Distance to the Dorado Group

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Received February 5, 2020; revised August 5, 2020; accepted August 5, 2020

Abstract—Based on the archival images from the Hubble Space Telescope, we performed the photometry of the brightest galaxies of the Dorado group: NGC 1433, NGC 1533, NGC 1566, and NGC 1672. In the obtained CM-diagrams, red giants are specified, and distances to galaxies are measured by the TRGB method. The estimates obtained: 14.2 ± 1.2, 15.1 ± 0.9, 14.9 ± 1.0, and 15.9 ± 0.9 Mpc show that all the galaxies mentioned are located at approximately similar distances and form a scattered group with the average distance \( D = 15.0 \) Mpc. In the lenticular galaxy NGC 1533, it was found that blue and red supergiants form a ring structure at a distance of 3.6 kpc from the center, and are also visible in the hydrogen arm between the galaxy NGC 1533 and the dwarf IC 2038. High metallicity of these stars (\( Z = 0.02 \)) indicates their origin from the gas of NGC 1533.

Keywords: galaxies: groups: individual: Dorado, galaxies: distances and redshift, galaxies: individual: NGC 1433, NGC 1533, NGC 1566, NGC 1672

DOI: 10.1134/S199034132004015X

1. INTRODUCTION

In the southern constellation Dorado, galaxies of different types and luminosities are concentrated. Shobbrook (1966) singled out 11 galaxies among them which, in his opinion, formed one group; he named it “Dorado.” Based on the measured radial velocities and photometry of galaxies, Shobbrook (1966) estimated the distance to the group as 9.8 Mpc. Its position in the celestial sphere is determined by six massive galaxies: NGC 1433, NGC 1533, NGC 1549, NGC 1553, NGC 1566, and NGC 1672, around which weaker galaxies are concentrated; this can be clearly seen in the diagram by Kilborn et al. (2005). The scattered location of the Dorado galaxies in the sky has led to various hypotheses for their grouping. de Vaucouleurs (1975) grouped (G16, G21, and G22) the bright galaxies and estimated the distance to the major group G16 as 18.4 Mpc. In the same year, Sandage (1975) published the lists of galaxy groups including 12 major and 6 possible members into the Dorado group. He specified the distance to the group as 16.9 Mpc. Subsequently, the membership of the Dorado group changed several times depending on the selection criteria for galaxies or after obtaining new data on radial velocities or measuring distances. Huchra and Geller (1982) divided 28 Dorado galaxies into two groups, HG3 and HG8; and Maia et al. (1989) increased the number of Dorado galaxies up to 60 referring them to groups 7 and 13. Huchra and Geller (1982) and Maia et al. (1989) estimated the distances to the galaxies from the radial velocities and the Hubble constant \( H = 100 \). Thus, all the Dorado galaxies were at a maximum distance of 12 Mpc based on their estimates.

Using photographic observations, Ferguson and Sandage (1990) carried out the photometry of galaxies up to \( B = 20^m \) and referred 79 galaxies to the Dorado group. For most new galaxies, the radial velocities were unknown, so the authors proceeded from the proximity of faint galaxies to bright ones. Carrasco et al. (2001) based on deep images, found 69 low-surface-brightness galaxies in the Dorado group and determined their color indices (\( V − I \)) and magnitudes in the \( V \) and \( I \) filters.

The performed studies have shown that the Dorado group is one of the richest groups of galaxies in the southern sky. Four bright galaxies, the stellar photometry of which we will present further, have active nuclei despite their different morphological types. NGC 1433 and NGC 1672 are Sy2 galaxies, NGC 1566 is a Sy1 galaxy, and NGC 1533 is a LINER galaxy (NED). Therefore, the issue on measuring distances to the Dorado galaxies requires a solution.

After obtaining the Hubble images of the Dorado galaxies, the surface brightness fluctuation method (the SBF method) became possible to be used; Tonry et al. (2001) used this method to measure the distances to several Dorado galaxies. The average estimate obtained, \( D = 18.5 \) Mpc, put this group farther than it was considered earlier.

