On the mutual location of the nearby galaxies M31, M32 and M110

Ts. B. Georgiev[1,2], P. Nedialkov[3] E. Ovcharov[3], A. Valcheva[3]
[1] Department of Natural Sciences, New Bulgarian University, BG-1618 Sofia
[2] Institute of Astronomy and NAO, Bulgarian Academy of Sciences, BG-1784 Sofia
[3] Department of Astronomy, University of Sofia, BG-1164 Sofia
tsgeorg@astro.bas.bg
(Submitted on 14.01.2015; Accepted on 06.02.2015)

Abstract. We performed BVRI surface photometry on the M32 and M110 galaxies building images and photometric sections calibrated in magnitudes and in color indexes. We compare the behavior of the color indexes across centers of both galaxies along two lines. The first line is oriented along the M31 isophote, where the color indexes and internal extinction of the M31 disk may be assumed to be constant. The second line is oriented along the direction toward the M31 center, where due to a probable gradient of the internal extinction of the M31 disk, the color indexes of the satellite galaxies also increase, if they were both located behind it. We find no notable asymmetry of the color sections of M32 in all cases, while the color sections of M110 show significant reddening toward M31 center. The behavior of the color indexes can be treated as photometric evidence that M32 is located in front of the disk of M31, while M110 is situated behind it.
Key words: galaxies local group; galaxies M31, M32, M110

Introduction

The knowledge about the mutual location of the Andromeda galaxy (M31, NGC224) and its close satellites M32 (NGC221) and M110 (NGC205) plays important role in the understanding of the structure and evolution of these galaxies. Since Ibata et al. (2001) found a giant stream of metal-rich stars in the halo of the M31, apparently pointed in the direction of M32 and M110, the investigations in this field became more relevant. Because the satellites are projected along the body of M31, the question about their true locations – in front of or behind the M31 disk - continues to be actual.

The galaxies M32 and M110 have been subject of numerous studies, mainly focussed on its morphology and suspected interaction with M31 (see Choi et al. 2002 and references therein). Ford et al. (1978) studied a planetary nebula in M32 and considered that M32 is visible in front of the M31 disk, but the models of M31-M32 interaction typically assumed that M32 is more distant than M31 (Dierickx et al. 2014). It seems, this situation forced Young et al. (2008) to publish a critical review of the evidence for M32 being a compact dwarf satellite of M31 rather than a more distant normal galaxy. The apparent proximity of M31 and M32 suggests that the prominent star forming ring in the disk of M31 and the compact elliptical structure of M32 may be a result of a recent collision.

At that times Choi et al. (2002) completed on extensive study of the tidal interaction of M32 and NGC205 with M31 through surface photometry and numerical simulations. The fact that M32 is really a compact elliptical galaxy, these authors concluded, gave a hint that it is in front of the M31 disk. Lately Dierickx et al. (2014) elucidates signatures of the M31-M32 galactic collision. They presented self-consistent model of the interaction that simultaneously reproduces observed positions, velocities and morphologies for both galaxies. They found M32 is currently closer to the Milky Way, but they considered this conclusion must be testable with future investigations. In respect to M32, M110 has not been subject of such detailed studies, but it is considered that M110 is definitely farther than M31 (Choi et al. 2002).

Numerous accurate methods for distance estimations in the Local Group have been applied in the last two decades and we begin with an analysis of the available data.

Figure 1a presents the distance moduli of M32 (10), for M31 (36) and for M110 (6), collected in the database HyperLeda (2014). The average distance moduli and their residual mean square deviation (rmsd) intervals for M32, M31 and M110 occur to be 24.42 ± 0.15 mag, 24.44 ± 0.09 mag and 24.55 ±0.13 mag. The respective distances are 767 kpc ± 7.5 %, 773 kpc ± 4.0 % and 812 kpc ± 6.3 %.

