Young Star Clusters in the Dwarf Irregular Galaxy, UGC 7636, Interacting with the Giant Elliptical Galaxy NGC 4472

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ABSTRACT

We present integrated Washington CT\textsubscript{1} photometry of 18 bright blue objects discovered in the dwarf galaxy UGC 7636 which is located 5\arcmin.5 southeast of the giant elliptical galaxy NGC 4472, the brightest galaxy in the Virgo cluster. Several lines of evidence indicate that UGC 7636 is interacting violently with NGC 4472. These objects are very blue with colors of $-0.4 < (C - T\textsubscript{1}) < 0.6$, and their magnitudes are in the range of $20.6 < T\textsubscript{1} < 22.9$ mag which corresponds to absolute magnitudes of $-10.6 < M_{T\textsubscript{1}} < -8.3$ mag for a distance modulus of $(m - M)_{0} = 31.2$. These objects are grouped spatially in three regions: the central region of UGC 7636, the tidal tail region, and the HI cloud region. No such objects were found in the counter tail region. It is concluded that these objects are probably young star clusters which formed $< 10^8$ yr ago during the interaction between UGC 7636 and NGC 4472. Surface photometry of UGC 7636 ($r < 83\arcsec$) shows that there is a significant excess of blue light along the tidal tail region compared with other regions. The star clusters are bluer than the stellar light in the tidal tail region, indicating that these clusters might have formed later than most stars in the tidal tail region which were formed later than most stars in the main body of the galaxy.

1. INTRODUCTION

UGC 7636 (VCC 1249) is a dwarf irregular galaxy (Im III-IV: Binggeli \textit{et al.} 1985) located 5\arcmin.5 southeast of the center of the giant elliptical galaxy NGC 4472 (M49), the brightest galaxy in the Virgo cluster. Its proximity to the giant elliptical galaxy (the projected distance between the two galaxies is only 28 kpc) and disturbed appearance imply that UGC 7636 might be experiencing strong interactions with NGC 4472. Therefore it is an ideal target to study interactions between dwarf and giant galaxies and the evolution of dwarf galaxies in clusters of galaxies. Basic information for UGC 7636 is listed in Table 1.

Surprisingly, there is no HI gas detected in the central region of either UGC 7636 or NGC 4472. Instead, an $80\arcsec \times 40\arcsec$ HI cloud of mass $\approx 7 \times 10^7 M_{\odot}$ is found between the two galaxies (Sancisi \textit{et al.} 1987, Patterson & Thuan 1992, Henning \textit{et al.} 1993, McNamara \textit{et al.} 1994). The structure of the HI cloud is

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similar, in general, to the optical structure of UGC 7636 (McNamara et al. 1994). The radial velocity of the HI cloud is $469 \pm 3$ km s$^{-1}$ (Patterson & Thuan 1992, McNamara et al. 1994), which is intermediate between the optical velocities of UGC 7636 ($276 \pm 78$ km s$^{-1}$; Huchra 1992) and NGC 4472 ($983 \pm 10$ km s$^{-1}$; RC3). Recently Irwin & Sarazin (1996) found in their x-ray study of the NGC 4472 region a marginally significant X-ray hole in the HI cloud position, suggesting that the HI cloud may lie at the front side of NGC 4472.

A CO search was carried out for the position of the HI cloud, with no detection (Huchtmeier et al. 1994, Irwin et al. 1997). CO gas of mass $4 \times 10^7 M_\odot$ has been detected 2' west of the HI cloud (1' south of NGC 4472), but the measured radial velocity of the CO gas, 883 km s$^{-1}$, indicates that the CO gas is associated with NGC 4472, rather than with UGC 7636 (Huchtmeier et al. 1988, Huchtmeier et al. 1994).

Previous optical imaging studies showed that UGC 7636 has a tidal tail extended toward NGC 4472 and a counter-tail extended southwest, and that there are a few blue knots in the interacting region (Patterson & Thuan 1992, McNamara et al. 1994). It has been suggested from these results that the HI cloud may be the gas stripped from UGC 7636 via ram pressure and/or tidal interaction (Sancisi et al. 1987, Patterson & Thuan 1992, McNamara et al. 1994).