The Tully–Fisher (TF) method is most frequently used to determine distances to spiral galaxies. Using this method, Tully et al. (2009) estimated the distance
to NGC 1433 equal to 8.32 Mpc and to NGC 1672—11.9 Mpc. In the comprehensive paper by Tully et al. (2013), where the measured distances to many galaxies with different methods are presented, the distances to other two Dorado galaxies are specified: for NGC 1533—20.5 Mpc and for NGC 1566—6.61 Mpc. The distance to NGC 1566 causes doubts, as the NGC 1533 heliocentric velocity \( v_h = 790 \) km s\(^{-1}\), while the NGC 1566 velocity is significantly greater, \( v_h = 1504 \) km s\(^{-1}\). However, Sorce et al. (2014) estimated the distance to NGC 1566 even smaller, \( D = 5.5\)–6.0 Mpc. Distance estimates from radial velocities showed smaller scatter. Firth et al. (2006) determined radial velocities of the Dorado galaxies and found that the distance to it is equal to 16.9 Mpc. Based on their measurements, the group itself is not virialized due to the presence of subgroups inside.

Recent measurements to the galaxies NGC 1433 and NGC 1566 with the TRGB method (Sabbi et al., 2018) yield estimates: 9.04 and 17.9 Mpc. Section 4 tells about these distances in detail.

The above distance measurements indicate large uncertainties in the values obtained, which in turn lead to the same uncertainties when compiling the Dorado group membership. Difficulties increase due to the fact that galaxies are significantly scattered across the sky, and for none of them an accurate distance estimate has not been obtained so far. Even to indicate which of the brightest galaxies is closer is impossible, since the distances for the group brightest galaxies vary widely (see Table 1). For fainter galaxies, the scatter in measurements can only be greater. More realistic distances can be obtained by simply dividing the radial velocities by the Hubble constant. However, this will not take into account the galaxies’ own velocities, the values of which are usually in the range from 50 to 150 km s\(^{-1}\), but inside groups and clusters they can be significantly greater due to the interaction of galaxies with each other. Table 1 shows the main parameters of the galaxies under study. The galaxy classification \( T \), the heliocentric velocities \( v_h \), the apparent magnitudes \( B_r \), and the sizes of galaxies \( a \times b \) are taken from NED, while we measured the distances and calculated the luminosities of the galaxies. The minimum and maximum distances, \( D_{\text{min}} \) and \( D_{\text{max}} \), are from the literature data.

To avoid the difficulties in compiling a list of galaxies for one large group, you can divide it into subgroups, each of which includes those galaxies that are concentrated around the bright ones. This is how the groups NGC 1533, NGC 1566, and NGC 1672 were allocated (Kilborn et al., 2005), which were earlier included in the same Dorado group. Something similar is observed in the Virgo cluster, where groups of galaxies around M87, M86, and M49 are distant from each other, but together they form one Virgo cluster.

2. STELLAR PHOTOMETRY

For the four bright galaxies of the Dorado group, the Hubble images were obtained using different programs and in different years; they could be used for stellar photometry and distance determination. Unfortunately, most images obtained are of the central regions of the galaxies, where bright background galaxies and the presence of supergiants and AGB stars brighter than red giants made these regions of little use for distance determination with the TRGB method. Therefore, we measured the distances only for the stars on the periphery of such galaxies. This selection resulted in the decrease of the whole number of sample stars but increased the number of red giants relative to other types of stars which allowed us to measure the position of the tip of the red giant branch (TRGB discontinuity) which is necessary to calculate the distance.

To study the stellar population of galaxies and determine the distance, we used the archive images of the Hubble Space Telescope (HST) obtained according to proposals 10438, 10354, 12659, 12999, 13364, and 15654 with the ACS/WFC and WFC3 cameras. Table 2 presents information on the original photometric data: the number of a proposal (ID), the camera (ACS or WFC3), the exposure time in seconds in the corresponding filters (F814W(\( I \)), F606W(\( V \)), F555W(\( V \)), F435W(\( B \)), F110W(\( IR \)), and F160W(\( IR \)).