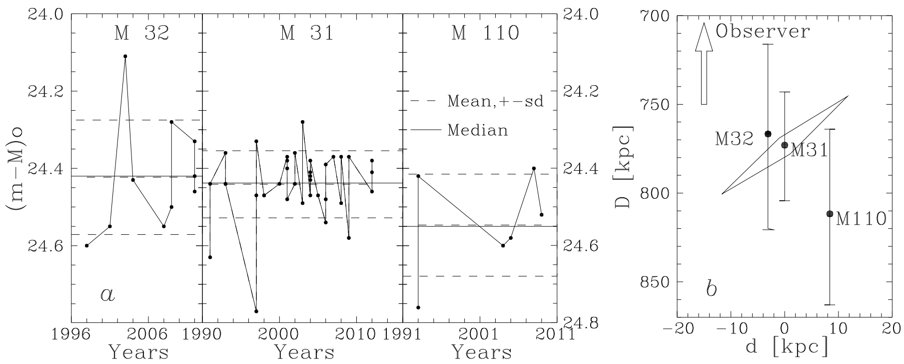

Fig. 1. *a*: Distance moduli $(m - M)_0$ and distances D of the galaxies M32, M31 and M110 (dots), derived by various methods in the last two decades (HyperLeda, 2014). Dashed horizontal lines represent the average values and theirs ± 1 msd intervals. Solid horizontal lines show the respective median values. *b*: Sketch of the locations of the triad galaxies and respective error bars, projected on a plane along the sightline of M31 and perpendicular to its major axis.

Figure 1b gives an aside view of the distance estimations and errorbars of the triad galaxies. At intermediate distances from the center of M31 the NE part of the disk of M31 is fainter and bluish than the SW part, which is the indication that the NE part of the disk is closer to us. Here the radius of the M31 disk is adopted to be 30 kpc, the inclination angle is 23 deg and the position angle of the major axis of M31 is 35 deg. Note that the scale of the distances d from M31 (abscissa) is 5 times expanded in respect to the scale of the distance D from the observer (ordinate) and by this reason the apparent inclination angle of the M 31 disk in Fig.1b is significantly larger than 23 deg. So, it seems M32 is located at 4.9 kpc in front of the M31 disk while M110 is situated at 13.4 kpc behind the M31 disk.

Another system of similar average distance estimations is given in NED (2014). It is based on 63, 272 and 24 determinations for M32, M31 and

M110, respectively. However we prefer the data in HyperLeda, because they contain only results of contemporary accurate distance estimator.

Though, some doubts arise. It is interesting that the averages and median distance moduli coincide, i.e. the distributions of the distance moduli have symmetric shapes. However, the distributions of the distance moduli have not normal shapes. They have obviously negative excess and by this reason the standard deviations are too large. That's why the one-sided Student test allows the hypothesis "M110 if farther then M32" with only 95 % statistical guaranty. Therefore, the applying of another method, that is able to distinguish the satellite in front of the M31 disk from the satellite behind the M31 disk, should be useful.

Here we apply such a method, searching for symmetry or asymmetry of the color sections of the satellites. The idea is comparison of the shapes of the color sections of M32 and M110 along lines of approximately constant color indexes (or constant internal extinction) of M31, along the M31 isophote, and along lines of suspected maximal gradients of the color indexes (or constant internal extinction) of M31, along the direction to the center of M31.

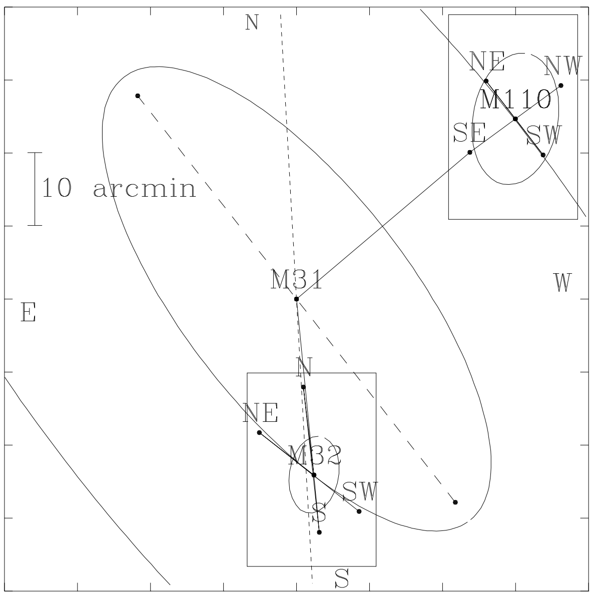

Fig. 2. Sketch of an $80' \times 80'$ sky field of triad galaxies, two elliptical isophotes of M31, passing across the centers of the satellites and the elliptical isophotes of the satellites at brightness level μ_B=25 mag/sq.arcsec (HyperLeda, 2014). Segments within the satellites boundaries represent the positions of the photometric sections shown below.

