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A photometric study of early-type dwarf galaxies in the Virgo cluster

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ABSTRACT

A photometric study is carried out for a sample of early-type dwarf galaxies in the Virgo cluster. These include dwarf elliptical galaxies (dEs), nucleated dwarf elliptical galaxies (dE(N)s), and dwarf lenticular galaxies (dS0s). The study was achieved by means of the color-magnitude relations (CMRs) in various photometric passbands. The CMR slope and scatter of dEs and dE(N)s are found to be very similar, indicating that they have similar origins. However, the CMRs of dS0s are found to be steeper and tighter than those of dEs and dE(N)s, which suggest different stellar populations for dS0s, with the existence of star formation activity.

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دراسة فوتومترية للمجرات القزمة القديمة في عنقود العذراء

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الكلمات المفتاحية:

عنقود العذراء ،
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القياس الضوئي .

الـــخُـــلاصـــة

يتم اجراء دراسة فوتومترية لعينة من المجرات القزمة القديمة في عنقود العذراء . وهذه تشمل مجرات بيضوية قزمة ومجرات بيضوية قزمة ذات نوى ومجرات عدسية قزمة . أجريت الدراسة باستخدام علاقات اللون - القدر عند حزم فوتومترية مختلفة . يظهر أن الميل ومقدار التشتت لهذه العلاقات متشابهة جدا بالنسبة للمجرات البيضوية القزمة والمجرات البيضوية القزمة ذات النوى ، مما يشير الى أن لهذين النوعين أصولا مماثلة . أما بالنسبة للمجرات العدسية القزمة فيظهر أن هذه العلاقات أشد انحدارا وأقل تشتتا مما في النوعين السابقين ، وهذا يدل على وجود تعدادات نجمية مختلفة في هذه المجرات، وأنها تتميز بوجود نشاط في تكوين النجوم.

1. Introduction

Dwarf galaxies may be defined as those galaxies that have absolute magnitudes $M_B > -18$ mag. They are the most numerous objects in the nearby universe [1]. Their study is very important for establishing models of galaxy formation and evolution. They are classified into two main types: early-type dwarfs and late-type ones. The first includes dwarf elliptical galaxies (dEs) and dwarf lenticular ones (dS0s); the second includes dwarf irregular galaxies and blue compact dwarfs [2]. Among all types of these galaxies, dEs have the dominant population in the nearby universe [3]. These dEs, together with dS0s, are mainly found in clusters of galaxies. Some dwarf elliptical galaxies have central nuclei of excess luminosities with stellar appearances. These nucleated dwarf elliptical galaxies, dE(N)s, are the most bright early-type dwarfs ($M_B > -16$ mag). They are commonly found in cluster centers as they prefer regions of high density [4].

The Virgo cluster of galaxies includes a large number of dwarfs [5]. Its proximity and richness make it very suitable for studying these types of galaxies due to their low surface brightness. In 1985, Binggeli, Sandage, and Tammann published the Virgo Cluster Catalog (VCC), which included 2096 galaxies, distributed within an area of about one cluster virial radius (1.72 Mpc) [3]. In this catalog, dEs are the most abundant type of galaxies. They are characterized by smooth intensity distribution and low surface brightness and, due to this latter feature; it is hardly observed and distinguished from dS0s.

Photometric studies of dwarf galaxies are very important due to their faint luminosities which make spectroscopic studies hard to achieve. One of the most fundamental photometric properties of early-type galaxies is the color-magnitude relation (CMR), in which brighter galaxies become redder. This was first observed for field elliptical galaxies by Baum in 1959 [6], and then in clusters by others [7], [8], [9]. This property is usually explained by metallicity, where brighter (more massive) galaxies have higher metallicities, and, hence, are redder.

2. Sample and Method

Our sample galaxies are taken from the Extended Virgo Cluster Catalog (EVCC) which contains 1589 galaxies distributed within an area of 60.1 Mpc^2, reaching out to 3.5 times the virial radius of the Virgo cluster [10]. This catalog includes basic information such as membership, morphology, and, also, photometric data, based on the Sloan Digital Sky Survey (SDSS) Data Release 7.

The sample consists of 147 dEs, 260 dE(N)s, and 91 dS0s, all of which are confirmed members, according to the EVCC catalog. All magnitudes are corrected for galactic foreground extinction using values given by Schlafly and Finkbeiner (2011) [11]. Because of the low redshifts of the Virgo cluster galaxies, K-corrections are negligible and, so,

here is no need for K-correcting the magnitudes [12].