Figure 1 presents images in the blue filter \( B \) of the four main galaxies of the Dorado group from the DSS archive (Digitized Sky Survey) with the positions of the HST images marked, and Fig. 2 shows the images of the same galaxies obtained with the HST in the F606W, F555W, and F435W filters.

### Table 1. Parameters of bright Dorado galaxies

| Galaxy     | \( T \)  | \( B_r \), mag | \( v_h \), km s\(^{-1}\) | \( a \times b \), arcmin | \( D \), Mpc | \( M_B \), mag | \( D_{\text{min}} \), Mpc | \( D_{\text{max}} \), Mpc |
|------------|---------|----------------|-------------------------|------------------------|-------------|-------------|------------------------|------------------------|
| NGC 1433  | (R)SB(r)ab | 10.70         | 1076                    | 6.5 \times 5.9         | 14.2        | -20.08      | 8.3\(^1\)               | 11.6\(^2\)              |
| NGC 1533  | SB(rs)0   | 11.70         | 790                     | 2.8 \times 2.3         | 15.1        | -19.26      | 13.4\(^2\)              | 24.1\(^3\)              |
| NGC 1566  | SAB(s)bc  | 10.33         | 1504                    | 8.3 \times 6.6         | 14.9        | -20.56      | 5.5\(^4\)               | 21.3\(^5\)              |
| NGC 1672  | SB(sb)    | 10.28         | 1331                    | 6.6 \times 5.5         | 15.9        | -20.81      | 9.9\(^6\)               | 14.5\(^2\)              |

\(^1\) Tully et al. (2009), \(^2\) Tully and Fisher (1988), \(^3\) Springob et al. (2014), \(^4\) Sorce et al. (2014), \(^5\) Willick et al. (1997), \(^6\) Giraud (1985).
The stellar photometry of galaxies was performed with two software packages: DAOPHOT II (Stetson, 1987, 1994) and DOLPHOT 2.0 (Dolphin, 2016). The stellar photometry with both packages was conducted in a standard way. We described this earlier in (Tikhonov and Galazutdinova, 2009; Tikhonov et al., 2009) for DAOPHOT II. The package DOLPHOT 2.0 (Dolphin, 2016) was used as was recommended by its author1, and the photometry procedure consisted of preliminary masking of bad pixels, removal of cosmic rays and further PSF photometry of the found stars in two filters. To separate star-like and diffuse objects (stellar clusters, distant or compact galaxies), we made selection by the “CHI” and “SHARP” parameters which determine the shape of the photometric profile of each measured star (Stetson, 1987). The difference between the profiles of diffuse objects and the profiles of isolated stars, which we selected as standard ones, made it possible to carry out such selection for the lists of objects obtained with DAOPHOT II and DOLPHOT 2.0.

The principles of the DOLPHOT and DAOPHOT photometry are the same, but there are some differences in their use. For example, in DAOPHOT, we took single stars from the studied fields as PSF stars, and in DOLPHOT we used the PSF profile library. The difference in the results of these two programs is noticeable when comparing the apparent distribution of very faint stars over the image field. Due to inefficiency of charge transfer and the existence of residual traces of cosmic rays, DOLPHOT shows an excessive number of faint stars in the central region of the field instead of their smooth distribution, while the distribution of stars in DAOPHOT is closer to realistic. Although, in DAOPHOT, there is a problem of choosing PSF stars with high concentration of stars. Taking into account pros and cons of the two software packages, we used both of them comparing the results obtained. When measuring the positions of TRGB discontinuities, both methods gave similar results and no significant differences were found between them.

The Hertzsprung–Russell diagrams (CM diagrams) obtained with the stellar photometry of three spiral galaxies are the usual diagrams for galaxies of this type, thus we present the diagram of NGC 1566 and the diagram of the periphery of NGC 1672 as examples (Fig. 3). The diagrams clearly show the branches of blue and red supergiants. Red giants do not visually stand out due to a large number of brighter supergiants and AGB stars.

