UGC 4703 Interacting Pair Near the Isolated Spiral Galaxy NGC 2718: A Milky Way Magellanic Cloud Analog

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Abstract

We present an analysis of physical and morphological properties of an interacting pair of dwarf galaxies, UGC 4703, located in the vicinity of an isolated Milky Way (MW) type spiral galaxy NGC 2718. Based on the comparison of physical and morphological properties with that of the Large and Small Magellanic Clouds (LMC and SMC), we report that the UGC 4703 pair–NGC 2718 system is probably an LMC–SMC–MW analog. Located at a sky-projected distance of 81 kpc from NGC 2718, we find that UGC 4703 is clearly interacting with its nearby lower-mass companion UGC 4703B, forming a bridge of stellar stream between them. Total B-band luminosity of UGC 4703 and its companion is $-17.75$ and $-16.25$ mag, respectively. We obtained H I 21 cm line data of UGC 4703 using the GMRT to get a more detailed view of neutral hydrogen (H I) emission. The H I image revealed evidence of interaction between the dwarf galaxy pair but no extended emission, such as the Magellanic Stream. We also detected star-forming regions along the UGC 4703/4703B bridge with stellar mass exceeding $10^7 M_\odot$. While comparing the optical and H I morphology of the interacting dwarf pairs (UGC 4703–4703B and LMC–SMC), we discuss possible differences in interaction histories of these systems.

Key words: galaxies: dwarf – galaxies: evolution – galaxies: groups: individual (NGC 2718) – galaxies: individual (UGC 4703) – galaxies: interactions – Magellanic Clouds

1. Introduction

Unusual morphology of the Large and Small Magellanic clouds (LMC and SMC) in optical and radio observations has been used to interpret their close encounter (Gardiner & Noguchi 1996) and the resultant triggered star formation (Harris & Zaritsky 2009; Glatt et al. 2010). Besla et al. (2007) suggested that both dwarf galaxies may be entering the Milky Way (MW) system as a binary pair for the first time. Magellanic clouds are the only bright and star-forming satellites of MW. A number of studies have shown that a satellite pair of LMC–SMC mass around a MW mass host is neither common in observation, nor in numerical simulation with hierarchical accretion (Boylan-Kolchin et al. 2010; Robotham et al. 2012; Tollerud et al. 2011). Analyzing a result of the Millennium-II Simulation, Boylan-Kolchin et al. (2010) predicted that there is a less than 10% chance that a MW mass halo hosts two subhalos of mass of Magellanic Clouds. Similarly, analyzing the Galaxy And Mass Assembly catalog of galaxies, Robotham et al. (2012) calculated the probability of such a system is less than 5%. Following this statistic, the merger probability of LMC–SMC morphology dwarf galaxy satellites around the MW mass host may be even smaller.

It is commonly believed that by having a shallow potential well, low-mass dwarf satellites should be more influenced by the tidal potential of parent halos, and less so by the merging events (Paudel et al. 2013; Paudel & Ree 2014). Nevertheless, mounting evidence suggests that the merger of dwarf galaxies might not be as rare as it was previously thought. Apart from the classic LMC–SMC interaction, there are several cases of merging dwarf galaxy candidates reported in recent studies (Martínez-Delgado et al. 2012; Johnson 2013; Crnojević et al. 2014; Paudel et al. 2015; Stierwalt et al. 2015). In our previous work, we studied merging of gas-rich dwarf galaxies, the UGC 6741 pair, which is located in a low-density environment, i.e., outskirts of the NGC 3853 group (Paudel et al. 2015). We found that UGC 6741 has a similar visual morphology to that of ARP 104.

Here, we report another system of merging dwarf galaxies near to the MW-type isolated host galaxy, NGC 2718. This resembles the LMC–SMC–MW system in various ways. This Letter is organized as follows. In Section 2, we introduce the system and the environment. Section 3 describes the photometric characterization and morphology, and Section 4 is dedicated to discussing its importance.