The method used in achieving this work is by finding the color-magnitude relations of all sample data in different photometric passbands and using a suitable data analysis software to find their parameters (slope, zero point and scatter).

3. Results and Discussion

Figure 1 shows the spatial distribution of all dwarf galaxies considered in our sample. As we mentioned above, these galaxies are all confirmed members of the Virgo cluster, according to the EVCC catalog (with redshifts around $z = 0.0036$). The majority of these dwarf galaxies are elliptical, as we mentioned earlier. It is obvious from the figure that dE(N)s are more concentrated to the cluster center than dEs. That is, they prefer regions of high density [13].

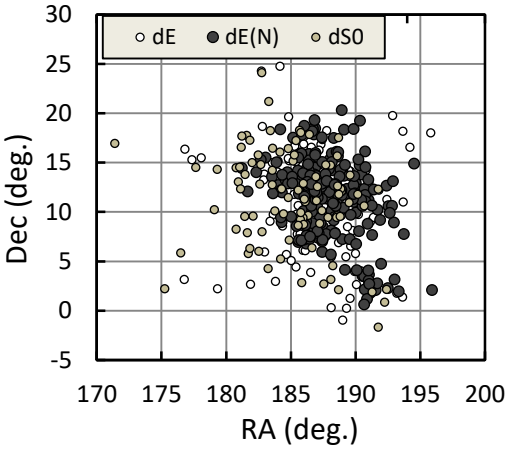

Figure 1 Projected spatial distributions of all samples

Our results show that dwarf early-type galaxies, like their normal counterparts, obey a color-magnitude relation, such that brighter galaxies become redder. According to Kodama and Arimoto (1997), this is explained either as a change in stellar metallicity or an increase in age toward brighter galaxies [14]. This behavior is obvious in Figures 2 through 5 which display the color-magnitude diagrams (CMDs) of the sample galaxies in different photometric pass bands with their best-fit lines. In each figure, the color-magnitude relations (CMRs) of all galaxy types within the sample are plotted with their best-fit lines, where a 3-sigma clipping was achieved to determine the red sequence galaxies, sigma being the dispersion or scatter about the best-fit line. White circles represent dEs, black circles represent dE(N)s, and grey circles represent dS0s.

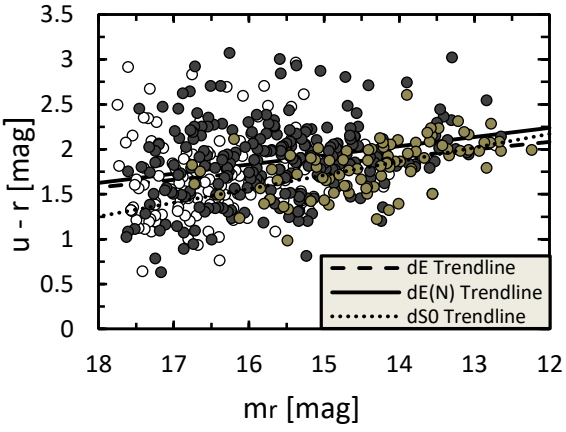

Figure 2 (u – r) vs. m_r CMRs.

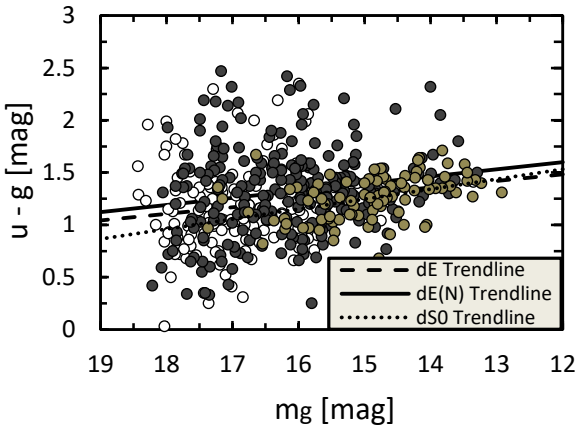

Figure-3 (u – g) vs. m_g CMRs.

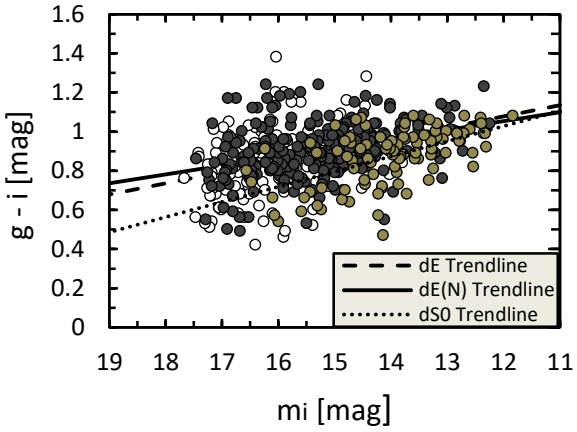

Figure 5 (g – i) vs. m_i CMRs.

