Highlights of Spanish Astrophysics VI, Proceedings of the IX Scientific Meeting of the Spanish Astronomical Society held on September 13 - 17, 2010, in Madrid, Spain. M. R. Zapatero Osorio et al. (eds.)

The kinematic properties of dwarf early-type galaxies in the Virgo cluster

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Abstract

We present new medium resolution kinematic data for a sample of 21 dwarf early-type galaxies (dEs) mainly in the Virgo cluster. These data are used to study the origin of dEs inhabiting clusters. Within them we detect two populations: half of the sample (52 %) are rotationally supported and the other half are pressure supported. We also find that the rotationally supported dEs are located in the outer parts of the cluster, present disky morphological shapes and are younger than those pressure supported that are concentrated in the core of the cluster without any underlying structures. Our analysis reveals that the rotationally supported objects have rotation curves similarly shaped to those of star forming galaxies of similar luminosities and follow the Tully-Fisher relation. This is expected if dEs are the descendant of low luminosity star forming systems which recently entered the cluster and lost their gas due to a ram pressure stripping event, quenching their star formation activity and transforming them into quiescent systems, but conserving their angular momentum.

1 Introduction

Two scenarios are nowadays in debate to explain the formation and evolution of galaxies: *the monolithic collapse*, where spheroids formed at very early epochs from a rapid gas collapse followed by a strong starburst that passively evolved to the present, and *the hierarchical scenario*, where the most massive galaxies formed from a subsequent merging of smaller structures. A way of quantifying the relative role of these different mechanisms is to study dwarf galaxies, the most numerous objects in the universe [13]. Among those, dEs are the dominant galaxy population in high density regions such as clusters. Their low mass and large number make them ideal probes of those mechanisms through which a cluster environment can alter the appearance of galaxies. If ΛCDM models predict dEs as the descendants of the cosmological building blocks, observations of nearby clusters favour the scenario where dEs formed after gas removal of late-type galaxies recently entering high density environments that quenched their star formation activity.

Several works have shown that the dE population is more complex and heterogeneous than originally thought ([16, 18, 19, 20, 21]). These evidences indicate a complex formation process shaping the evolution of dEs in clusters. The study of their kinematic properties is a powerful tool to unravel their origin.

2 Observations and data reduction

The observed sample consists of 18 dEs in the Virgo cluster and 3 in the field in the magnitude range $-17.5 > M_B > -15.5$. It was selected from the Virgo Cluster Catalog (VCC [3]) requiring to have SDSS photometry and to be within GALEX pointings (see details in [25]). The observations were carried out at WHT(4.2 m) and INT(2.5 m) at Roque de los Muchachos Observatory (La Palma). We obtained long-slit spectroscopy (3445–8950 Å) along the major axis of the dEs reaching, with $2''$ slit-width in 1 hour integration per object, a spectral resolution of $\sim$ 45 km s^{-1} (FWHM). The reduction, done using standard procedures for long-slit spectra, used R$_{\rm E}$D$^{\rm uc}_{\rm m}$E [8], a package specially focused on the parallel treatment of errors. Details on the observations and analysis are presented in [25].

3 Results

Given the radial decrease of the galaxy surface brightness, not all the galaxies reached a plateau on their rotation curves. To be cautious, for those galaxies where the $v_{\max}$ (maximum rotation) is measured at a radius $< 6''$, the value is considered as a lower limit (indicated with an arrow in all the Figures). Figure 1 (see also [24]) shows the anisotropy diagram where $v_{\max}/\sigma$ is the ratio between the maximum rotational velocity and the central velocity dispersion of the galaxies. The C_4 parameter, that quantifies how different the isophotes are from a perfect ellipse ($C_4 > 0$ means disky isophotes, $C_4 < 0$ boxy isophotes [17]), agrees with [18] morphological classification (except for VCC917).

Figure 1, where rotationally supported galaxies (above the solid line) are separated from pressure dominated ones, shows that: 1) as ellipticals, dEs can be separated into slow ($v_{\max}/\sigma$ <0.1) and fast ($v_{\max}/\sigma$ >0.1) rotators [12]; 2) a large fraction (52 %) of the dEs are rotationally supported, and 3) all rotationally supported galaxies have morphological and/or photometric signs of a spiral origin.

The apparent discordance with [14], who found that the majority of the dEs are not rotating, is due to the fact that their data are limited to the core of the galaxies, never reaching radii larger than $6''$, where the increase of the rotational velocity is generally observed [24].