It is naturally expected that stars and star clusters might have formed during the interaction between the two galaxies (Holtzman et al. 1996, Schweizer et al. 1996 and references therein). In this paper, we present a study of star clusters in UGC 7636 based on deep CCD images. We have found 18 bright blue star clusters in UGC 7636, a few of which were previously known (Patterson & Thuan 1992, McNamara et al. 1994). The integrated photometry of these bright blue clusters are presented as well as the surface photometry of UGC 7636. The preliminary results presented in a conference proceedings (Kim et al. 1996) are superseded by this paper. This paper is organized as follows. Section 2 explains briefly observations and data reductions, and Section 3 describes the morphological structure of UGC 7636. Section 4 presents the photometry of bright blue star clusters in UGC 7636, and Section 5 shows the surface photometry of UGC 7636. In Section 6 we discuss the gas stripping and star formation history in UGC 7636. Finally the primary results are summarized in Sec. 7.

2. OBSERVATIONS AND DATA REDUCTION

Deep Washington system (Canterna 1976) $CT_1$ images of a $16'.4 \times 16'.4$ field centered on NGC 4472 were obtained using the 2048 x 2048 pixel Tektronix T2KB CCD at the prime focus of the KPNO 4m telescope on the night of 1993 February 26. The exposure times were $3 \times 1000$ s for $T_1$ and $5 \times 1000$ s for $C$, and the seeing was $\approx 1''25$. These images were obtained primarily to study the globular cluster system of NGC 4472, the results of which are presented in Geisler et al. (1996) and Lee et al. (1997), including detailed descriptions of the observations.

We have chosen a $6'.5 \times 6'.4$ ($811 \times 801$ pixels) section centered on UGC 7636 in the original field to investigate UGC 7636 in detail in this study. Instrumental magnitudes of the point sources in the images were obtained using the digital photometry program DAOPHOT II in IRAF\(^1\). The resulting instrumental magnitudes and colors were calibrated using the standard stars observed on the same night. The rms scatter of the standard stars was 0.016 and 0.022 for $T_1$ and $(C - T_1)$, respectively. The surface photometry

\(^1\)IRAF is distributed by the National Optical Astronomy Observatories, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.
of UGC 7636 was obtained using the ellipse fitting routine ELLIPSE in STSDAS/IRAF.

We assume UGC 7636 is at the same distance as NGC 4472, since the interaction between the two galaxies indicates that they are close to each other. We adopt the value of $17.4 \pm 1.6$ Mpc for the distance to NGC 4472 which is derived from the luminosity functions of globular clusters in NGC 4472 (Lee et al. [1997]). At this distance, the projected scale is $1'' = 84.4$ pc. The foreground reddening toward UGC 7636 is known to be negligible, $E(B-V) = 0.0$ (Burstein & Heiles 1982).

3. MORPHOLOGICAL STRUCTURE OF UGC 7636

The details of the structure of UGC 7636 are not easily seen in the original images, because it is located in the bright background due to the halo of NGC 4472. For this reason we have subtracted the contribution due to the unresolved stellar light of NGC 4472 from the original images using the model galaxy which was created by modelling the smoothed image of NGC 4472.

Fig. 1 displays a grey scale map of the resulting $C$ CCD image, overlayed by the intensity contours. Fig. 1 shows that the inner parts of UGC 7636 are almost circular, but that the outer parts are significantly distorted. A distorted feature extended toward NGC 4472 in the northwest direction represents the tidal tail, and another extension from the center of UGC 7636 along the southwest direction is a counter tail, as pointed out by Patterson & Thuan (1992) and McNamara et al. (1994). The detailed structure of the inner region of UGC 7636 is shown in Figs. 2 and 4. These figures show that there are several bright knots connected by bridges in the central region of UGC 7636, and the overall shape of the central region is like a leading-edge, consistent with the results shown by McNamara et al. (1994).

A contour map of the HI cloud based on the VLA observations by McNamara et al. (1994) is also overlayed in Fig. 1. The peak of the HI cloud ($\alpha_{1950} = 12^h27^m 23^s$, $\delta_{1950} = 8^\circ 14' 12''$) is $\approx 2'.2$ (corresponding to a projected distance of 11 kpc) from the center of UGC 7636, and there is little HI gas in the main body of UGC 7636. Comparison of the contour maps of UGC 7636 and the HI cloud shows that the general morphology of the stellar light of UGC 7636 is strikingly similar to that of the HI cloud, as found by McNamara et al. (1994).

We have created a ($C - T_1$) color map of UGC 7636 to investigate the spatial variation of the colors, the contour map of which is overlayed on the greyscale map of the $C$ image in Fig. 2. Fig. 2 shows several interesting features. First, the colors of UGC 7636 are blue in the central region and get redder outward. Secondly, there is a blue color excess in the tidal tail region, $\approx 1'$ (corresponding to a projected distance of 5 kpc) northwest of UGC 7636. Thirdly, there is a group of several blue objects in the HI cloud region, where these is seen little, if any, stellar light from UGC 7636. The quantitative measurements of the colors will be given in the following sections.