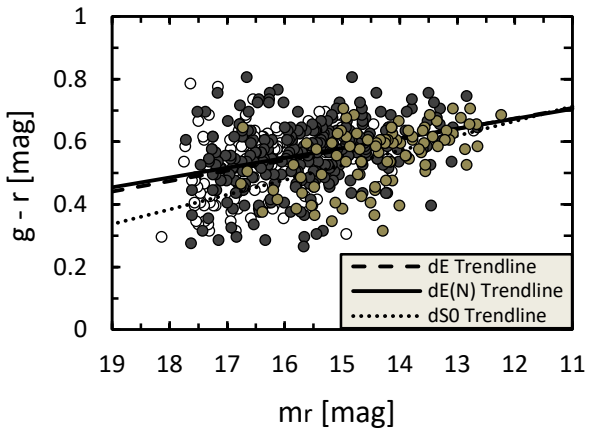

Figure 4 (g – r) vs. m_r CMRs.

The results are outlined in Table 1. It is obvious from this table that the steepness of the CMR changes in various color-magnitude spaces, being steeper for (u – r) vs. m_r and more gentle for (g – r) vs. m_r. All types of dwarfs follow the same trend, as shown in the Table.

Table-1: CMR data of all dwarf types for various photometric passbands.

Color vs. magnitude	Slope	Zero-point	Scatter
Dwarf elliptical galaxies, dEs			
(u – r) vs. m_r	-0.084±0.038	3.089±0.623	0.437
(u – g) vs. m_g	-0.063±0.037	2.237±0.617	0.403
(g – r) vs. m_r	-0.033±0.009	1.075±0.143	0.104
(g – i) vs. m_i	-0.057±0.014	1.765±0.226	0.170
Nucleated dwarf elliptical galaxies, dE(N)s			
(u – r) vs. m_r	-0.102±0.024	3.459±0.375	0.428
(u – g) vs. m_g	-0.068±0.024	2.416±0.393	0.411

(g – r) vs. m_r	-0.031±0.006	1.048±0.089	0.105
(g – i) vs. m_i	-0.045±0.007	1.598±0.112	0.139
Dwarf lenticular galaxies, dS0s			
(u – r) vs. m_r	-0.153±0.026	4.009±0.372	0.437
(u – g) vs. m_g	-0.095±0.022	2.674±0.325	0.214
(g – r) vs. m_r	-0.047±0.009	1.231±0.127	0.095
(g – i) vs. m_i	-0.077±0.013	1.957±0.177	0.144

A close similarity is seen between the CMRs of dEs and dE(N)s in the (u – g) vs. m_g and (g – r) vs. m_r color-magnitude diagrams. This indicates a similar origin of both these types of dwarfs. This result agrees with that obtained by Lisker et al. (2008) [15]. However, in all color-magnitude spaces, the slopes of the CMRs of dS0s are steeper than those of dEs and dE(N)s. This may indicate star formation activity and different stellar populations of dS0s as compared to dEs and dE(N)s. The same result was observed for UV CMRs by Kim et al. (2010) [16].

The scatter around the CMR of dEs and dE(N)s is almost the same in all CMDs. But in most of our CMDs, the scatter of dS0s is smaller than that of dEs, indicating a distinct star formation history. Yet, the scatter values obtained here for dwarf galaxies are large, as compared to their values for normal galaxies [17]. The reason is that dwarf galaxies have longer star formation histories, which lead to more scattered distributions [18]. These results are in good agreement with those of Kim et al. (2014) [10].

4. Conclusions

We carried out a photometric study of a sample of early-type dwarf galaxies, selected from the Extended Virgo Cluster Catalog (EVCC). The study includes 147 dEs , 260 dE(N)s, and 91 dS0s. A comparison is made between the CMRs of these early-type dwarfs in various photometric passbands. The steepness of the CMR was found to change in different color-magnitude spaces, being steeper for (u – r) vs. m_r and more gentle for (g – r) vs. m_r. A close similarity was seen between the CMR slope and scatter of dEs and dE(N)s, which indicates a similar origin. However, the CMRs of dS0s were found to be steeper and tighter than those of dEs and dE(N)s, indicating the existence of star formation activity in dS0s and having different stellar populations as compared to dEs and dE(N)s.

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