In this paper we present photometric evidences that M32 is situated in front of the M31 disk while M 110 is located behind.

1. Observing material and photometry

The observations, used here, were carried out by the 50/70/172 cm Schmidt telescope plus CCD ST8 on August 30, 2003, at the Rozhen NAO (Bulgaria) at 1750 m over the sea level. The scale is 1.08 arcsec.pix^{-1} and the frame size is 1020 × 1530 pix ($18.3' \times 27.5'$).

The standard deviation of the pixel noise is 1-2 %. The total exposure times in B, V, R and I band of the used frames for M32 and M110 are 20 min, 10 min, 10 min and 5 min, respectively, at air masses 1.04 1.05. The nucleus of M32 occurs overexposured in R band and the central part of the east edge of the CCD frames shows less sensitivity, especially in B band. However, these circumstances are not influential to our results.

The preliminary and preparatory processing of the CCD frames, as well as stellar and surface photometry was carried out by a C-code, written by one of the authors (TG). After dark subtraction and flat fielding the frames were cleaned by median filtering with 5 pix window size. This procedure cuts the tips of the stellar images and the galactic nuclei, but we have no interest in them. Then the frames were rebinned to a common coordinate frame and reduced 3×3 fold. Further we processed B, V, R and I frames with scales 3.24 arcsec.pix^{-1} and sizes 340×510 pix. Magnitude zero-points were transferred from fields with standard stars, observed before or after galaxies and situated at approximately the same zenith distances. The possible error of the magnitude zero-point transfer seems to be about 0.1 mag. (The isophote maps of the galaxies are shown in Fig.3).

The frames containing the satellites M32 and M110 are situated in the large image of the galaxy M31 (See, Fig.2) and by this reason the sky background levels seem to be slightly overestimated. Indirect evidences for this are the truncated minor axis profiles of M110 (Fig.3). However, such truncations are presented also in the collection of radial profiles of M110, given by Kim & Lee (1998). We believe this effect is negligible in the bright parts of M32 and M110, though we denote our calibrated magnitudes and color indexes by small letters: b, v, (b-v) etc.

Our results are based on photometric sections of the images of M32 and M110 (Fig.48). We build calibrated frames in b, v, r and i band, as well as in 7 color indexes: (b-v), (b-r), (b-i), (v-r), (v-i), (r-i) and (b-r)+(v-i). The last color index contains all used bands and seems to be the best for our purposes. The magnitude and color section of the magnitude and color images, are extracted by computer simulated scans with a step of 2 arcsec and a window size of 5 pixels (16 arcsec). Thus, we derived additionally smoothed profiles where the stars and the nuclei of the galaxies are blurred since we are interested in the large scale behavior of the magnitude and color sections.

Figure 2 represents the field around M 31 and locations of our frames (rectangles). The used distances are plotted in Fig.1.b. Note that the image is rotated by position angle 2.3 deg clock-wise for compensation of the rotation of the CCD mounting.

Figure 3 shows isophote maps of the galaxies M32 and M 110. The line in the image of M110 in R band is a satellite trace. Probably due to a bad flatfielding, the frames in B band show increased sensitivity in theirs NE and SE corners (see M110 in B band).