4. BRIGHT BLUE STAR CLUSTERS

We have measured the magnitudes and colors of $\approx 2,360$ point sources in the final images. Fig. 3 displays the color-magnitude diagrams of the measured objects in the entire field, the G-region and the F-region. The G-region corresponds to the main body of UGC 7636, and the F-region is a control field far from the main body of UGC 7636, as marked in Fig. 1. The G-region and F-region are of the same area and are located at a similar distance from the center of NGC 4472.
Fig. 3 reveals the presence of several notable features. The first of these is distinguished by the strong vertical structure with intermediate colors of $1.0 < (C - T_1) < 2.3$ extending from $T_1 \sim 19.5$ mag to the faintest magnitudes. Most of these are globular clusters in NGC 4472. These populations are very typical of giant elliptical galaxies (Lee & Geisler 1993, Geisler et al. 1996). Comparison of the G-region and F-region indicates that there are few, if any, of these red globular clusters belonging to UGC 7636.

The second dominant population is manifested as the broad horizontal structure of faint, blue objects with $T_1 > 23.5$ mag. These are predominantly unresolved faint background galaxies, as revealed by their blue colors and uniform distribution over the field (see also Lee & Geisler 1993).

The third population is a small number of very red objects with colors of $(C - T_1) > 2.6$. These objects are distributed uniformly over the field and are probably foreground stars in the Galaxy. Detailed studies of the globular clusters in NGC 4472 and the other two populations are given in Geisler et al. (1996) and Lee et al. (1997).

The fourth feature is a small number of bright blue objects in the range $20.6 < T_1 < 22.9$ mag and $-0.4 < (C - T_1) < 0.6$ (represented by the large filled circles in Fig. 3(a)), which are the primary subject of this study. These objects are marked and identified in the greyscale maps given in Figs. 1 and 4, and the photometry of these objects is listed in Table 2. We have used aperture photometry to measure the magnitudes of some of these objects that were missed in the point-spread function fitting with DAOPHOT. We have subtracted the smoothed unresolved stellar light of UGC 7636 from the original image (Fig. 1) to show clearly the point sources in Fig. 4. Figs. 1 and 4 show that these objects are all located in the area associated with UGC 7636 and are grouped spatially in three regions: the central region of UGC 7636 (10 objects), the tidal tail region (3 objects), and the HI cloud region (5 objects). The positions of these objects correspond to the blue regions in the color map shown in Fig. 2. These results indicate that these objects are probably members of UGC 7636.

Some of these blue objects were studied previously. Patterson & Thuan (1992) found one blue patch with $(B - I) = -0.1 \pm 0.2$ at the tip of the tidal tail, which corresponds to C6 in this study. Later McNamara et al. (1994) presented $UBR$ photometry of several isolated blue regions in UGC 7636. The two bluest regions, A and B, in their study correspond to C2 and C6 in this study, respectively.

For the purpose of comparison of our colors with previous studies, we have estimated the colors of $UBI$ from $(C - T_1)$ colors of these objects obtained in this study using the transformation relations given by Geisler (1996): $(U - R) = 1.345(C - T_1) - 0.323$, $(B - R) = 0.748(C - T_1) + 0.125$, and $(B - I) = 0.989(C - T_1) + 0.191$. Table 3 lists the comparison of the three sets of photometry. The $(B - I)$ color of C6 given by Patterson & Thuan (1992) agrees very well with ours, but the $(U - R)$ and $(B - R)$ colors given by McNamara et al. (1994) are significantly redder than ours. Considering that our photometry of the globular clusters in NGC 4472 agrees well with that of other globular cluster systems (Geisler et al. 1996), the differences between our values and those of McNamara et al. are probably due to the uncertainty in the calibration of the photometry of McNamara et al. who used the photometry of NGC 4472 (Peletier et al. 1993) for the calibration of their photometry of UGC 7636.

