KDG 218, a Nearby Ultra-Diffuse Galaxy

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We present properties of the low-surface-brightness galaxy KDG 218 observed with the HST/ACS. The galaxy has a half-light (effective) diameter of $a_e = 47''$ and a central surface brightness of $SB_V(0) = 24''4/\square''$. The galaxy remains unresolved with the HST/ACS, which implies its distance of $D > 13.1$ Mpc and linear effective diameter of $A_e > 3.0$ kpc. We notice that KDG 218 is most likely associated with a galaxy group around the massive lenticular NGC 4958 galaxy at approximately 22 Mpc, or with the Virgo Southern Extension filament at approximately 16.5 Mpc. At these distances, the galaxy is classified as an ultra-diffuse galaxy (UDG) similar to those found in the Virgo, Fornax, and Coma clusters. We also present a sample of 15 UDG candidates in the Local Volume. These sample galaxies have the following mean parameters: $\langle D \rangle = 5.1$ Mpc, $(A_e) = 4.8$ kpc, and $\langle (SB_B(e)) \rangle = 27''4/\square''$. All the local UDG candidates reside near massive galaxies located in the regions with the mean stellar mass density (within 1 Mpc) about 50 times greater than the average cosmic density. The typical average surface brightness in the nearest dwarf systems resolved into stars reaches approximately $[28–30]''/\square''$.

Generally, normal and dwarf galaxies in the wide range of the absolute magnitudes $M$ follow the relation $SB \sim M/3$ which reflects the approximate consistency of the mean spatial luminosity in massive and dwarf galaxies [4]. However, recently a new population of extremely low-surface-brightness galaxies has been found, the luminosity of which is typical of dwarf systems ($M_B > -15$), and sizes are comparable with those of normal galaxies. This galaxy category was called ultra-diffuse galaxies (UDG). According to the paper [5], galaxies with the effective diameter $A_e > 3.0$ kpc and the central surface brightness in $g$ band $SB_g(0) > 24''/\square''$ should be referred to UDGs. The same authors [6] detected about 50 UDG candidates in the rich Coma cluster and confirmed with spectroscopic observations that they really belong to the cluster. In the last two years, ultra-diffuse galaxies were found in the nearby Virgo cluster [7, 8], in the Fornax cluster [9], in the Perseus supercluster [10, 11], and in some other clusters [12].
The authors of the paper [13] reported on the detection of at least 800 UDG candidates in the central region of the Coma cluster. The presence of ultra-diffuse galaxies in the local groups around Cen A, NGC 253, and NGC 5485 was also shown in [14–16]. According to paper [17], about 40% of UDGs belong to clusters, about 20%—to groups, and about 40%—to scattered filaments, while in the general field such objects are almost not found.

In this paper, we present arguments of the fact that the low-surface-brightness galaxy KDG 218 located on the outskirts of the Virgo cluster may be assigned to UDG-type systems.

2. OBSERVED PROPERTIES OF KDG 218

2.1. Observations with the HST/ACS

The low-surface-brightness galaxy KDG 218 with the equatorial coordinates $13^{h}05^{m}43^{s}9−07^\circ 45^\prime 32^\prime$ (J2000.0) was included in the program of distance measurements for galaxies located on the front border of the Virgo cluster (the program GO-14636, PI I. D. Karachentsev). The KDG 218 images were obtained on May 18, 2017 using the Advanced Camera for Survey (ACS) at the Hubble Space Telescope (HST) in the F606W (broad-band $V$) and F814W (broad-band $I$) filters with integrated exposures of 1030 s in each filter. Figure 1 shows the image of the galaxy in the F606W filter. In the Updated Nearby Galaxy Catalog (=UNGC [4]), KDG 218 is classified as a dwarf system of the transition type $T_r$ with the integral magnitude $B = 16^{m}8$, angular diameter $1^{\prime}$, and average surface brightness $SB = 26^{m}6/\square^\prime\prime$. We carried out stellar photometry using the DOLPHOT [18] package. Figure 2 presents color-magnitude diagrams (CMD) for the detected stars within the galaxy and in the whole ACS field. As we can see, KDG 218 is almost unresolved into stars. Inside the galaxy, there are no blue stars brighter than $I \approx 25^{m}$, and redder stars can be considered as foreground and background objects. We do not find the presence of RGB stars in the CMD. Some concentration of stars near the photometric limit in the F814W and F606W filters is caused by the photometric errors which is confirmed with simulation of artificial stars with DOLPHOT.