The diagram of the galaxy NGC 1533 (Fig. 4) is interesting by the fact that in a lenticular galaxy, where large star-formation regions are not visible, there are blue and red supergiants. Radio observations in HI (Ryan-Weber et al., 2004) revealed a ring structure around NGC 1533 and an extended arm connecting it and the dwarf peculiar galaxy IC2038, with which it interacts (Cattapan et al., 2019). The structure of the gaseous arm between galaxies is clearly seen in diagram 7 in the paper by Werk et al. (2010).

The CM diagram of NGC 1533 we obtained (Fig. 4a) shows a branch populated by globular clusters with the color index $(V - I) = 1$. A similar diagram is presented in the paper by DeGraaff et al. (2007). However, the diagram in Fig. 4a was obtained with the intentionally increased parameter CHI $< 2.5$ which resulted in the appearance of diffuse objects in the list of stars and in the CM diagram. If we use the standard version, CHI $< 1.2$, then most globular clusters will disappear in the CM diagram and only stars and very compact star-like globular clusters will remain (Fig. 4b).

Blue stars, the branch of which is visible in the diagram in Fig. 4, are partially scattered throughout the galaxy, although, most of them are part of small clusters located mainly in the inner regions of the galaxy. Single clusters are visible even beyond 30 kpc from the center of the galaxy (DeGraaff et al., 2007; Werk et al., 2008, 2010). An important issue in studying young stars in NGC 1533 is the question on the source of gas, from which young stars visible in the CM diagram

| Galaxy     | ID  | Camera | $T_{\text{exp}}$, s |
|------------|-----|--------|---------------------|
|            |     |        | F814W | F606W | F555W | F435W | F110W | F160W |
| NGC 1433   | 13364 | WFC3   | 986   | 1140  | 1212  | 1412  |
| NGC 1433   | 12659 | WFC3   | 4950  | 2288  | 1212  | 1412  |
| NGC 1533-1 | 10438 | ACS    | 989   | 1143  | 1212  | 1412  |
| NGC 1533-2 | 10438 | ACS    | 1244  | 768   | 1212  | 1412  |
| NGC 1672   | 10354 | ACS    | 2444  | 2444  | 1212  | 1412  |
| NGC 1672   | 15654 | ACS    | 3775  | 3063  | 1212  | 1412  |

1 http://americano.dolphinsim.com/dolphot/dolphot.pdf.
were born. Since NGC 1533 interacts with the dwarf irregular galaxy IC 2038 which has hydrogen, it can be assumed that the periphery of the dwarf galaxy could have been stripped and became a source of hydrogen for NGC 1533.

The diagram of Fig. 5(1) presents the distribution of blue stars with the color index \((V - I) < 0.3\) over the body of the galaxy. You can see that individual stars and small clusters form a ring around the center of the galaxy. In addition, these blue stars are concentrated in the periphery, where a fragment of the gaseous arm between NGC 1533 and IC 2038 appears in the HST image. In the CM diagram of NGC 1533 (Fig. 4b), a low-contrast branch of red stars with the color index \((V - I) = 1.75\) is visible. We selected these stars and built their distribution over the body of the galaxy (Fig. 5(2)). It can be seen that these red stars, like blue supergiants, also form a ring and concentrate in the arm between the two galaxies. The presence of a ring structure from star-formation regions is confirmed by images of the GALEX space telescope in the near and far ultraviolet regions, in which separate clusters are observed also forming a ring structure like young stars. It can be noted that in morphological description of the type of the galaxy NGC 1533—SB(rs)0, the presence of a ring is also indicated, but it is unclear whether the ring-shaped structure of young stars, which is visible in our diagrams, is related to this ring.