The absolute magnitudes of these objects are derived to be $-10.6 < M_{T_1} < -8.3$ mag for the adopted distance modulus of $(m - M)_0 = 31.2$ and zero foreground reddening. They are as bright as the bright globular clusters in NGC 4472 seen in Fig.3. However, they are fainter than the brightest blue star clusters (as bright as $M_V \sim -15$ mag) found in other interacting galaxies, the progenitors of which are normal galaxies, such as NGC 4038/4039, NGC 3921, NGC 3597, and NGC 6052 (Whitmore & Schweizer 1997, Schweizer et al. 1996, Holtzman et al. 1996).
The color distribution of these objects is weakly bimodal with peaks at \((C - T_1) = -0.05 \pm 0.12\) (10 objects, referred to as the BBC group 1 hereafter) and \((C - T_1) = 0.51 \pm 0.07\) (8 objects, BBC group 2 hereafter), with a total mean value of \((C - T_1) = 0.19 \pm 0.30\). For reference the approximate transformation relation between \((B - V)\) and \((C - T_1)\) colors is \((B - V) = 0.475(C - T_1) + 0.076\). So the corresponding \((B - V)\) colors of the two peaks are estimated to be \((B - V) \sim 0.0\) and \((B - V) \sim 0.3\). The mean \((V - I)\) color for the same region in our photometry is 0.78. This value suggests these fainter blue objects are not associated with UGC 7636.

Considering all the characteristics of these objects found above, it is concluded that they are probably star clusters associated with UGC 7636. The blue colors and high luminosities of these clusters suggest that they are very young. We derive mean ages of \(\approx 10^7\) yr and \(10^8\) yr for the BBC group 1 and the BBC group 2, respectively, using the \((B - V)\)-age relation of a model for the evolution of a single age population with solar metallicity given by Bruzual & Charlot (1993). Inspection of the structure of these clusters (see Fig. 4) reveals that some of them are not as compact as globular clusters, but extended or accompanied by faint objects (which is why we have used aperture photometry to derive their magnitudes). This indicates that some of them are loose clusters or OB associations. We have included brief notes for the FWHM and morphological features of these ten clusters in the notes of Table 2. Seven of these ten clusters belong to the BBC group 1 and the other three belong to the BBC group 2.

There are several fainter blue objects with colors of \((C - T_1) \sim 0\) in the range of \(23 < T_1 < 24\) mag. Some of these objects may be star clusters of UGC 7636. But it is difficult to tell whether they are members of UGC 7636 or background galaxies, because of the dominant population of background galaxies in the corresponding position of the color-magnitude diagram. Indeed, comparison of the F and G region CMDs suggests these fainter blue objects are not associated with UGC 7636.

5. SURFACE PHOTOMETRY OF UGC 7636

The surface brightness and color profiles of the entire region centered on UGC 7636 within a radius of 83'' are displayed in Fig. 5 and are listed in Table 4.

The integrated magnitude and color within \(r < 83''\) are \(T_1 = 13.80\) mag and \((C - T_1) = 1.07\). Gallagher & Hunter (1986) presented the integrated colors within the diameter of 30'' of UGC 7636, \((B - V) = 0.50\) and \((U - B) = 0.08\). The \((C - T_1)\) color for the same region in our photometry is 0.78. This value corresponds to \((B - V) = 0.45\) and \((U - B) = 0.02\), only slightly bluer than the values given by Gallagher & Hunter (1986).

Fig. 5 shows that the surface brightness profiles of UGC 7636 are well fit by exponential functions with two components, consistent with the results given by Patterson & Thuan (1992, 1996) who presented \(BI\) surface photometry for the region within the radius of 80'' and James (1991) who presented \(H\)-band data.

A least-squares fit of the profiles to an exponential law with two components (for \(0'' < r < 30''\) and \(30'' < r < 80''\)) yields the scale lengths, 12''.8 (= 1.1 kpc) and 28''.1 (= 2.4 kpc) for the \(C\) band and 15''.4 (= 1.3 kpc) and 33''.3 (= 3.0 kpc) for the \(T_1\) band. Note that Patterson & Thuan (1992) obtained the scale lengths for the inner region of UGC 7636, 13''.5 and 18''.3 for \(B\)-band and \(I\)-band, respectively, and Patterson & Thuan (1996) estimated the scale lengths for the outer region, 31''.8 and 38''.9 for \(B\)-band and \(I\)-band, respectively, which are consistent with our results: the scale lengths increase with wavelength. The color of the center of UGC 7636 is as blue as \((C - T_1) = 0.7\) and the color gets redder as the galactocentric radius increases outward, reaching \((C - T_1) = 1.4\) at 78'', which is consistent with the result based on
colors given by Patterson & Thuan (1996).