Assuming that the red giant branch tip with $M_I(\text{TRGB}) = -4^{m}05$ and $V - I \approx +1.0$ is not higher than $I \approx 26^{m}6$, we obtain the distance module estimate for KDG 218 $(m-M)_0 > 30.58$. According to the paper [19], $A_I = 0^{0}07$ is accepted for the Galactic extinction here. Thus, the KDG 218 galaxy is at a distance not closer than 13.1 Mpc.

Let us notice that the distribution of star-like objects selected using DOLPHOT with apparent magnitudes of $26.5 > I > 26.0$ and color indices of $1.7 > V - I > 0.8$ shows weak concentration towards the center of KDG 218. Abundance of such objects inside the galaxy is $\Delta N = 62 \pm 11$. Possibly, some part of this abundance is determined by the presence of globular clusters in KDG 218, luminosity and color of which correspond to the selected intervals.

2.2. Surface Photometry

We used images of KDG 218 obtained with the HST/ACS to perform the surface photometry of the galaxy. Figure 3 shows the results. The panel a presents behavior of the integral magnitude of KDG 218 in the $I$ (1) and $V$ (2) filters depending on the circular radius $R$ (in arcseconds). The bottom panel a reflects the variations with the radius of the integral color index. From these data, the integral magnitudes of the galaxy within $R = 42^\prime$ are $V(< 42^\prime) = 16.18 \pm 0.05$ mag and $I(< 42^\prime) = 15.22 \pm 0.05$ mag. Taking into consideration the relation $B - V = 0.85(V - I) - 0.2$ [20], we obtain $B_T \simeq B(< 42^\prime) = 16^{m}80$ for KDG 218 that is in good agreement with the by-eye estimate $B_T = 16^{m}8$ mentioned above. The galaxy’s color index $B - V = 0.62$ corresponds to its transition type (Tr) with an older stellar population. The panel b of Fig. 3 demonstrates the measured profile of the KDG 218 brightness in the $I$ and $V$ bands as well as the variations of the color index $(V - I)$. The central surface brightness of the galaxy is

$$SB_V(0) = 24.39 \pm 0.05^{m}/\square^\prime\prime$$
Figure 1. Image of the KDG 218 galaxy obtained with the HST/ACS in the F606W filter. The field size is about 3.5' × 3.5', the North is on the right, the East is at the top.

Figure 2. Color–magnitude diagrams in the central region of KDG 218 of a1' × 1' size (left) and in the whole ACS image (right).
Figure 3. Apparent integral magnitude (a) and surface brightness (b) in the V and I bands in dependence on aperture radius in arcseconds.

and

$$SB_I(0) = 23.45 \pm 0.05$$

or

$$SB_B(0) = 24.99$$

. The brightness profile averaged over two filters corresponds to the Sersic parameter $n = 0.60 \pm 0.03$ with the effective radius $R_e = 23\arcsec 6 \pm 0\arcsec 6$.

2.3. Neighborhood and Distance Estimation

KDG 218 resides in the region of the so-called “Virgo Southern Extension” at an angular distance of $21\degree 9$ from the center of the Virgo cluster identified with NGC 4486. This distance corresponds almost exactly to the radius of the zero-velocity surface $23\arcsec 6 \pm 2\arcsec 3$ [21] which separates the collapsing region around the cluster against the global cosmological expansion. Unfortunately, KDG 218 still has its radial velocity unmeasured.