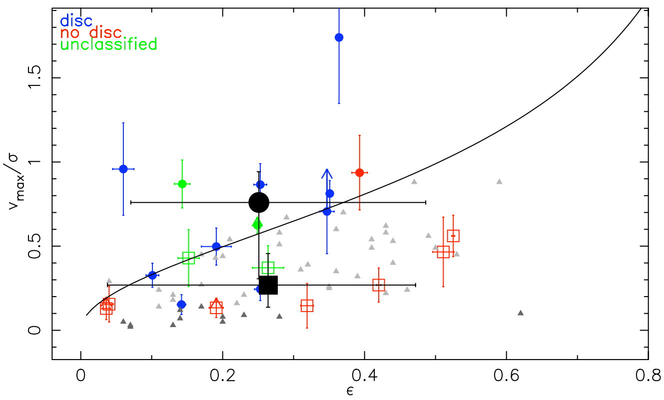

Figure 1: Anisotropy diagram. The model for an isotropic oblate system flattened by rotation ([4], black line). Triangles are giant ellipticals (from [12]): slow rotators ($v_{\max}/\sigma < 0.1$) in dark grey and fast rotators ($v_{\max}/\sigma > 0.1$) in light grey. Blue, red and green symbols show our sample of dEs as classified by [18] into disk, no disk and not in their sample respectively. The filled dots and the open squares indicate galaxies with and without disks on the basis of C_4. Lower limits on $v_{\max}$ are indicated with arrows. The black symbols represent the median for dEs with (dot)/without disk (square) based on C_4 classification.

The left panel of Fig. 2 shows $(v_{\max}/\sigma)^* = (v_{\max}/\sigma)/\sqrt{\epsilon/(1-\epsilon)}$, the anisotropic parameter corrected for inclination, as a function of the Virgocentric distance. It shows that rotationally supported systems are generally located in the cluster outskirts or in the field, while the pressure supported dwarfs are found only in the central regions of the cluster. This idea has been suggested before [14, 26], but no clear confirmation was found. Our observations reach distances further away from M87 and the evidence for a trend is now clear. We emphasize, however, that any relation with the clustercentric distance is smeared out by projection effects.

The right panel of Fig. 2 presents the anisotropic parameter vs. the ages from [22]. It shows that dEs with disks are ~ 3 Gyr younger than the others and while dEs with no signs of a spiral origin might be of all ages but on average old (5/8 of the squares are older than 7 Gyr), disk galaxies are preferentially young (9/12 of the dots are younger than 7 Gyr), suggesting that the two populations might have a different origin.

Catinella et al. [9] made a systematic study of the shape of the rotation curves of late-type spiral galaxies as a function of luminosity. They fitted the rotation curves following the Polyex model which is an analytical function that depends on 3 parameters: V_0, $r_{\rm PE}$ and α, the amplitude, the exponential scale of the inner region and the slope of the outer part of the rotation curve, respectively. The mean fitted rotation curves from [9] are normalised

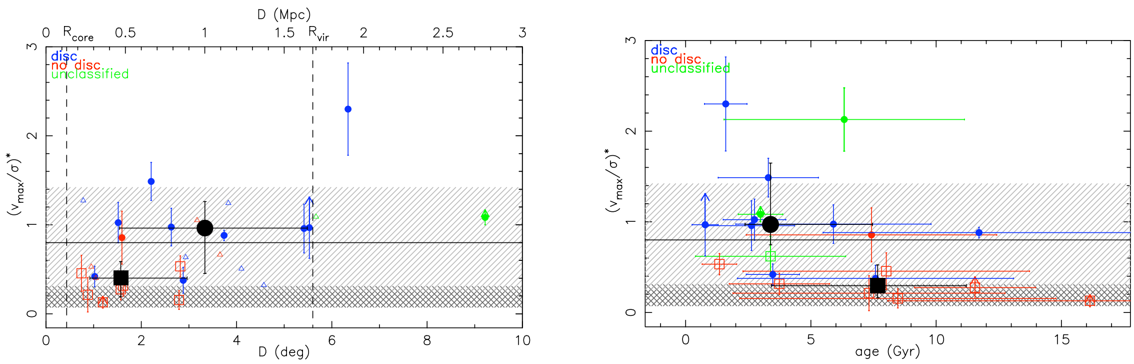

Figure 2: Anisotropy parameter vs. the angular distance to M87 (centre of Virgo) in the left and vs. the age in the right. The symbols are as in Fig. 1. The light and dark grey rectangles limit the regions for fast and slow rotating Es [12]. The solid line ($(v_{\rm max}/\sigma)^* = 0.8$) divides the diagrams into rotationally and pressure supported galaxies. In the left panel the open triangles are from [26]. In the right panel the ages are from [22].

to the optical radius ($R_{\rm opt}$, radius containing 83% of the total I-band luminosity), and the velocities are corrected from inclination using $\cos^2 i = ((1-\epsilon)^2 - q_0^2)/(1-q_0^2)$ [15], where i is the inclination, ϵ is the ellipticity and $q_0 = 0.3$, a conservative value for dwarf galaxies shaped as thick disks (see [25]). To reach the dwarf regime in the fitted rotation curves by [9] we have extrapolated linearly the three Polyex parameters to $M_I = -18.49$, the mean I-band magnitude of the dEs here analysed.