We have divided the entire region centered on UGC 7636 into several sectors to investigate the azimuthal variation of the surface brightness and colors. Fig. 6 displays the surface brightness and color profiles of three sectors along the tidal tail region (interacting region), the minor axis and the counter tail region. The position angles of the three azimuthal sectors are 323° - 353°, 250° - 280°, and 178° - 208°, respectively. Fig. 6 shows that there is a significant excess of blue light along the tidal tail region compared with other regions, becoming the bluest at r ≈ 68″. The colors of the counter tail region are much redder than the tidal tail region, and similar to those of the minor axis region.

6. DISCUSSION

6.1. Gas Stripping of UGC 7636

Several lines of evidence suggest strongly that the HI gas has been stripped from UGC 7636, including the location of the HI cloud near UGC 7636, the similarity in the structure of UGC 7636 and the HI cloud, and the absence of HI gas in UGC 7636. However, the debate over how the HI gas was removed from UGC 7636 has been controversial. Two kinds of processes have been proposed to explain the removal of the HI gas from UGC 7636 (Sancisi et al. 1987, Patterson & Thuan 1992, McNamara et al. 1994). First, it has been suggested that the gas was stripped out of UGC 7636 by ram pressure due to the motion of UGC 7636 through the hot dense halo of X-ray emitting gas (Forman et al. 1985, Irwin & Sarazin 1996) in NGC 4472 (see also Gunn & Gott 1972). Alternatively, tidal interactions between UGC 7636 and NGC 4472 may have removed the gas as well as some stars from UGC 7636, as typically seen in interacting galaxies. There are pros and cons for each of these processes in explaining the observational results of UGC 7636, which are summarized below.

The evidence supporting the ram pressure stripping idea includes: (a) the location of UGC 7636 in the hot \( T \sim 10^7 \) K and dense \( n_0 \sim 10^{-3} \) cm\(^{-3}\) halo of X-ray emitting gas in NGC 4472, the brightest galaxy in the Virgo cluster; (b) the similarity in the structure of UGC 7636 and the HI cloud (McNamara et al. 1994); (c) the radial velocity of the HI cloud which is intermediate between those of UGC 7636 and NGC 4472; (d) the large velocity width (110 km s\(^{-1}\)) of the spatially extended HI envelope (note that the HI line of the cloud consists of both broad and narrow components) (Patterson & Thuan 1992, McNamara et al. 1994); (e) the absence of H\( \alpha \) emission in the central region of UGC 7636 (Gallagher & Hunter 1989); and (f) the overall structure of the central region of UGC 7636 which is bow-shaped (or like a leading-edge) toward the southeast along the line connecting UGC 7636 and the HI cloud.

On the other hand, the evidence supporting the tidal interaction scenario includes: (a) the presence of the faint tidal tail and counter tail of UGC 7636 (Patterson & Thuan 1992, McNamara et al. 1994, this study); (b) the blue colors of the tidal tail region and the central region of UGC 7636 (Patterson & Thuan 1992, McNamara et al. 1994, this study); (c) the disturbed morphology of the central region of UGC 7636 (McNamara et al. 1994, this study); (d) a small velocity width (23 km s\(^{-1}\)) in the narrow component of the HI line, which is typical for HI bridges and tails in the interacting galaxies (Patterson & Thuan 1992, McNamara et al. 1994); and (e) the estimated value, only 7″, of the tidal radius of UGC 7636 constrained by NGC 4472, indicating the tidal interaction due to NGC 4472 must have reached deep into the central region of UGC 7636 (McNamara et al. 1994).

The points summarized above suggest that both tidal interaction and ram pressure have played a role
in gas removal and star formation in UGC 7636. The similarity in the morphological structure of both stellar tidal tail and HI cloud implies clearly that both objects are subject to tidal interactions, while the spatial separation of the stellar tidal tail and the HI cloud indicates that the HI gas was stripped probably by the ram pressure. McNamara et al. (1994) presented a scenario that the stars and HI appear to have been tidally distorted in situ, and then the HI gas was removed from UGC 7636 by the ram pressure, also suggesting that only a modest enhancement of star formation appears to have been induced by the interaction. They also pointed out that the absence of young stars in the HI cloud is consistent with the ram pressure stripping. However, this last argument is not consistent with the presence of young star clusters in the HI cloud found in our study. Therefore it is concluded that the UGC 7636 system must have been affected by the tidal interaction before, during and after the gas removal to which ram pressure might have made a significant contribution.