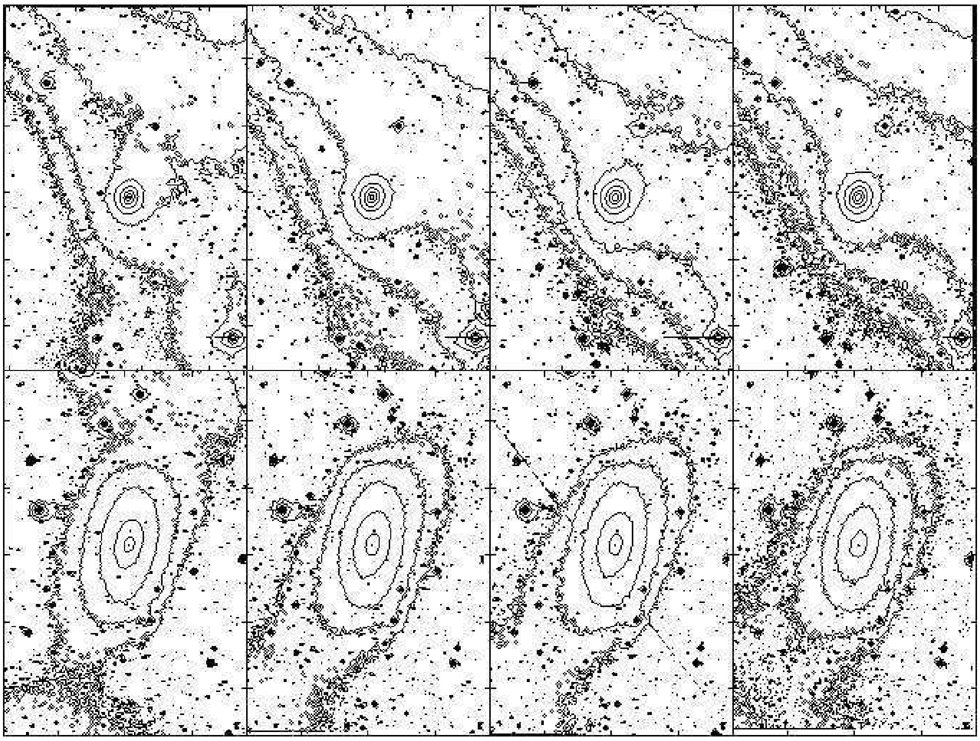

Fig. 3. Isophote maps of the images of M32 (top panel) and M110 (bottom panel) in $BVRI$ bands (from left to the right). The isophote step is 1 mag. The corresponding lowest isophote levels are 27.0, 26.5, 26.0 and 25.5 mag/sq.arcsec. North is to the top and east is to the left. The tic mark step is 5 arcmin.

2. Results

Figure 5 shows 3+3 color profiles across the center of M32. The triangle shape of the brightest parts of the profiles in the left panels has the same appearance in the right panels. Exceptions are only sections in (r-i) that do not show more red central part. The additional positive or negative peaks in the centers of sections are due to overexposure of the M32 nucleus in R band. The minima of the color indexes at 3.5 arcmin toward the center of M31 seem to be caused by the M31 spiral arm. Generally, we do not find notable influence of the large scale gradients of the M31 color indexes and consider this fact as evidence that M32 is located in front of the M31 disk.

Figure 6 shows 3+3 color profiles across the center of M110. The trapeze shape of the brightest parts of the profiles in the left panels has the same appearance in the right panels. Exceptions are the sections in (v-r) and (r-i), which do not show redder central part. The additional negative peaks in the centers of the sections are due to the M110 nucleus, which is bluer in comparison with its vicinity.

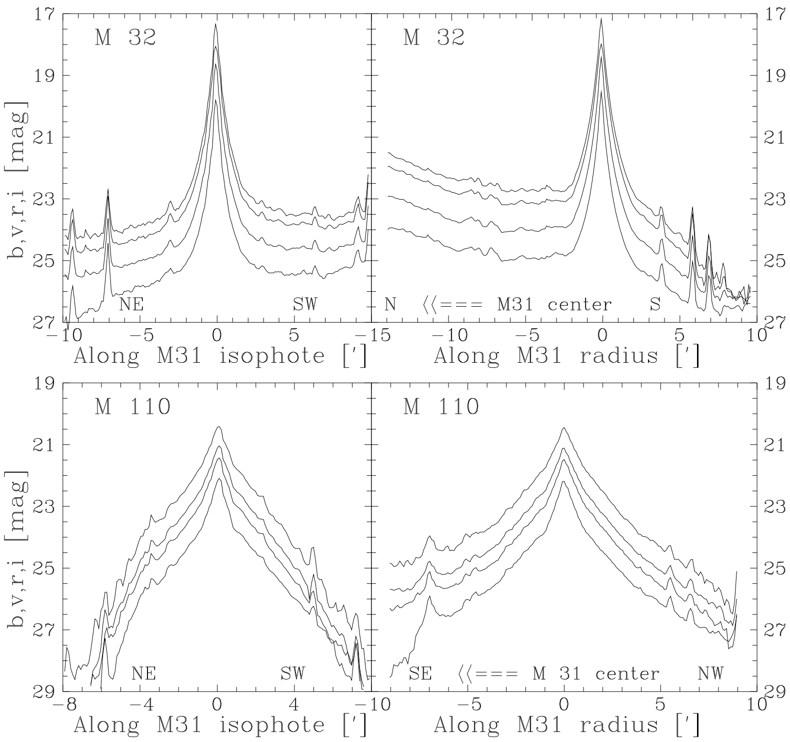

Fig. 4. Surface brightness sections across the nuclei of the galaxies M32 (upper panels) and M110 (lower panels) in our B, V, R and I bands along a line, tangential to the M31 isophote (left panels) and along a line toward the M31 center (right panels).