2. Identification

As our primary interest is to perform a detailed study of the merging system of dwarf galaxies in various environments, we carried out a systematic search of such objects by visually inspecting the SDSS color image in the local volume ($z < 0.02$). In this work, we present UGC 4703, an interacting pair of dwarf galaxies. It is similar to our previously studied galaxy UGC 6741, but located near MW mass spiral galaxy NGC 2718. The main aim of this work is to report the similarity between the UGC 4703 interacting pair around NGC 2718 and the LMC–SMC interaction around MW.

At the position R.A. = 08:58:29.75, decl. = +06:19:16.8 and a redshift of $z = 0.01199$, we found a rare pair of star-forming dwarf galaxies with a connecting bridge of stellar stream. The brighter galaxy in the pair, UGC 4703, is slightly fainter than LMC with an $r$-band absolute magnitude $M_r = -18.25$ mag, and the fainter companion, hereafter UGC 4703B, has an $r$-band absolute magnitude $M_r = -16.76$ mag. The pair is located northwest of NGC 2718, at an angular distance of $\approx 5/2$. Assuming the distance to the NGC 2718 group to be 54.5 Mpc, the physical projected separation between NGC

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Based on Hubble flow with a redshift $z = 0.012$. 



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2718 and UGC 4703 is 81 kpc. A relative line of sight radial velocity between the two is 263 km s$^{-1}$. According to available notes in the NED, UGC 4703 is already identified as a star-forming pair of galaxies interconnected by a thin straight bridge.

3. Data Analysis

This work benefits from substantial multi-wavelength data available in public archives. This allowed us to perform the required detailed analysis of morphology and stellar population properties of our sources. We report a multi-wavelength study of the system based on the archival images from the Sloan Digital Survey (SDSS), Galaxy Evolutionary Explorer (GALEX), and the Spitzer Space Telescope, which covers a wavelength range from far-ultraviolet (FUV) to infrared. Additionally, we observed the system in a H\textsc{i} 21 cm line using the Giant Metrewave Radio Telescope (GMRT).

3.1. Analysis of Archival Data

In Figure 1, we show the SDSS r-band image of an area around NGC 2718 and its satellites with a field of view of 9$\prime$ x 5$\prime$. NGC 2718 is a well-studied isolated galaxy (Hernández-Toledo et al. 2010; Karachentseva et al. 2010). We find no bright galaxy ($M_r < -19$ mag) around it within a 1 Mpc sky-projected radius and a radial velocity $\pm 500$ km s$^{-1}$. Our NED query found no dwarf ($M_r > -19$ mag) companions other than the two, UGC 4703 and UGC 4703B, around NGC 2718. NGC 2718 is a nuclear starburst galaxy, and in the RC3 catalog, it is classified as of the face-on SAB type. It has a total stellar mass of $\log(M_*/M_\odot) = 10.7$ and a total H\textsc{i} mass of $\log(M_{\text{HI}}/M_\odot) = 10.05$ (Chang et al. 2015; Courtois & Tully 2015). Only NGC 2718 and UGC 4703 were targeted by the SDSS spectroscopy survey, and the measured redshifts for them are 0.0127 and 0.0119, respectively. Unfortunately, the SDSS target selection picks up a background red galaxy located on the edge of UGC 4703B; however, the NED cataloged redshift of UGC 4703B is 0.0118.

A stellar bridge connecting UGC 4703 and its companion UGC 4703B can be clearly seen in the SDSS image. A sky-projected separation between the two is 20 kpc. In Figure 1 (bottom panels), we show a more detailed view of the interacting pair. In the bottom left panel, we show a color image cutout directly obtained from the SDSS sky-server. In the $g-r-i$ combined color image, we can see a few extremely blue knots in the central region of UGC 4703, which indicate an ongoing burst of star formation. The H\textsc{a} emission line equivalent width measured from the SDSS optical spectrum of UGC 4703 is 181 Å. This gives a star formation age of the order of a few Myr (Leitherer et al. 1999). The optical morphology of UGC 4703B, however, is much smoother where no distinct blue star-forming knots are visible. From a detailed inspection of UGC 4703 morphology in Figure 1 (bottom right panel), it seems like a spiral galaxy and now one of its spiral arms is outflung in the direction of NGC 2718.