Figure 3 shows that the rotation curves of star forming and quiescent systems are surprisingly similar despite the fact that the former are gas rich systems while the latter do not show any gaseous contribution (left panel). If the rotationally supported dEs have the same shape of the rotation curves as the low luminosity late-type spirals, they should also follow the Tully-Fisher relation shown in the right panel of Fig. 3, in particular considering that the rotation velocity is probably underestimated.

4 Discussion and conclusions

The strong morphological segregation observed in high density environments [23, 13, 5] indicates that the cluster environment plays a major role in the formation of dEs. Figures 1 and 2 indicate that dEs can be divided into rotationally and pressure supported systems. They show that the rotationally supported dEs, characterised by a disky structure, are preferentially located in the field and in the periphery of the cluster, while the pressure supported systems, without disky underlying structures, are closer to the center. They also indicate that rotationally supported dEs have, on average, younger stellar populations than pressure

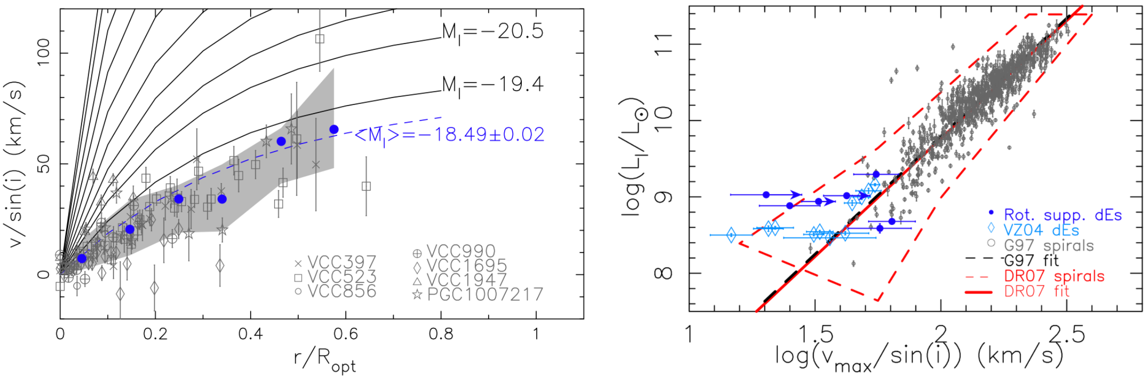

Figure 3: *Left:* Observed rotation curves of rotationally supported dEs (grey symbols) in comparison to the fitted rotation curves of late-type spiral galaxies (black solid and blue dashed lines) from [9]. Blue dots represent the median of our rotationally supported dEs and the grey area indicates the 1σ deviation. *Right:* Tully-Fisher relation for our rotationally supported dEs (in dark blue) compared to the data on dEs by [26] (in light blue) and on normal spirals by [15] (in grey) and [11] (DR07, in red).

supported dEs. Figure 3 indicates that the rotationally supported population have the same shape of the rotation curve observed in low luminosity late-type spiral systems and follow the Tully-Fisher relation, the most representative scaling relation for spiral galaxies. Since the angular momentum of these objects is conserved, the most plausible scenario for gas stripping is the ram pressure exerted by the dense and hot inter-galactic medium (IGM) on the fragile inter-stellar medium of the low luminosity star forming galaxies freshly entering the cluster environment (see [6, 7]).

For these rotationally supported objects gravitational interactions with the cluster potential or with other cluster members (galaxy harassment) can be excluded since they would, on relatively short time scales, reduce the angular momentum of the perturbed galaxies, leading to the formation of pressure supported systems. This process, however, could still be invoked to explain the kinematic and structural properties of the remaining pressure supported dEs populating the core of the cluster (half of our sample). Indeed the properties observed in these pressure dominated objects can also be explained if they were star forming systems that entered into the cluster in early epochs, maybe through the accretion of groups where preprocessing was active, and later modified by galaxy harassment. Another possibility is to be star forming systems that entered into the cluster several Gyr ago, where ram pressure, although less efficient than today because of the lower density of the IGM and of the smaller velocity dispersion of the cluster still in formation, had the time through multiple cluster crossing to remove the gas and stop the star formation activity. This pressure supported systems are also consistent with an in situ formation, through the isotropic collapse of the gas at early epochs. In this scenario pressure supported systems would be the low luminosity extension of Es, with the exception that they probably did not undergo major merging events [10].

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