To study the stellar population of the rings visible in Fig. 5, we have selected the stars included in it at \(700 < \text{RAD} < 1200\) pixels corresponding to \(2.6 < \text{RAD} < 4.4\) kpc. Figure 6 shows the distribution of these stars by the color index \((V - I)\). The diagram easily identifies the maxima corresponding to blue supergiants (BSG) and compact globular clusters at \((V - I) = 1\). It is quite obvious that the maximum at \((V - I) = 1.75\)
corresponds to red supergiants. It becomes clear why blue and red stars form almost identical visible distributions over the body of the galaxy. The red supergiants are not very old, and they are concentrated in the same regions where they were born, and where the younger blue supergiants can be seen.

Figure 7 presents the CM diagram of the ring stars shown in Fig. 5. We have drawn the most suitable isochrones in this diagram (Bertelli et al., 1994). These isochrones showed that the age of red supergiants is in the range from 12 to 30 Myr, and their metallicity is equal to the metallicity of the Sun ($Z = 0.02$). It is possible that older supergiants are also present in the sample, but they are difficult to identify. It follows from the results obtained that hydrogen, from which the ring stars were formed, cannot be the hydrogen of the dwarf galaxy IC 2038, whose luminosity $M_V = -16$, since such galaxies have a lower metallicity of hydrogen clouds and young stars born from them (Tikhonov, 2018). In addition, a high metallicity indicates that the young stars visible in NGC 1533 cannot be the stars of

Fig. 2. HST images of the galaxies shown in Fig. 1: NGC 1433 (a) and NGC 1566 (b) in the F555W filter, NGC 1533 (c) and NGC 1672 (d) in the F606W and F435W filters respectively.
**Fig. 3.** CM diagram of stars from central regions of the galaxy NGC 1566 and the periphery of the galaxy NGC 1672. The lines mark the position of the branches of blue supergiants (BSG) and red supergiants (RSG) in NGC 1566.

**Fig. 4.** CM diagram of the galaxy NGC 1533 with different CHI values. With CHI $< 2.5$, the diagram contains globular clusters, the branch of which is visible with $(V - I) = 1$. With CHI $< 1.2$, stars and very few compact clusters remain in the diagram.

**Fig. 5.** Distribution in the form of a ring of blue (1) and red (2) supergiants in the galaxy NGC 1533. The coordinate system center is aligned with the center of the galaxy. The size and orientation of the diagram is the same as that of the NGC 1533 image in Fig. 2. The concentration of stars on the periphery of a galaxy belongs to the gas bar between the galaxies NGC 1533 and IC 2038.
the first star-formation wave in the periphery of the galaxy, as was suggested by Ryan-Weber et al. (2004).

Red supergiants can also be seen in the arm between the galaxies NGC 1533 and IC 2038, although, in a smaller number than in the ring. Measurement of their metallicity gives a slightly lower value than for ring stars. It can be suggested that the decrease in the metallicity of the arm stars between the galaxies indicates possible mixing of gas in two galaxies, one of which supplies hydrogen, and the other enriches it with metals.

Figure 5 shows that blue and red stars are located not only in the ring and arm, but also closer to the center of the galaxy. Indeed, the CM diagram of the central region of the galaxy contains single blue and red supergiants at 0.7 < RAD < 1.7 kpc, but the main concentration of red stars near the center of the galaxy (Fig. 5(2)) is created by AGB stars.

3. DETERMINATION OF DISTANCES

The red giant branch (RGB) required for distance measurements is not visible in the CM diagrams of the galaxies (Fig. 3) due to the large number of brighter stars and the increased brightness of the galaxy background. In the images of the galaxy NGC 1533 (Fig. 1), it is easy to find periphery areas, where bright stars are absent and the brightness of the galaxy is low. Stars were selected in such areas to determine the TRGB discontinuity. The stellar halo of NGC 1672 extends far beyond the body of the galaxy visible in Fig. 1. Therefore, to search for red giants, the image of the galaxy periphery was used, where bright stars occupy only a part of the image. It was more difficult to create samples of stars near the galaxies NGC 1433 and NGC 1566, where almost the entire area is occupied by bright stars with the high background brightness. In these galaxies, the stars were chosen outside the spiral branches at RAD > 2000 pixels which corresponds to 100″ or 6.9 kpc for NGC 1433 and RAD > 2500 pixels which to 125″ or 9.0 kpc for NGC 1566. In addition, the color index selection (1.2 < (V − I) < 1.7) was applied so that the luminosity function of red giants was not affected by blue stars and AGB stars with a high color index.