There is a spiral late-type galaxy NGC 4948 with the heliocentric radial velocity $V_h = 1123$ km s$^{-1}$ near KDG 218 at an angular separation of 17$\arcsec$. Its distance determined with the SNIa supernova. In the neighborhood, there are several more galaxies, distances to which were estimated [23] with the Tully–Fisher method.

Table 1 presents equatorial and supergalactic coordinates as well as morphological types, heliocentric velocities ($V_h$, km s$^{-1}$), apparent magnitudes ($B_T$), distances ($D$, Mpc), and methods used in their estimation for 16 galaxies with radial velocities in the range of $V_h = [620, 1620]$ km s$^{-1}$ within a radius of 150$\arcsec$ around KDG 218. Into this list ranged by the angular distance from KDG 218, the low-surface-brightness galaxy [KKS 2000]42 was included, integral parameters of which are similar to those
Table 1. Galaxies within 150' of KDG 218 between $V_h$ 620 and 1620 km s$^{-1}$

| Name          | RA (2000.0) Dec | SGL, deg | SGB, deg | Type | $V_h$, km s$^{-1}$ | $B_T$, mag | $D$, Mpc | Method |
|---------------|----------------|----------|----------|------|-------------------|------------|----------|--------|
| KDG 218       | 130543.9 − 074532 | 124.64   | +00.46   | Tr   | –                 | 16.8       |          |        |
| DDO 163       | 130514.3 − 075321 | 124.74   | +00.31   | Sm   | 1123              | 16.0      | 23.7     | TF     |
| NGC 4948      | 130455.9 − 075652 | 124.77   | +00.22   | Sdm  | 1123              | 14.0      | 22.0     | SN     |
| 2MASX         | 130701.6 − 074155 | 124.67   | +00.79   | Sdm  | 1612              | 15.1      | –        |        |
| NGC 4958      | 130548.9 − 080113 | 124.90   | +00.41   | S0   | 1455              | 12.1      | 21.4     | TF     |
| [KKS 2000]42  | 130619.1 − 080533 | 125.00   | +00.51   | Tr   | –                 | 18.3      | –        |        |
| NGC 4948A     | 130505.8 − 080941 | 124.99   | +00.20   | Sdm  | 1541              | 14.5      | 15.6     | TF     |
| NGC 4951      | 130507.7 − 062938 | 123.39   | +00.66   | Scd  | 1176              | 12.6      | 15.5     | TF     |
| GALEX         | 130456.2 − 094850 | 126.57   | −00.29   | BCD  | 1460              | 16.3      | –        |        |
| IC 4212       | 131203.0 − 065833 | 124.32   | +02.18   | Scd  | 1476              | 14.5      | 21.9     | TF     |
| IC 3908       | 125640.6 − 073346 | 123.84   | −01.65   | Sd   | 1296              | 13.5      | 21.6     | TF     |
| NGC 4818      | 125648.9 − 083131 | 124.78   | −01.87   | Sab  | 1065              | 12.1      | 12.2     | TF     |
| NGC 4813      | 125636.1 − 064904 | 123.12   | −01.46   | Sa   | 1394              | 14.1      | –        |        |
| RFGC 2432     | 125848.9 − 060646 | 122.59   | −00.74   | Sm   | 1600              | 14.5      | 24.2     | TF     |
| NGC 4941      | 130413.1 − 053306 | 122.42   | +00.70   | Sab  | 1108              | 12.4      | 14.6     | TF     |
| GALEX         | 131038.6 − 095554 | 127.07   | +01.03   | BCD  | 1165              | 16.5      | –        |        |
| UGCA 311      | 125746.8 − 093801 | 125.91   | −01.94   | Sdm  | 1482              | 14.2      | 26.5     | TF     |

Figure 4. Map of the neighborhood of the galaxies with radial velocities of $V_h$ = [620 − 1620] km s$^{-1}$ and projected separation less than 2.5' around KDG 218.

of KDG 218 = [KKS 2000]41. Figure 4 shows the distribution of the KDG 218 neighbors in extragalactic coordinates, where the sizes of the galaxies are proportional to their apparent magnitude, and two low-surface-brightness objects are marked with open circles. The center of the Virgo cluster (SGL= 102°88, SGB= −2°35) is on the right, far from the figure borders.