In Fig.6 we see that (i) the contribution of the M110 is much more prominent on the left than on the right panels, as well as (ii) the color indexes of the bright part of M110 on the right panels are getting redder towards the M31 center. Such behavior of the color indexes profiles strongly supports the hypothesis of M110 is located behind the disk of M31.

Figure 7 presents the generalized color sections of the galaxies M32 and M110,where the applied color index (b-r) + (v-i) = (b+v) (r+i) includes all photometric bands. Here the negative peaks in the center of M32 are due to the overexposured frame in R-band, while the negative peaks in the center of M110 are due to the bluish color of the nucleus. These sections visualize better the conclusions that M32 is in front of M31 disk while M110 is located behind the disk.

Figure 8 shows maps of the color indexes (b-i) and (b-r)+(v-i) and represents the most generalized information about the studied problem. The ellipses encompass the "standard" dimensions of the galaxies, given in HyperLeda (2014) and NED (2014): 7.8 arcmin and 11 arcmin for M32, as well as 16.2 arcmin and 19 arcmin for M110. For both galaxies in both databases the position angle is -10 deg and an axial ratio is 0.64. The reason

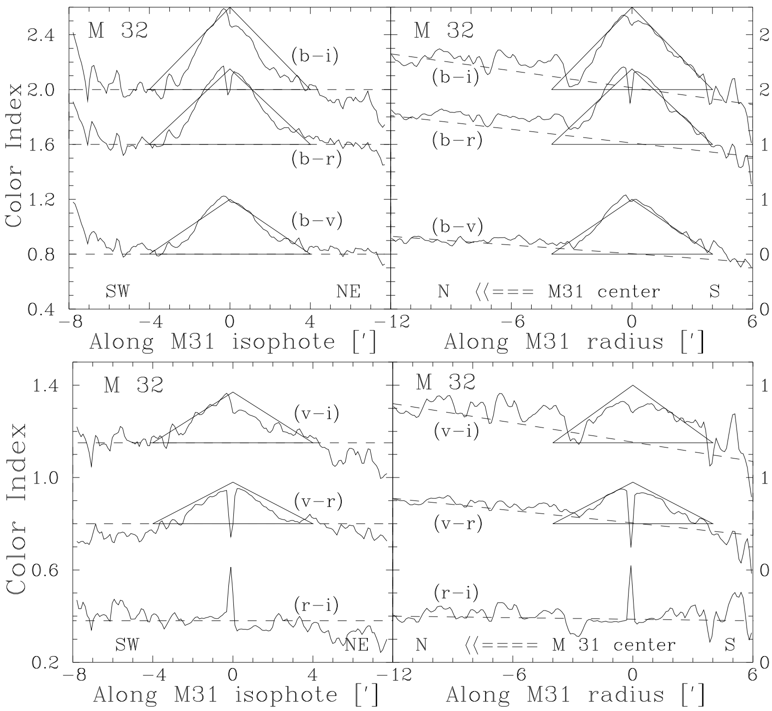

Fig. 5. Color indexes sections across the center of the M32 along a line, tangential the isophote of M31 (left panels) and along a line toward M31 center (right panels). Dashed lines show the large scale trends of the color indexes. Triangles represent the profile shapes of the brightest part of M32, as derived on the left panels, and shown without changes on the right panels.

for the red areas on the left part of the images is the locally decreased detector sensitivity in B band.

As can be seen in Fig.8 the trend of the color indexes indicates a decreasing reddening toward the outskirts of M31. While the color profile of M32 seems to be symmetric along this direction, the inner part of the of M110 galaxy (relative to M31 center) tends to be slightly redder.

Conclusions

The two closest elliptical satellites M32 and M110 of the large nearby disk galaxy M31 are objects with different nature, but they are having by presumption elliptically symmetric magnitude and color profiles. Let us compare their color indexes, collected in HyperLeda (2014).

