DOI: http://dx.doi.org/10.18524/1810-4215.2016.29.85268

NO THE HOLMBERG EFFECT FOR GALAXY PAIRS SELECTED FROM THE SDSS DR9 AT Z $\leq$ 0.06

D.V. Dobrycheva, I.B. Vavilova

Main Astronomical Observatory of the National Academy of Sciences of Ukraine
daria@mao.kiev.ua, *irivav@mao.kiev.ua*

ABSTRACT. We studied the Holmberg effect in galaxy pairs selected from the SDSS DR9, where 60561 galaxies were limited by redshift $0.02 < z < 0.06$ and absolute magnitude: $M_r \leq -20.7^m$ for central galaxies (N=18578) and $M_r > -21.5^m$ for neighbor galaxies (N=41983). We have made a morphological classification for each galaxy using both the visual inspection and machine learning methods. We considered four morphological types of galaxy pairs (E, early, and L, late, types) for testing the Holmberg effect: E- E, E-L, L-E, L-L (first companion of pairs is a central galaxy and second one is a faint satellite galaxy). We concluded about the absence of the Holmberg effect: R_{g-i} = 0.3 for L-E pairs at $0.04 < z \leq 0.06$ and $R_{g-i} = 0.2$ for E-E and E-L pairs at $0.02 \leq z \leq 0.04$.

Summarizing, a correlation of color indices in pairs for the samples of galaxies composed with the half of large sky surveys likely SDSS was not confirmed or confirmed partially. The Holmberg effect is rather connected with morphological types of galaxies than with their color indices. Taking into account a scenario of the secular evolution, the presence of at least one elliptical galaxy in pair may be indicator of previous mergers in the earlier epoch. So, figuring manifestations of the Holmberg effect in its original interpretation no longer seems such urgent.

Keywords: galaxies: color indices.

1. Introduction

In 1958, Holmberg has found a color indices (B-V) dependence for 32 pairs of galaxies with a correlation coefficient of $R = +0.80 \pm 0.6$ using the difference in the radial velocity of pair components $\Delta V \leq 250$ km/s as a selection criteria (Holmberg, 1958). Later on such a correlation of color indices in the close paired galaxies was called the “Holmberg effect” and tested many times for different galaxy samples. The interest to this effect is caused that it may be explained as a tendency to have similar morphological types for galaxies, which are evolving together.

We note below several results obtained in 1980-2000 before the era of big data, which were in favor of this effect. Tomov (1979) has obtained (B-V) and (U-B) color indices for 105 pairs of galaxies from RC2 Catalog by de Vaucouleurs and confirmed the effect. Then, Demin et al. (1984) have continued work with this sample and found a “color indices - morphological types” relation for pairs with a different morphological types of galaxies (E - elliptical, S - spiral) with correlation coefficients $R_{B-V(U-B)} \sim 0.7 - 0.8$ for E-E and S-S pairs, $R_{B-V(U-B)} \sim 0.5 - 0.6$ for E-S pairs. Reshetnikov (1998) in his work with a sample of 24 interacting galaxies selected from the catalogs by Arp, by Vorontsov-Velyaminov, and by Karachentsev (issued in 1966, 1959, and 1972, respectively) obtained $R_{B-V(U-B)} \sim 0.8 - 0.9$. Hernandez-Toledo et al. (2001) for a sample of 45 S-S paired galaxies from the catalog by Karachentsev of 1972 year have resulted as $R_{B-V} = 0.77$.

One of the explanation of such a linear correlation for pairs with different morphological composition was that the evolution of galaxies in pairs is occurring in parallel under the influence of a common gravitational interaction and mutual gas dynamic processes over several billion years (Karachentsev, 1987) and can provide, for example, the periodic bursts in S-S pairs from starforming regions originating simultaneously in both components (Demin, 1984).

It is important to emphasize that in those years the data on the radial velocities were sparsed as well as only several dozens gravitationally connected galaxy pairs were known. The selection criteria were based on the two-dimensional projected sky separation and galaxy diameter. For example, when later on, Franco-Balderas et al. (2003, 2004) reexamined a morphological classification of galaxy pairs from the Karachentsev's catalog and remeasured their photometric parameters, they obtained that the Holmberg effect is a very weak or entirely absent for these objects.