After selection, the luminosity functions were obtained for the stars of four galaxies (Fig. 8). The beginning of the red giant branches (TRGB discontinuities) and the beginning of the branches of AGB stars are marked in the diagrams. The difference between them is approximately one magnitude. To objectively present the positions of the TRGB discontinuities, we used the Sobel function (Madore and Freedman, 1995), the maxima of which correspond to sharp changes in the number of stars which is observed at the boundary of the red giant branch. The thin line in the diagrams of Fig. 8 show the Sobel function, the positions of the maxima of which we used to determine the distances to galaxies.

In addition to the TRGB discontinuities, we measured the color indices of the tips of the red giant branches (V − I)_TRGB, the values of which do not differ from those of galaxies of a similar type. The values of light absorption in the direction of galaxies are taken from the paper by Schlafly and Finkbeiner (2011) and are given in Table 3. Distances to NGC 1433, NGC 1533, NGC 156, and NGC 1672, as well as the distance moduli and metallicities of red giants in these galaxies, we determined using the equations from the paper by Lee et al. (1993) on the application of the TRGB method. Table 3 presents the results obtained, where I TRGB is the position of the TRGB discontinuity on the luminosity function in the I filter, (m − M) is
the distance modulus, $[\text{Fe}/\text{H}]$ is the metallicity of red giants, $D$ is the distance to the galaxy, $A_I$ is the extinction in the $I$ filter.

The distance measurement accuracy (external accuracy) specified in Table 3 is the result of the addition of several possible sources of measurement errors. The accuracy of the method by Lee et al. (1993) is 0.1 m. The accuracy of determining the TRGB discontinuity varies from galaxy to galaxy and does not exceed 0.05 m. The remaining components of the measurement error do not exceed 0.02 m–0.03 m.

4. RESULTS AND DISCUSSION

The exact distances for the main galaxies of the Dorado group have been determined by the TRGB method for the first time ever. For the subgroups of galaxies around NGC 1433, NGC 1566, and NGC 1672, they are approximately similar, and we can assume that these galaxies form a single group in which the virialization process has not ended. The average distance to the Dorado group for the four galaxies without correction for the masses of individual galaxies: $D = 14.99$ Mpc. This is significantly smaller than the distance based on the SBF method and is more consistent with the distance obtained from the radial velocities and the Hubble constant. The found distances of galaxies will allow one to accurately estimate the energy of their active nuclei and to establish the spatial positions of the Dorado galaxies among neighbors.

We have established that young stars of the lenticular galaxy NGC 1533, forming a ring (Fig. 5) and being located in the arm to IC 2038, have a high metallicity ($Z = 0.02$) equal to the metallicity of the Sun, and their age reaches 30 Myr. Based on the high metallicity of

### Table 3. Photometry of the galaxies

| Galaxy   | $I_{\text{TRGB}}$, mag | $(m - M)$, mag | $D$, Mpc     | $[\text{Fe}/\text{H}]$ | $A_I$, mag | $E(V - I)$, mag |
|----------|------------------------|----------------|--------------|------------------------|------------|-----------------|
| NGC 1433 | 26.72                  | 30.75          | 14.15 ± 1.15 | −1.46                  | 0.014      | 0.011           |
| NGC 1533 | 26.89                  | 30.90          | 15.12 ± 0.90 | −1.64                  | 0.024      | 0.020           |
| NGC 1566 | 26.87                  | 30.86          | 14.88 ± 1.00 | −1.79                  | 0.014      | 0.011           |
| NGC 1672 | 27.03                  | 31.00          | 15.86 ± 0.92 | −1.74                  | 0.035      | 0.029           |

Fig. 8. Luminosity function of red giants and AGB stars for four galaxies. The vertical bars mark the positions of TRGB discontinuities and the boundaries of the increase in the number of AGB stars.
In some publications (see, for example, Carrasco et al., 2001; Firth et al. (see, for example, 2006) it is reported that Dorado was first mentioned was in the paper by Shahbazian (1957) with number 18. However, the above publication only mention the stellar cluster in the northern sky. Apparently, the first error was copied by later authors without reading the paper.