6.2. Star and Cluster Formation History in UGC 7636

The existence of five young star clusters with ages $< 10^8$ yr in the HI cloud indicates that the HI gas was stripped from UGC 7636 before $\approx 10^8$ yr ago and the star clusters were formed later in the stripped HI gas. There is little hint of unresolved stellar light in the HI cloud in our deep CCD images. The faint unresolved stars, if any, in the HI cloud region must be much fainter than those in UGC 7636 and below the detection limit of our images. Therefore it appears that it is mostly star clusters which were formed recently and are visible now in the HI cloud.

The three groups of clusters in the three regions show little difference in the mean color (i.e., age) and luminosity, and they all have a color distribution which suggest bimodality, as seen in Fig. 3(b). This implies that these clusters might have been formed in two different periods ($\approx 10^7$ yr and $\approx 10^8$ yr ago), and that they were formed in all three regions contemporaneously.

From the presence of bright young star clusters in the three regions and the similarity of the mean ages of the clusters in each region, we conclude that there must have been some gas left in UGC 7636 out of which star clusters would be formed later, when most of the gas was stripped from UGC 7636. These bright star clusters were probably formed by tidal interactions, ram pressure, or thermal pressure due to the hot X-ray gas of NGC 4472.

The mean color of these star clusters is bluer than the color of the stellar light of the tidal tail region (Fig. 6), indicating that these clusters were formed later than most stars in the tidal tail region which were formed later than most stars in the main body of the galaxy.

7. SUMMARY AND CONCLUSIONS

We have presented integrated Washington $CT_1$ photometry of objects in UGC 7636 based on deep CCD images. Surface photometry of UGC 7636 is also presented. The primary results in this study are summarized below.

1. The color-magnitude diagram of the UGC 7636 region shows that there are 18 bright blue objects which are most likely young star clusters. They are grouped spatially in three regions: the central region of UGC 7636, the tidal tail region and the HI cloud region. The colors and magnitudes of these clusters are in the range $-0.4 < (C - T_1) < 0.6$ and $20.6 < T_1 < 22.9$ mag ($-10.6 < M_{T_1} < -8.3$
mag). The blue colors of these clusters indicate they are young, with mean ages of $10^7$ yr and $10^8$ yr for the two distinct peaks in the color distribution.

2. The surface brightness profiles of UGC 7636 within $r = 83''$ are well fit by an exponential disk law with two components. The colors get continuously redder outward. There is a significant excess of blue light in the tidal tail region compared with other regions. The colors of the counter tail region are much redder than the tidal tail region, but similar to those of the minor axis region.

3. Several lines of evidence indicate that both tidal interaction and ram pressure have played a role in gas removal and star formation in UGC7636.

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Table 1. Basic information for UGC 7636.

| Parameter                                      | Information                         | References |
|------------------------------------------------|-------------------------------------|------------|
| $\alpha_{1950}, \delta_{1950}$                | $12^h27^m28.2, +08^\circ12'24''$   | 1          |
| $l, b$                                         | 287.1378 deg, 70.1426 deg           | 1          |
| Foreground reddening, $E(B - V)$               | 0                                   | 2          |
| Type                                           | Im III-IV                           | 3          |
| Optical radial velocity                        | $276 \pm 78$ km s$^{-1}$            | 4          |
| (Optical radial velocity of M49)               | $983 \pm 10$ km s$^{-1}$            | 1          |
| HI radial velocity                             | $469 \pm 3$ km s$^{-1}$             | 5          |
| FWHM velocity width of the HI line             | 23 and 110 km s$^{-1}$              | 6          |
| $B$-band total magnitudes, $B_T^T, M_B^T$      | 14.94, $-16.76$ mag                 | 6          |
| $I$-band total magnitudes, $I_T^T, M_I^T$      | 12.55, $-18.65$ mag                 | 6          |
| $(B - V)(D < 30''')$                           | $0.50 \pm 0.04$ mag                 | 7          |
| $(U - B)(D < 30'')$                            | $0.08 \pm 0.05$ mag                 | 7          |
| Size of the HI cloud                           | $80'' \times 40''$ (6.7 kpc $\times$ 3.4 kpc) | 5          |
| Mass of the HI cloud, $M$(HI)                  | $6.9(\pm0.4) \times 10^7$ $M_\odot$ | 5          |
| Number of star clusters                        | 18                                  | 8          |
| Distance modulus, $(m - M)_0$                  | $31.2 \pm 0.2$ mag                  | 9          |
| Distance                                       | $17.4 \pm 1.6$ Mpc                 | 9          |