The era of big data and surveys likely SDSS allowed us to compile more wider samples of galaxies with a good quality photometric and spectroscopic properties. Looking ahead, we say that significant correlations of the color indices for galaxies in pairs were not found in studies of samples from the SDSS survey.

Table 1: Correlation coefficients, R, of color indices ($M_g - M_i$) of galaxies in pairs from SDSS DR9 sample

Morph. type	Sub-sample	N pairs	R, SDSS pairs	R, random pairs
L-L	1	35	0.05	0.006
	2	87	0.17	0.00001
L-E	1	24	0.02	0.007
	2	62	0.3	0.003
E-E	1	174	0.2	0.0001
	2	289	0.05	0.001
E-L	1	106	0.2	0.001
	2	229	0.15	0.006

In this work we examine the presence of Holmberg effect both for a new sample of galaxy pairs selected from SDSS DR9 at $z \leq 0.1$ by the three-dimensional Voronoi tesselation method (Dobrycheva, 2015) and for several aforementioned samples of galaxies, for which we updated their color indices by reducing to the SDSS colorimetry. These results are presented in Section 2 and 3, respectively. Their comparison with results obtained for others SDSS samples and concluding remarks are given in Section 4.

2. The Holmberg effect verification for the paired galaxies from SDSS DR9

2.1. The sample of galaxy pairs from SDSS DR9

The studied sample of paired galaxies selected from SDSS DR9 is described in our papers (Dobrycheva, 2013; Dobrycheva et al., 2015). It is consisted of $N = 60561$ galaxies with redshifts $0.02 \leq z \leq 0.06$ and absolute magnitudes $-24^m \leq M_r \leq -19.4^m$. We determined the absolute magnitudes as follows:

$$M_r = m_r - 5 * lg(D_L) - 25 - ext_r - K(z)_r,$$

where m_r - visual magnitude in r band, D_L - distance luminosity, ext_r - the Galactic absorption in r band by Schlegel et al. (1998), $K(z)_r$ - k-correction in r band according to Chilingarian et al. (2010, 2012). We determined the color indices using the following formulas:

$$M_g - M_i = (m_g - m_i) - (ext_g - ext_i) - (K(z)_g - K(z)_i),$$

where m_g and m_i - visual magnitude in g and i band; ext_g and ext_i - the Galactic absorption in g and i band; $K(z)_g$ and $K(z)_i$ - k-correction in g and i band, respectively.

We divided the studied sample into subsamples of the central galaxies ($M_r \leq -20.7^m$, N=18578) and their neighbors ($-20.7^m < M_r \leq -19.4^m$, N=41983) (see Figure 1). We applied the 3D Voronoi tessellation method (Elyiv et al., 2009)) to identify galaxy paired systems as "the central galaxy - the closest neighbor"determining a distance between the components up to 100 kpc. Such approach allowed us to consider the central galaxies from the central sample as the cores of the Voronoi cell, whereas the neighbors as the galaxies, which hit in the field of the Voronoi cell, from the neighbors sample. To study the Holmberg effect we divided our sample into two subsamples by redshift:

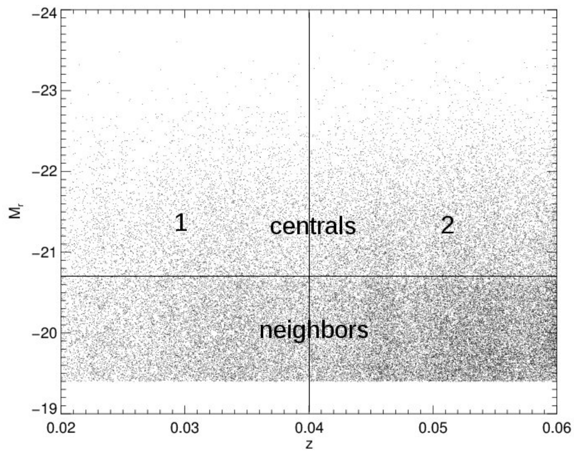

Figure 1: The absolute magnitude of galaxies as a function of redshift for central galaxies (N=18578) and their neighbors (N=41983) selected from SDSS DR9 at $0.02 \leq z \leq 0.06$.