The NED states that Sabbi et al. (2018) measured the distances by the TRGB method for the galaxies NGC 1433 and NGC 1566. For the galaxy NGC 1566, this message is wrong, since the authors themselves write that the TRGB discontinuity is outside the boundaries of the CM diagram they obtained.

For the galaxy NGC 1433, Sabbi et al. (2018) obtained the distance $D = 9.1$ Mpc, i.e., it should be a relatively nearby galaxy. Indeed, if we take the stars of this galaxy outside the bright nucleus and carry out the usual selection by color, CHI, and SHARP parameters, then on the luminosity function you can see a discontinuity at $I = 25.7$ which corresponds to the distance $D = 9.1$ Mpc. However, this discontinuity refers to AGB stars, and the true TRGB discontinuity is weaker by one magnitude. Earlier (Tikhonov and Galazutdinova, 2018), we described in detail a similar error for the galaxies Maffei1 and Maffei2, where the beginning of the branch of AGB stars was taken as the TRGB discontinuity.

To show the actual positions of the re giant branch, Figure 9 shows the CM diagram of the NGC 1433 galaxy periphery. The diagram shows that at $I = 25.7$, which corresponds to a distance of $9.1$ Mpc, the red giant branch (RGB) is absent. Visualy, it seems that in Fig. 9 the TRGB discontinuity is visible at $I = 26.5$, but a more detailed study of the distribution of stars shows that the actual TRGB discontinuity is located at $I = 26.72$ (Fig. 8), and the supposed discontinuity at $I = 26.5$ is caused by the presence of AGB stars in the sample.

The HST archive contains infrared images in the F110W and F160W filters obtained for the field at a distance of $30'$ from NGC 1433. We carried out photometry of these images and found out that there is an increase in the number of stars (Fig. 10) at $F160W = 24.95$. This value is consistent with the distance to NGC 1433 at $I_{TRGB} = 26.72$. The angular distance between NGC 1433 and this field is $124$ kpc. In the massive elliptical galaxy M87, the stellar periphery can be observed to a distance of $190$ kpc (Tikhonov et al., 2019), and in the lenticular galaxy NGC 5129, whose brightness is similar to that of NGC 1433, the stellar halo can be observed up to $140$ kpc (Rejkuba et al., 2014), i.e., there is reason to believe that the halo of NGC 1433 extends up to $124$ kpc.
ACKNOWLEDGMENTS

The paper is based on observations from the NASA/ESA Hubble Space Telescope from the Space Telescope Science Institute operated by AURA, Inc. under contract no. NAS5–26555. These observations are related to proposals 10438, 10354, 12999, 13364, and 15654. In this paper, we used the NED and HyperLeda databases.

FUNDING

The study was carried out with the financial support of the Russian Foundation for Basic Research and the National Science Foundation of Bulgaria within the framework of scientific project no. 19-52-18007.

CONFLICT OF INTEREST

The authors declare no conflict of interest regarding the publication of this paper.