According to the given data KDG 218 along with NGC 4948 and DDO 163 is a possible companion of the massive S0 galaxy NGC 4958 at a distance of $D \approx 22$ Mpc. In this case, the angular diameter of KDG 218 $a_e = 0.79$, in which the half of galaxy’s luminosity is included, corresponds to the effective linear diameter $A_e = 5.04$ kpc. Consequently, both central surface brightness, $SB_g(0) = 24^{m}8/\Omega''$, and effective diameter of KDG 218 satisfy the criterion of an ultra-diffuse galaxy. This criterion remains valid if KDG 218 resides in the VirgoSE filament at the distance of the Virgo cluster itself (16.5 Mpc) and also with the minimum distance estimate that we obtained $D_{min(TRGB)} = 13.1$ Mpc.

3. ULTRA-DIFFUSE GALAXIES IN THE LOCAL VOLUME

3.1. Nearby Ultra-Diffuse Galaxy IKN

This galaxy is one of the most diffuse in the nearby M81 group. It was resolved into stars with the HST for the first time by [24]. The distance measured with the TRGB is 3.75 Mpc, confirming the status of IKN as a companion of M81. Detailed surface photometry is not provided for IKN, because a rather bright star is projected onto its northern side. Okamoto et al. [25]
obtained deep images of the central region of the M81 group at the Hyper Suprime-Cam of the Subaru telescope. The distribution map of RGB stars (Fig. 5 [25]) shows that the maximum diameter of IKN reaches 7.9 or 8.6 kpc. Georgiev et al. [26] and Tudorica et al. [27] have detected six globular clusters in IKN, the half of which are concentrated in a 3.4 kpc-diameter circle. Taking these data into consideration and using the photometric profile of IKN on the southern side of the galaxy from the images obtained with the 6-m telescope [28] we estimated the effective diameter of IKN equal to 3.15 kpc. There is a dwarf galaxy BK5N not far from IKN with the central surface brightness in $R$ band $SB_R(0) = 24^{m}5/\square''$ according to the photometry in the MegaCam CFHT images [29]. Having compared the images of these galaxies, we obtained the central brightness for IKN by $1^{m}5$ fainter which in transition to $g$ band and taking the Galactic extinction into account yields $SB_g(0) \simeq 26^{m}9/\square''$ for IKN. Consequently, the effective diameter and central surface brightness of IKN quite well match its classification as an ultra-diffuse galaxy.

3.2. Other Nearby Ultra-Diffuse Galaxy Candidates

The best way to learn about any galaxy population is to study its nearest representatives, the structure and properties of which can be seen in maximum details. For this purpose, we selected 15 Local Volume galaxies ($D < 11$ Mpc) from the UNGC catalog that match the determination of an ultra-diffuse galaxy. Unfortunately, the surface photometry data for even the nearest galaxies are very few. Particularly, a number of galaxies have no estimated central surface brightness and effective diameter. Instead of which we used the galaxy’s Holmberg diameter measured at $SB_B(0) \simeq 26^{m}5/\square''$ and effective surface brightness. Table 2 shows the summary of parameters of 15 ultra-diffuse galaxy candidates in the Local Volume. Its columns present: (1, 2)—galaxy’s name and its equatorial coordinates; (3)—distance measured with the TRGB method (2 decimal places) or from the membership in the group; (4)—effective or Holmberg diameter; (5)—apparent axial ratio; (6)—absolute $B$-magnitude corrected for the Galactic extinction; (7)—average surface brightness in the $B$ band inside the effective radius; (8)—logarithm of the stellar mass calculated from the $K$ luminosity with $M^*/L_K = 1.0 \times M_{\odot}/L_{\odot}$; (9)—tidal index from the UNGC determined by the tidal force of the nearest and massive neighbor (=Main Disturber), the name of which is given in column (10); (11)—logarithm of density created by surrounding galaxies within a 1 Mpc radius and expressed in units of average cosmic density. The last row in the table gives average values of each parameter.