1) $0.02 \leq z < 0.04$, $M_r \leq -20.7^m$;
2) $0.04 < z \leq 0.06$, $M_r \leq -20.7^m$ (Figure 1).

2.2. Verification of the Holmberg effect

We calculate the correlation coefficients, R, between color indices $M_g - M_i$ for central galaxy and the nearest neighbor (up to 100 kpc between components) for the aforementioned galaxy sample. The relationships for pairs with different morphological composition are presented in Figure 3, 4, where the first symbol (E-E, E-L, S-S, S-L) indicates the type of central galaxy. We compared these results with those for pairs, where one galaxy was taken from a sample of central galaxies and other one was selected randomly from a sample of the nearest neighbors. Repeating this procedure 100 times for random choice of color indeces ($M_g - M_i$) of neighbor galaxy, we determined the average value. The obtained results are given in Table 1, where column 1 represents morphological types of galaxies in pair; column 2 - index number of subsamples (see Section 2.1 and Figure 1); N - number of pairs; R, SDSS pairs, and R, random pairs, are the correlation coefficients by Kolmogorov-Smirnov test for galaxy pairs from SDSS and random galaxy pairs,

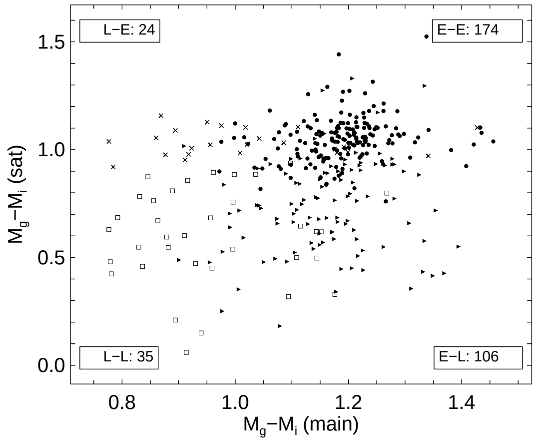

Figure 2: Relationships of color indices ($M_g - M_i$) for the components of galaxy pairs from SDSS DR9 (subsample 1 from Figure 1). The abscissa corresponds to the component of a pair with bigger color indices.

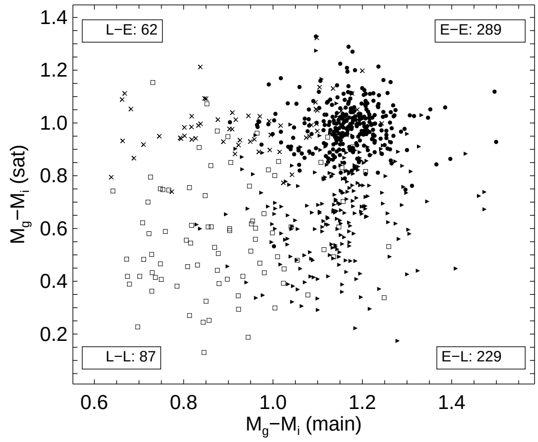

Figure 3: Relationships of color indices ($M_g - M_i$) for the components of galaxy pairs from SDSS DR9 (subsample 2 from Figure 1). The abscissa corresponds to the component of a pair with bigger color indices.

respectively. One can see that there is no correlation between color indices in the studied galaxy pairs, for example, even the biggest values of coefficients are $R_{g-i} = 0.3$ for L-E pairs at $0.04 < z \leq 0.06$ and $R_{g-i} = 0.2$ for E-E and E-L pairs at $0.02 \leq z \leq 0.04$.