The brightest part of M32 seems to be the bulge of a (not large) spiral galaxy which lost its disk in an interaction with M31. This bulge is bright and red, with usual total intrinsic color index (B-V)c = 0.8. It is seen along the same sightline with the bright and severely absorbing disk of

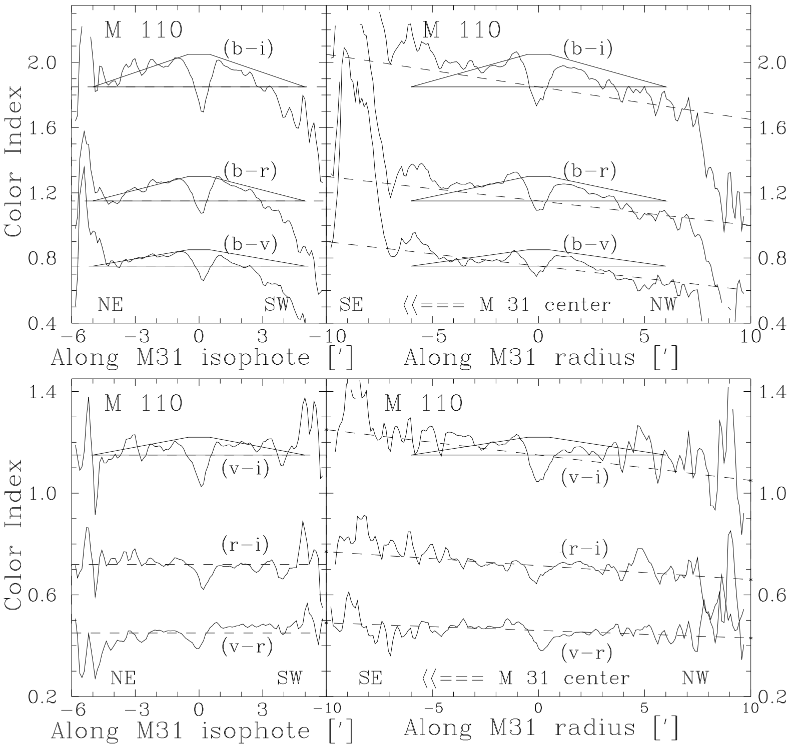

Fig. 6. Color indexes sections profiles across the center of the M110 along a line, tangential the isophote of M31 (left panels) and along a line toward M31 center (right panels). Dashed lines show the large scale trends of the color indexes. Triangles represent the profile shapes of the brightest part of M110, as derived on the left panels, and shown without changes on the right.

M31. However, we can not provide any hints for an increasing reddening of M32's bulge toward the center of M31 (Fig. 5,7,8) and conclude that M32 is located in front of the disk of M31.

M110 seems to be small elliptic galaxy with a total intrinsic color index (B-V)c = 0.77. It is very close to the color of a more distant elliptical satellite of M31 - NGC 185, with (B-V)c = 0.74. Both dwarf galaxies have blue nuclei, but M110 is about 3 times more luminous. The other distant and more faint elliptical satellite of M31 NGC 147, with (B-V)c = 0.78, has no nucleus. The differences between the total colors of these similar galaxies are small and we can not suspect an additional reddening of M110. However, the asymmetry of the color sections of M110 (Fig. 6,7,8), is a direct evidence that M110 is located behind the disk of M31.

We hope such an investigation will be performed on better observing material.

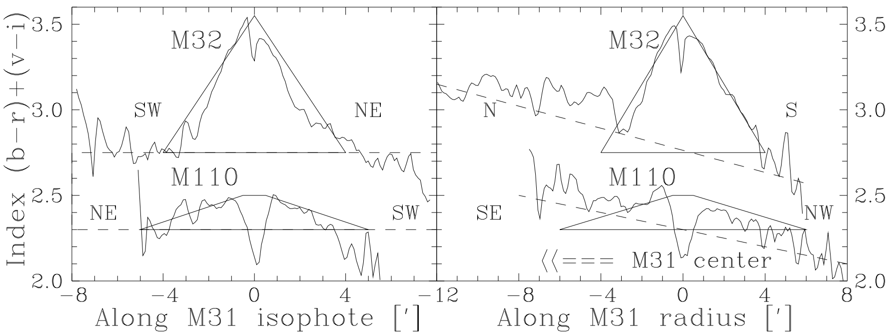

Fig. 7. Comparison of the sections of the M32 and M110 images with use of (b-r)+(v-i) combined color index. Dashed lines show the large scale trends of the color indexes. Triangle and trapeze figures represent the profile shapes of the brightest part of M32 and M110 as derived on the left panels, and shown without changes on the right.