References. — (1) RC3; (2) Burstein & Heiles 1982; (3) Binggeli et al. 1985, 1993; (4) Huchra 1992; (5) McNamara et al. 1994; (6) Patterson & Thuan 1992, 1996; (7) Gallagher & Hunter 1986; (8) This study; (9) Lee et al. 1997.
Table 2. Photometry of bright blue star clusters in UGC 7636.

| ID | X[px]  | Y[px]  | T₁     | σ(T₁) | (C – T₁) | σ(C – T₁) | Remarks                  |
|----|--------|--------|--------|-------|----------|-----------|--------------------------|
| C1 | 258.52 | 663.34 | 21.04  | 0.04  | –0.03    | 0.04       | r(aperture) = 8 px       |
| C2 | 267.50 | 606.19 | 21.76  | 0.03  | 0.06     | 0.03       | r(aperture) = 3.5 px     |
| C3 | 285.26 | 602.16 | 22.70  | 0.15  | 0.06     | 0.16       | r(aperture) = 7 px       |
| C4 | 299.05 | 650.47 | 22.14  | 0.02  | 0.58     | 0.03       | PSF mag                  |
| C5 | 303.40 | 693.81 | 22.62  | 0.04  | –0.12    | 0.04       | PSF mag                  |
| C6 | 334.29 | 510.38 | 21.89  | 0.07  | –0.32    | 0.08       | r(aperture) = 8 px       |
| C7 | 335.54 | 471.48 | 22.36  | 0.08  | 0.49     | 0.10       | r(aperture) = 5 px       |
| C8 | 372.26 | 502.82 | 22.27  | 0.14  | –0.14    | 0.15       | r(aperture) = 7 px       |
| C9 | 393.91 | 346.03 | 22.17  | 0.04  | 0.50     | 0.05       | PSF mag                  |
| C10| 399.48 | 385.98 | 20.86  | 0.03  | 0.36     | 0.04       | PSF mag                  |
| C11| 408.92 | 354.95 | 21.89  | 0.15  | 0.55     | 0.20       | r(aperture) = 5 px       |
| C12| 414.48 | 382.30 | 21.19  | 0.09  | –0.10    | 0.11       | r(aperture) = 4 px       |
| C13| 414.58 | 367.83 | 22.63  | 0.05  | 0.01     | 0.06       | PSF mag                  |
| C14| 430.33 | 371.69 | 22.03  | 0.17  | 0.05     | 0.22       | r(aperture) = 5 px       |
| C15| 434.16 | 389.86 | 20.59  | 0.05  | 0.53     | 0.06       | r(aperture) = 5 px       |
| C16| 434.72 | 403.51 | 22.92  | 0.05  | 0.58     | 0.07       | PSF mag                  |
| C17| 442.68 | 372.07 | 22.93  | 0.08  | 0.46     | 0.09       | PSF mag                  |
| C18| 445.18 | 417.91 | 22.12  | 0.03  | –0.02    | 0.05       | PSF mag                  |

Note. — (1) C1: FWHM = 2″.0, elongated structure; (2) C2: FWHM = 1″.8, faint companions; (3) C3: FWHM = 1″.8, faint background; (4) C6: FWHM = 1″.5; (5) C7: FWHM = 1″.4; (6) C8: FWHM = 2″.2, irregular and elongated structure; (7) C11: FWHM = 1″.7; (8) C12: FWHM = 1″.4; (9) C14: FWHM = 2″.2, extended structure; (10) C15: FWHM = 2″.4, extended structure, companions.

Table 3. Comparison of photometries.

| Object | (C – T₁)ₐ | (U – R)ₐ | (B – R)ₐ | (B – I)ₐ | (U – R)ₐ(C–T₁) | (B – R)ₐ(C–T₁) | (B – I)ₐ(C–T₁) |
|--------|------------|----------|----------|----------|----------------|----------------|----------------|
| C2     | 0.06       | 0.25     | 1.12     | …        | –0.24          | 0.17           | 0.25           |
| C6     | –0.32      | 0.10     | 0.82     | –0.1     | –0.75          | –0.11          | –0.13          |

References. — a: This study; b: McNamara et al. 1994; c: Patterson & Thuan 1992.
Table 4. Surface photometry of UGC 7636.