3. The Holmberg effect verification for the paired galaxies from other samples

3.1. The updated galaxy sample by Tomov, which is cross-matched with SDSS DR13

We inspected the sample of galaxy pairs by Tomov (1979) reducing their data to the SDSS DR13. First of all, we determined for 69 pairs of galaxies (after cross-matching) their morphological types visually by the SDSS Navigate tools using the simplest scheme into E (early) type, which includes E, S0, S0a types, and L (late), which includes types from Sa to Irr. We used NED (NASA/IPAC Extragalactic Database) for updating radial velocity for all galaxies. We remind that Demin (1981), when analyzing this sample, has proposed a criterion for physical pair based on the difference of the radial velocities of components: it does not exceed a value of $V \leq 300$ km/s. Using this criterion we excluded 17 optical pairs of galaxies. The absolute magnitudes M_r and color indices $M_g - M_i$ for the rest of 104 galaxies were redetermined according to the formulas described in Section 2.1. As a result, these pairs of galaxies have $0.0009 < z < 0.04$; relationships of color indices ($M_g - M_i$) for galaxies of L-L, L-E, E-E, E-L pairs are illustrated in Figure 4.

Finally, after taking into account the confidence

Table 2: Correlation coefficients for color indices ($M_g - M_i$) of 34 galaxy pairs from sample by Tomov (1979), which are reduced and cross-matched with SDSS DR13 data

Type of pairs	N pairs	R, Tomov's pairs	R, random pairs
L-L	16	0.30	0.02
L-E	0	0	0.01
E-E	15	0.48	0.07
E-L	3	0.52	0.01

interval and relationships of color indices ($M_g - M_i$), the galaxy sample by Tomov, which is cross-matched with SDSS DR13, contained 34 pairs. We determined the correlation coefficients for color indices in the same way as for our sample of paired galaxies from SDSS DR9. One can see (Table 2) that its biggest value is $R_{g-i} \sim 0.5$ for E-E and E-L pairs and this is not in favor of the presence of the Holmberg effect due to a weak statistics and significance level.

3.2. The Catalog of galaxy pairs in the Local Supercluster, which is cross-matched with SDSS DR13

We have taken the Catalog of pairs of galaxies in the Local Supercluster (Karachentsev et al., 2008) to test the Holmberg effect. This catalog contains 509 pairs with line-of-sight velocities $V_{LG} < 3500$ km/s. The component line-of-sight velocity differences and projected distances of the double systems have power-law distributions with the median values of 35 km/s and 123 kpc, respectively. We cross-matched

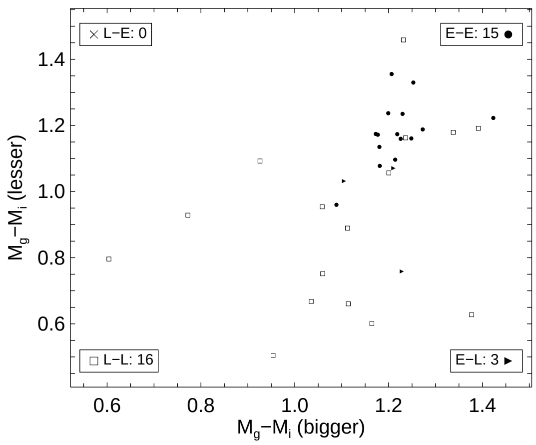

Figure 4: Relationships of color indices ($M_g - M_i$) for the components of physical pairs of galaxies from Tomov's sample (1979) within confidence interval. The abscissa corresponds to the component of a pair with bigger absolute magnitude.

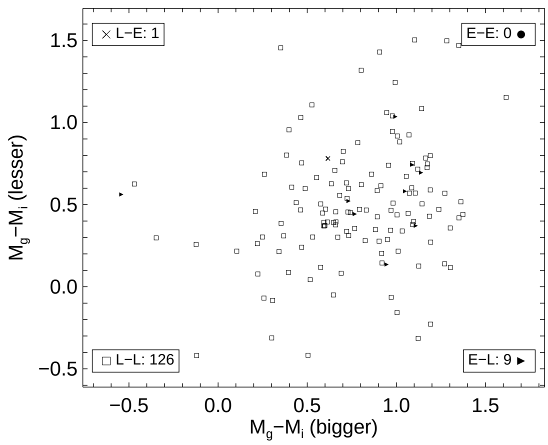

Figure 5: Relationships of color indices ($M_g - M_i$) within confidence interval for the components of galaxy pairs in the Local Supercluster (Karachentsev et al., 2008), which are cross-matched with SDSS DR13. The abscissa corresponds to the component of a pair with bigger absolute magnitude.