The data from Table 2 allow the first estimation of the abundance of ultra-diffuse galaxies to be conducted. The total number of the known galaxies with $D < 11$ Mpc is 988, consequently, the relative abundance of ultra-diffuse galaxies in the Local Volume does not exceed 1.5%.

Considering the characteristics of the nearest UDG candidates presented in Table 2, we can conclude on the following.

1. The UDG population is not a homogeneous sample. It contains irregular diffuse galaxies (Garland, d0226+3325) as well as the objects of the transition (Tr) type (KK69, NGC 4631dw1, and [TT 2009]30), in which star formation is taking place.

2. Among the diffuse galaxies having an old stellar population there are elongated objects with the axial ratio $b/a < 0.5$ (Sag dSph, KK208, Scl-MM-Dw2, and And XIX). Obviously, their disturbed shape is caused by tidal action from close massive neighbor.

3. The common feature of 15 diffuse galaxies is their location in high-density regions. According to the UNGC [4], the average index $\langle TI_1 \rangle = 1.71$ means that the local stellar mass density around them is 50 times higher than the average cosmic density. The same feature is testified by the high average value of the index $\langle TI_1 \rangle = 2.6$ which indicates the presence of a close massive neighbor near UDG.

The data given in Table 2 leave the question open: if there are any isolated diffuse galaxies far from massive neighbors, the destroying tidal influence of which seems the obvious cause of trans-
formation of a certain dwarf into an extended diffuse stellar flow. To answer this question, deep surveys of wide sky coverage are needed which are still absent. In particular, it is interesting to check if there are any ultra-diffuse galaxies in the local non-virialized cloud of dwarfs CVnI, the near side of which ($D \simeq 2.5$ Mpc) almost contacts the Local Group.

Among low-surface-brightness galaxies, there is a population of “nucleated” ones, where the presence of the “nucleus” can influence the galaxy’s classification as an ultra-diffuse one via its central surface brightness. Alternatively, one can use not the central but the effective surface brightness $SB(e)$. Then, taking into consideration the Table 2 data, the criterion of the ultra-diffuse galaxy takes the form:

$$A_e > 3.0 \text{kpc}, \quad SB_B(e) > 26^m5/\Omega'', \quad b/a > 0.5.$$  

Here we put the limitation by the apparent axial ratio $b/a$ in order to exclude trivial cases, when the increase of the effective diameter of a dwarf galaxy and decrease of its surface brightness are caused by disruption of its structure with tidal forces.

4. CONCLUSION

In recent years, a series of publications appeared reporting on the existence and properties of a special population of ultra-diffuse galaxies. Objects of this type with large linear sizes but low surface brightness are found in clusters and galaxy groups mainly. According to the papers [12, 30], the abundance of UDGs is the highest in rich clusters. Along with this, they avoid the densest central region of a cluster and are relatively rare on its periphery. Thus, a UDG population is an important indicator of dynamic processes in clusters and groups. From the data in [31, 32], ultra-diffuse galaxies have a high dark-to-stellar mass ratio, which can reach $M_{DM}/M^*$ about $10^2-10^3$ for them.

According to our HST observations, the distance of KDG 218 is $D > 13.1$ Mpc. It is most likely located in the NGC 4958 group at a distance of 22 Mpc or in the VirgoSE scattered filament adjoining the Virgo cluster (16.5 Mpc). In both cases, the effective diameter of KDG 218, $A_e > 3.0$ kpc, and the central surface brightness, $SB_V(0) = 24^m36/\Omega''$, correspond to the criterion of an ultra-diffuse galaxy.

We also give the list of 15 galaxies of the Local Volume that can be considered as the nearest UDG candidates by their sizes and surface brightnesses.
brightness. The reliable photometry has not been conducted for these galaxies yet, and they need a detailed study.

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