| $r_{\text{eff}}$ [arcsec] | $\mu T_1$       | $\mu (C - T_1)$ | $r_{\text{out}}$ [arcsec] | $T_1$  | $(C - T_1)$ |
|-----------------|----------------|-----------------|-----------------|--------|-------------|
| 1.36            | 22.29 ± 0.02   | 0.66 ± 0.03     | 2.00            | 19.55  | 0.66        |
| 3.19            | 22.35 ± 0.02   | 0.70 ± 0.04     | 4.00            | 18.08  | 0.69        |
| 5.09            | 22.42 ± 0.04   | 0.74 ± 0.05     | 6.00            | 17.25  | 0.72        |
| 7.03            | 22.53 ± 0.04   | 0.76 ± 0.06     | 8.00            | 17.06  | 0.73        |
| 9.04            | 22.69 ± 0.17   | 0.80 ± 0.09     | 10.00           | 17.35  | 0.05        |
| 10.88           | 22.79 ± 0.19   | 0.78 ± 0.28     | 11.72           | 16.40  | 0.07        |
| 12.63           | 22.90 ± 0.19   | 0.78 ± 0.30     | 13.48           | 16.06  | 0.04        |
| 14.50           | 23.05 ± 0.22   | 0.80 ± 0.34     | 15.50           | 15.05  | 0.78        |
| 16.70           | 23.26 ± 0.13   | 0.89 ± 0.29     | 17.82           | 15.35  | 0.08        |
| 19.19           | 23.46 ± 0.13   | 0.93 ± 0.15     | 20.50           | 15.17  | 0.82        |
| 22.08           | 23.67 ± 0.07   | 0.97 ± 0.10     | 23.57           | 15.00  | 0.84        |
| 25.39           | 23.91 ± 0.24   | 1.00 ± 0.28     | 27.11           | 14.84  | 0.86        |
| 29.22           | 24.16 ± 0.28   | 1.05 ± 0.31     | 31.18           | 14.70  | 0.88        |
| 33.58           | 24.37 ± 0.09   | 1.06 ± 0.14     | 35.85           | 14.56  | 0.90        |
| 38.62           | 24.50 ± 0.19   | 1.14 ± 0.24     | 41.23           | 14.42  | 0.93        |
| 44.37           | 24.68 ± 0.22   | 1.15 ± 0.28     | 47.41           | 14.28  | 0.96        |
| 50.78           | 24.96 ± 0.24   | 1.09 ± 0.29     | 54.53           | 14.16  | 0.97        |
| 58.70           | 25.06 ± 0.20   | 1.21 ± 0.31     | 62.71           | 14.02  | 1.00        |
| 67.53           | 25.28 ± 0.22   | 1.37 ± 0.35     | 72.11           | 13.89  | 1.04        |
| 77.69           | 25.80 ± 0.35   | 1.41 ± 0.54     | 82.93           | 13.80  | 1.07        |
Fig. 1.— A grey scale map of the C CCD image of UGC 7636, overlayed by the intensity contours. North is up and east is to the left. The size of the field is 6′.5 × 6′.4. NGC 4472 which is off the image is at 5′.5 northwest of UGC 7636. The contours labelled as HI represent the VLA HI map given by McNamara et al. (1994). The dark spot at ≈1′ east of UGC 7636 represents a saturated image of a bright foreground star. The rectangles (86′′ × 163′′) represent the G-region and F-region. The small circles represent the bright blue star clusters investigated in this study.
Fig. 2.— A \((C - T_1)\) color contour map of UGC 7636 overlayed on the greyscale map of the \(C\) image. The size of the field is \(4'.9 \times 4'.9\). Contour levels represent approximately the colors of \((C - T_1) = 0.71, 0.77, 0.88, 0.99, 1.06,\) and 1.14, respectively, outward from the center.
Fig. 3.— (a) $T_1$ vs. $(C - T_1)$ diagram of the measured point sources in the entire field. Bright blue star clusters are represented by the filled circles and the others by the small dots. (b) $T_1$ vs. $(C - T_1)$ diagram of the measured objects in the G-region. The filled circles, triangles, and open squares represent the bright blue star clusters in the central region of UGC 7636, the tidal tail region and the HI cloud region, respectively. (c) $T_1$ vs. $(C - T_1)$ diagram of the measured objects in the F-region, the control field.
Fig. 4.— Identification of the bright blue star clusters in the $C$ image. The size of the field is $3'.25 \times 3'.25$. The smoothed unresolved stellar light of UGC 7636 has been subtracted from the original image to show clearly the resolved point sources.
Fig. 5.— Surface brightness and color profiles of UGC 7636. The thin solid lines show fits by exponential functions with two components.
Fig. 6.— Surface brightness and color profiles of three azimuthal sectors of UGC 7636. The thick solid, dashed, and dotted lines represent, respectively, the tidal tail, counter tail and minor axis directions. Note that there is a significant excess of blue light along the direction of the tidal tail region.