Table 3: Correlation coefficients for color indices ($M_g - M_i$) of 136 galaxy pairs in the local Supercluster, which are reduced and cross-matched with SDSS DR13 data

Type of pairs	N pairs	R, LS pairs	R, random pairs
L-L	126	0.26	0.002
L-E	1	-	0.005
E-E	0	-	-
E-L	9	0.07	0.04

this catalog with SDSS DR13 data and turned out that SDSS DR13 covers only 242 from 509 galaxy pairs. We used NED (NASA/IPAC Extragalactic Database) for updating radial velocity of galaxies. The morphological types for each galaxies were determined by the authors of this catalog, we grouped only them onto early (E) and late (L) types. The absolute magnitudes M_r and color indices $M_g - M_i$ for 484 galaxies were calculated as it is described in Section 2.1. After determination of relationships of color indices ($M_g - M_i$) between components of pairs and taking into account the confidence interval, we obtained 136 pairs (see Table 3 and Figure 5). One can see that there is no correlation of color indices, the biggest value of correlation coefficient is $R_{g-i} \sim 0.26$ for L-L galaxy pairs.

4. Discussion and concluding remarks

The SDSS has allowed to examine the Holmberg effect based on the high quality colorimetry.

Allam et al. (2004) using 1479 merging pairs from SDSS (Stoughton et al., 2002) found that the level of significance of the correlation apparently depends on the color indices: the highest ($> 12\sigma$) for the $g-r$ (closest SDSS analog to B-V) and the lowest ($< 2\sigma$) for the $i-z$ color indices. They obtained $R_{g-r} = 0.38 \pm 0.03$ for galaxies in pairs and explained a weak correlation in terms of random star formation in merging systems. Deng et al. (2008) investigated the Holmberg effect for the Main galaxy pairs of the SDSS DR4 (Adelman-McCarthy et al., 2006) and found that except for $i-z$ color the color indices between two components of the Main galaxy pairs have larger correlation coefficient. They have noticed weak tendencies indicating the Holmberg effect and absence of the significant dependences. But it is noteworthy that the Luminous Red Galaxy pair sample (Eisenstein et al., 2001) does not exhibit a statistically significant Holmberg effect.

Summarizing, we may note that for the samples of galaxies composed with the half of large sky surveys likely SDSS, this effect was not confirmed (Franco-Balderas et al., 2003; 2004; Allam et al., 2004; Melnyk et al., 2012; Dobrycheva et al., 2015) or confirmed partially/low significance level (Deng et al., 2008, 2010). In this work we verified the Holmberg effect with the sample of about 1000 paired galaxies selected from SDSS DR9 at $z < 0.06$ and not found a correlation between their $g-i$ color indices. This effect in the modern interpretation is rather connected with morphological types of galaxies than with their color indices.

In accordance with the hierarchical scenario of structure formation and the important role of small and large interactions, the elliptical galaxies could be formed by the merger of late-type galaxies. The well-known relation "morphology-density"(Kauffmann et al., 2004; Tinker et al., 2013; Kovac et al., 2014; Wetzel, 2014), which manifests itself even on the scale of small groups (Karatsentsev, 1987); Melnik et al., 2006; Vavilova et al., 2009; Melnyk et al., 2012; Dobrycheva et al., 2015) testifies to this. It is known also the observational asymmetry in distribution of the early-type galaxies from large to low redshifts (Baldry et al., 2014; Cucciati et al., 2006; Tal et al., 2014). In other words, the presence of at least one elliptical galaxy in the pair may be indicator of previous mergers in the earlier epoch. So, figuring manifestations of the Holmberg effect in its original interpretation no longer seems such urgent.

Following the link below you will get access to the studied sample of galaxies ($0.02 < z < 0.04$) selected from the SDSS DR9 and described in Section 2.1 of this paper: *ftp.mao.kiev.ua/pub/astro/cats/galaxies/gal_sam_SDSSDR9_z_from_0.02_to_0.06.csv.*

Following the link below you will get access to the complete sample of galaxies at $z < 0.1$ selected from the SDSS DR9 and described in papers by Dobrycheva (2013) and Dobrycheva et al. (2015): *ftp.mao.kiev.ua/pub/astro/cats/galaxies/gal_sam_SDSSDR9_z_to_0.1.csv.*

Acknowledgments. We thank the scientific group working on the Sloan Digital Sky Survey http://www.sdss3.org. Funding from SDSS-III has been provided by the Alfred P. Sloan Foundation and the U.S. Dept. of Energy Office of Science. This work was partially supported in frame of the Target Program of the Scientific Space Research of the NAS of Ukraine.