REFERENCES

1. G. Bertelli, A. Bressan, C. Chiosi, et al., Astron. and Astrophys. Suppl. 106, 275 (1994).
2. E. R. Carrasco, C. Mendes de Oliveira, L. Infante, and M. Bolte, Astron. J. 121 (1), 148 (2001).
3. A. Cattapan, M. Spavone, E. Iodice, et al., Astrophys. J. 874 (2), 130 (2019).
4. G. de Vaucouleurs, Nearby Groups of Galaxies (Chicago Univ. Press, Chicago, USA, 1975), p. 557.
5. R. B. DeGraaff, J. P. Blakeslee, G. R. Meurer, and M. E. Putman, Astrophys. J. 671 (2), 1624 (2007).
6. A. Dolphin, DOLPHOT: Stellar photometry (2016), ascl:1608.013.
7. H. C. Ferguson and A. Sandage, Astron. J. 100, 1 (1990).
8. P. Firth, E. A. Evstigneeva, J. B. Jones, et al., Monthly Notices Royal Astron. Soc. 372 (4), 1856 (2006).
9. E. Giraud, Astron. and Astrophys. 153, 125 (1985).
10. J. P. Huchra and M. J. Geller, Astrophys. J. 257, 423 (1982).
11. V. A. Kilborn, B. S. Koribalski, D. A. Forbes, et al., Monthly Notices Royal Astron. Soc. 356 (1), 77 (2005).
12. M. G. Lee, W. L. Freedman, and B. F. Madore, Astrophys. J. 417, 553 (1993).
13. B. F. Madore and W. L. Freedman, Astron. J. 109, 1645 (1995).
14. M. A. G. Maia, L. N. da Costa, and D. W. Latham, Astrophys. J. Suppl. 69, 809 (1989).
15. M. Rejkuba, W. E. Harris, L. Greggio, et al., Astrophys. J. 791 (1), L2 (2014).
16. E. V. Ryan-Weber, G. R. Meurer, K. C. Freeman, et al., Astron. J. 127 (3), 1431 (2004).
17. E. Sabbi, D. Calzetti, L. Ubeda, et al., Astrophys. J. Suppl. 235 (1), 23 (2018).
18. A. Sandage, Astrophys. J. 202, 563 (1975).
19. E. F. Schlaufy and D. P. Finkbeiner, Astrophys. J. 737 (2), 103 (2011).
20. R. K. Shahbazian, Astronomicheskij Tsirkulyar 177, 11 (1957).
21. R. R. Shobbrook, Monthly Notices Royal Astron. Soc. 131, 365 (1966).
22. J. G. Sorce, R. B. Tully, H. M. Courtois, et al., Monthly Notices Royal Astron. Soc. 444 (1), 527 (2014).
23. C. M. Springob, C. Magoulas, M. Colless, et al., Monthly Notices Royal Astron. Soc. 445 (3), 2677 (2014).
24. P. B. Stetson, Publ. Astron. Soc. Pacific 99, 191 (1987).
25. P. B. Stetson, Publ. Astron. Soc. Pacific 106, 250 (1994).
26. N. A. Tikhonov, Astrophysical Bulletin 73 (1), 22 (2018).
27. N. A. Tikhonov and O. A. Galazutdinova, Astronomy Letters 35 (11), 748 (2009).
28. N. A. Tikhonov and O. A. Galazutdinova, Astrophysical Bulletin 74 (3), 279 (2018).
29. N. A. Tikhonov, O. A. Galazutdinova, and G. M. Karataeva, Astrophysical Bulletin 74 (3), 257 (2019).
30. N.A.Tikhonov, O.A.Galazutdinova, and E.N.Tikhonov, Astronomy Letters 35 (9), 599 (2009).
31. J. L. Tonry, A. Dressler, J. P. Blakeslee, et al., Astrophys. J. 546 (2), 681 (2001).
32. R. B. Tully, H. M. Courtois, A. E. Dolphin, et al., Astron. J. 146 (4), 86 (2013).
33. R. B. Tully and J. R. Fisher, Catalog of Nearby Galaxies (Cambridge Univ. Press, Cambridge, 1988).
34. R. B. Tully, L. Rizzi, E. J. Shaya, et al., Astron. J. 138 (2), 323 (2009).
35. J. K. Werk, M. E. Putman, G. R. Meurer, et al., Astrophys. J. 678 (2), 888 (2008).
36. J. K. Werk, M. E. Putman, G. R. Meurer, et al., Astron. J. 139 (1), 279 (2010).
37. J. A. Willick, S. Courteau, S. M. Faber, et al., Astrophys. J. Suppl. 109 (2), 333 (1997).

Translated by N. Oborina