The stellar bridge connecting the interacting pair is not homogeneous in surface brightness and color, and seems bifurcated (see the bottom right panel of Figure 1 for more detail). Interestingly, each one of these streams (S1 and S2) seems to originate from different galaxies. It is impossible to determine the difference between these two in terms of stellar population properties from the shallow SDSS images, but the stellar bridge, overall, is bluer than both of the interacting galaxies. We find a bright star-forming clump nearly at the end of the stellar stream starting from UGC 4703B, i.e., S2. It may be a potential candidate of tidal dwarf galaxy (TDG) in formation. In the bottom left color image, we can see that it is much bluer than the surrounding stellar stream.

We performed the aperture photometry to derive total brightness of the objects of interest, i.e., UGC 4703, UGC 4703B, and the potential TDG candidate. The sizes of apertures were selected visually where we used a wide enough aperture that secured all of the flux. We used a similar approach to subtract the sky-background count as in Paudel et al. (2015). Before doing the aperture photometry, we masked all unrelated foreground and background objects manually. The GALEX all-sky survey (Martin et al. 2005) archival images were used to derive the UV magnitudes. We used the SDSS-III (Abazajian et al. 2009) image to derive the optical band magnitudes. IR fluxes were measured from the Spitzer Space Telescope, which were obtained from the IRSA archive. We list the results of aperture photometry in various band from UV to IR in Table 1. We find that both the dwarfs, UGC 4703 and UGC 4703B, have similar $g-r$ color indices of 0.34 mag. The putative TDG $g-r$ color index is $-0.07$ mag, whereas an average $g-r$ color index of the stellar bridge is 0.1 mag. We derived the star formation rate from the FUV flux using a calibration provided by Kennicutt (1998). Eskew et al. (2012) calibration was used to convert the Spitzer [3.6] and [4.5] channel flux to stellar mass. The total $r$-band luminosity and stellar mass of the UGC 4703, UGC 4703B, and TDG candidates were estimated to be $-18.25$, $-16.75$, and $-14.19$ mag and $1.9 \times 10^3$, $5.5 \times 10^3$, and $1.9 \times 10^3 M_\odot$, respectively.

3.2. Radio 21 cm Observation

To get a detailed view of the H\textsc{i} distribution of the UGC 4703 system and its connection to NGC 2718, we carried out H\textsc{i} interferometric observations of UGC 4703 using the GMRT. The system was observed on 2017 June 15. A baseband bandwidth of 16 MHz was used for the observations, yielding a velocity resolution $\sim 7$ km s$^{-1}$. The GMRT primary beam at the $L$ band is 24$\prime$, and the synthesized beam of the images presented in this Letter is 45$\prime\prime$ x 38$\prime\prime$. The data were analyzed using the software AIPS, and the procedure followed was similar to that explained in Sengupta et al. (2017). Figure 2 (top panel) shows the contours from the integrated H\textsc{i} map overlaid on the SDSS $g$, $r$, and $i$-band combined image. While an H\textsc{i} bridge is visible, validating an interaction between UGC 4703 and UGC 4703B, it is clear that there is no apparent sign of interaction between the MW-type NGC 2718 and the dwarf satellites in both the optical and radio H\textsc{i} images. In the interacting satellites, the H\textsc{i} emission is mainly concentrated around UGC 4703 with an extension of tenuous emission in the direction of UGC 4703B along the stellar bridge. In UGC 4703, the peak H\textsc{i} column density $(1.6 \times 10^{20}$ cm$^{-2}$) overlaps with its bright central star-forming

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6. The exact definition of TDG is vague. Here, a working definition is any stellar system of mass range $\geq 10^7 M_\odot$ born out of expelled debris of interacting galaxies.