References

Adelman-McCarthy J.K., Agueros M.A., Allam S.S. et al.: 2006, *ApJ*, **162**, 38.

Allam D. Tucker Smith et al.: 2004, *ApJ*, **127**, 1883.

Baldry I.K., Glazebrook K., Brinkmann J. et al.: 2004, *ApJ*, **600**, 681.

Chilingarian I., Melchior A.-L., Zolotukhin I.: 2010, *MNRAS*, **405**, 1409.

Chilingarian I., Zolotukhin I.: 2012, *MNRAS*, **419**, 1727.

Cucciati O., Iovino A., Marinoni C. et al.: 2006, *A&A*, **458**, 39.

Demin V.V., Dibai E.A., Tomov A.N.: 1981, *AZh*, **582**, 925.

Demin V.V., Zasov A.N., Dibai E.A. et al.: 1984, *AZh*,**61**, 625.

Deng X.-F., He J.-Z., Jiang P. et al.: 2008, *ApJ*, **677**, 1040.

Deng X.-F., Xin Y., Peng J., Wu P.: 2010, *Ap*, **53**, 342.

Deng X.-F., He J.-Z., Wen X.-Q. et al.: 2008, *ChJPh*, **46**, 517.

Dobrycheva D.: 2013, *Odessa Astron. Publ.*, **26/2**, 187.

Dobrycheva D.V., Melnyk O.V., Vavilova I.B., Elyiv A.A.: 2015, *Ap*, **58**, 168.

Eisenstein D.J., Annis J., Gunn J.E. et al.: 2001, *AJ*, **122**, 2267.

Elyiv A., Melnyk O., Vavilova I.: 2009, *MNRAS*, **394**, 1409.

Franco-Balderas A., Hernandez-Telode H.M., Dultzin-Hacyan D. et al.: 2003, *A&A*, **367**, 1029.

Franco-Balderas A., Hernandez-Telode H.M., Dultzin-Hacyan D. et al.: 2004, *A&A*, **417**, 411.

Hernandez-Toledo H.M., Puerari I.: 2001, *A&A*, **379**, 54.

Holmberg E.: 1958, *Lund Medd. Astron. Obs. Ser. II*, **136**, 103.

Karachentsev I.D., Makarov D.I.: 2008, *AstBu*, **63**, 299.

Karachentsev I.D.: 1987, *Double galaxies, Moscow: Nauka*, 280.

Kauffmann G., White S.D.M., Heckman T.M. et al.: 2004, *MNRAS*, **353**, 713.

Kovac K., Lilly S.J., Knobel C. et al.: 2014, *MNRAS*, **438**, 717.

Melnyk O.V., Elyiv A.A., Vavilova I.B.: 2006, *KFNT*, **22**, 283.

Melnyk O.V., Dobrycheva D.V., Vavilovav I.B.: 2012, *Ap* **55**, 293.

Reshetnikov V. P.: 1998, *AstL*, **24**, 153.

Schlegel D.J., Funkbeiner D.P., Davis M.: 1998, *ApJ*, **500**, 525.

Stoughton C., Lupton R.H., Bernardi M. et al.: 2002, *AJ*, **123**, 485.

Tal T., Dekel A., Oesch P. et al.: 2014, *ApJ*, **789**, 164.

Tinker J.L., Leauthaud A., Bundy K. et al.: 2013, *ApJ.*, **778**, 93.

Tomov A.N.: 1979, *Candidate's dissertation.*

Vavilova I.B., Melnyk O.V., Elyiv A.A.: 2009, *Astron. Nachr.*, **330**, 1004.

Wetzel A.R., Tinker J.L., Conroy C. et al.: 2014, *MNRAS*, **439**, 2687.