocity dispersion profiles and rotation curves along the major and minor axes of a well-selected sample of dEs in the Virgo cluster. Note that we need the information

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along the minor axis to get a full dynamical description of the objects. The aim is to obtain high signal-to-noise (S/N per Å ≥ 20) spectra out to galactocentric distances of at least 1 effective radius ($r_{\rm eff}$). Excluding the faintest Virgo dEs, this corresponds to surface brightnesses of, typically, $23 \leq \mu_B \leq 24$ mag arcsec^{-2} (only a 10 m class telescope is able to reach these values with the required S/N). To optimize the observing time, this analysis will be performed in the near-IR (Ca II triplet region) spectral range. The dynamical properties will be compared with those of classical low luminosity ellipticals and the predictions of galaxy formation scenarios. A key objective is to search for correlations between dynamics and core properties (nucleated versus non-nucleated), isophotal shapes (boxy versus disky), luminosity profiles (shape parameter), and stellar populations.

2. We will obtain line strength gradients out to the outer regions of the dE sample. Apart from kinematical purposes, the observations in the red spectral range will allow us to measure gradients in near-infrared spectral features like the Ca II triplet. Recently, we have completed a calibration of the Ca triplet using a new stellar library (Cenarro et al. 2001). In Vazdekis et al. (2002), we show that this feature is especially sensitive to the slope of the initial mass function and therefore can put important constraints on stellar population models. We will also obtain deeper, but lower resolution, spectroscopic data along the major axes in the blue spectral range. This will allow us to measure very deep gradients in the most relevant absorption features around $\lambda\lambda$ 3400–6000 Å, including the λ 4000 Å break, the Balmer lines, and several Fe and α-elements features. We have just completed a much-improved stellar library in the $\lambda\lambda$ 3500–7500 Å spectral range (about 1000 stars at 2 Å resolution with an excellent coverage of the stellar parameter space). This library will allow us to construct a new generation of spectral synthesis models that will permit an accurate interpretation of the spectroscopic data in the age–metallicity-IMF space. Furthermore, the simultaneous use of several age indicators (like the 4000 Å break and the Balmer indices) can help to discriminate between different star formation histories (Sánchez-Blázquez et al. 2001), thus providing important clues to understanding the nature of dEs and their relationship to classical E galaxies.

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