References

Choi, P. I.; Guhathakurta, P.; Johnston, K. V., 2002, AJ 124/1 , 310
Dierickx, M.; Blecha, L.; Loeb, A., 2014, ApJ 788, L 39
Ford H.; Jakoby G.H.; Jenner D.C, 1978, ApJ 223, 94
HyperLeda, 2014, $CRAL, ObservatoiredeLion$, http://leda.univ-lyon1.fr/
Ibata, R.; Irwin, M.; Lewis, G.; Ferguson; A.M. N.; Tanvir,N., 2001, Nature 412, 49
Kim S .C., Lee M. G., 1998, J. Korean Astron. Soc. 35,51
NED 2014, $TheNASA/IPACExtragalacticDatabase$, http://ned.ipac.caltech.edu/
Young, C. K.; Currie, M. J.; Dickens, R. J.; Luo, A.-L.;Zhang, T.-J., 2008,ChAA 8 269

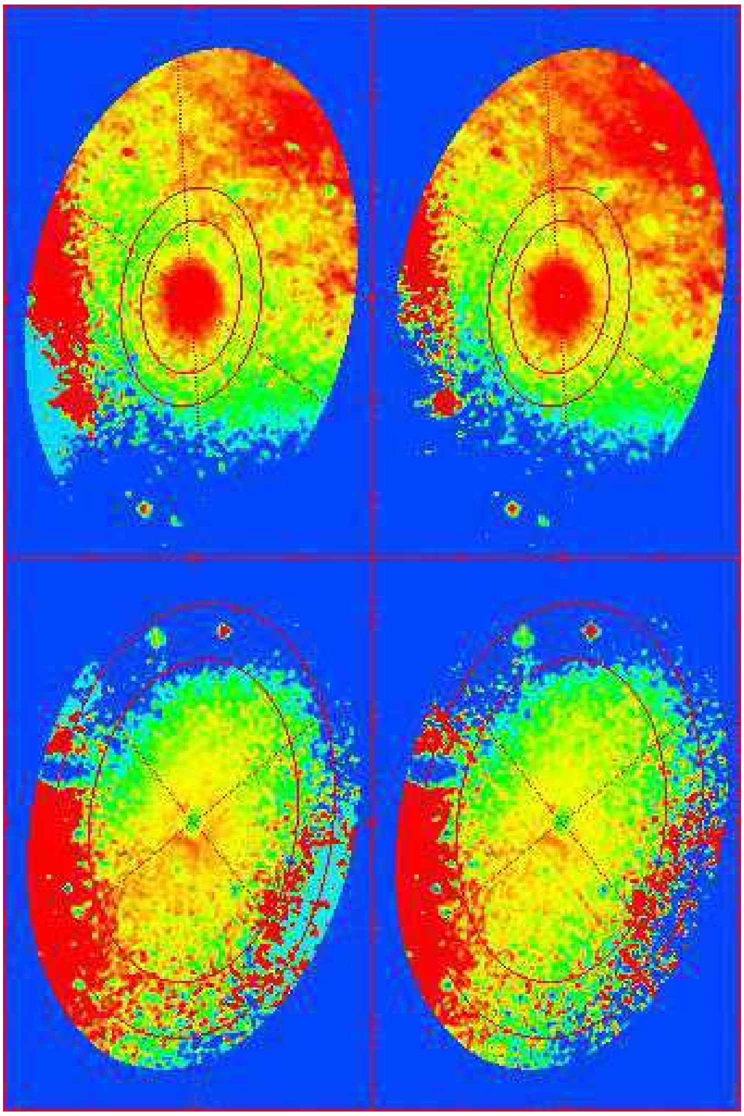

Fig. 8. Color scale maps of the color indexes (b-i) and (b-r)+(v-i) in M32 (upper panels) and M110 (lower panels). North is to the top, east to the left. More red color represents more red color index. The photometric sections are derived along the dashed lines. The ellipses show the standard dimensions and orientation of these satellite galaxies given in databases HyperLeda and NED. Note the slight reddening of M110s color indexes along the line toward M31 center.