7. http://irsa.ipac.caltech.edu

8. http://www.aips.nrao.edu
Interestingly, H\textsc{i} emission around UGC 4703B does not overlap with the optical counterpart. The emission is not strong; the H\textsc{i} column density levels at UGC 4703B are similar to the bridge (between \((2-6) \times 10^{19} \text{ cm}^{-2}\) with no prominent H\textsc{i} column density concentration on the galaxy. The integrated H\textsc{i} line flux density of the UGC 4703/4703B system estimated from our GMRT data is \(~1.4\) Jy km s\(^{-1}\) compared to the uncorrected flux density estimated from the Arecibo spectrum from NED \(~2.0\) Jy km s\(^{-1}\). Two factors contributed to this flux discrepancy. Our data quality of that day was not good, and heavy flagging resulted in losing crucial UV coverage. Additionally, the GMRT synthesized beam could have resolved out some diffuse emission from the extended, low column density bridge area of the UGC 4703 system. Thus, the Arecibo flux density was used to estimate the total H\textsc{i} mass of the system, UGC 4703/UGC 4703B combined, which is \(1.4 \times 10^9 M_\odot\). Lack of better spatial resolution and the disturbed, interacting H\textsc{i} morphology prevent us from estimating more accurate individual H\textsc{i} masses of UGC 4703 and UGC 4703B. However, from the H\textsc{i} image and H\textsc{i} column density contours, we can conclude that gas content in UGC 4703B is significantly lower than in UGC 4703. It seems that such low gas mass content in UGC 4703B is intrinsic, which is not due to the detection limit of our observation. Figure 2 (bottom right panel) shows the velocity field of the UGC 4703/4703B system. We detect a hint of a modest velocity gradient in NGC 4703, which becomes irregular along the bridge and the UGC 4703B region, though lack of better spatial resolution prevents us from making stronger claims about the gradient in UGC 4703.
optical magnitudes are corrected for galactic extinction. We used the Schla­
Seibert et al. (2005). The stellar masses are derived from the Spitzer [3.6] and [4.5] channel flux, and star formation rates are derived from the GALEX FUV flux.

### 4. Discussion

#### 4.1. Comparison with the LMC–SMC–MW System

Visible to the naked eye in the southern sky, the LMC and SMC are the best-studied star-forming galaxies, and thus the system is regarded as an important laboratory for studying the evolution of dwarf galaxies. They are currently suffering different scales of tidal force from both the massive central host galaxy, MW, and their own lower-mass companions. Understanding the origin of the LMC–SMC system in the vicinity of the MW has been an active area of research, and a widely discussed mechanism is binary infall (Besla et al. 2007, 2010; Kallivayalil et al. 2009; Diaz & Bekki 2011). In particular, Besla et al. (2007) show that the LMC–SMC pair might be entering the MW halo for the first time and has not yet completed an orbit. This model was updated by Besla et al. (2012) to explore the morphology of the stream produced from a head-on collision between the Clouds, specifically by the SMC moving in a highly eccentric orbit around the LMC, far from the MW potential. Here, we report another system similar in geometry and morphology to LMC–SMC and compare their properties to gain a better understanding of the system with dwarf–dwarf interaction in the proximity of a massive halo.

We list a direct comparison of physical parameters between the LMC–SMC–MW system and the UGC 4703 pair–NGC 2718 system in Table 2. NGC 2718 and MW have a similar stellar mass of $\approx 5 \times 10^{10} M_\odot$. NGC 2718 is located in a fairly isolated environment. Its nearest bright ($M_V < -19$ mag) galaxy is NGC 2731 at a sky-projected distance of 1.18 Mpc and a relative line of sight velocity between the two is 1260 km s$^{-1}$. In contrast, MW is part of the Local Group where the nearest bright neighbor is M33 at a distance of 0.86 Mpc.

Since we do not have resolved distances of each individual galaxy of the NGC 2718 group, the derived geometric properties are sky-projected. For the LMC–SMC–MW system, we use three-dimensional geometric properties that we obtained from D’Onghia & Fox (2016). The geometrical configuration of both systems looks similar. The interacting dwarfs are located within $\sim 100$ kpc of the massive hosts, i.e., NGC 2718 and MW, and the relative line of sight radial velocities between the hosts and dwarfs are $< 300$ km s$^{-1}$. The relative line of sight velocity between UGC 4703 and UGC 4703B is 15 km s$^{-1}$ and between LMC and SMC is 105 km s$^{-1}$. The sky-projected separation between UGC 4703 and UGC 4703B is 21 kpc and between LMC and SMC is 23 kpc. The current star formation rates of individual galaxies in the UGC 4703 pair are also similar to the LMC–SMC pair. Star mass ratios of both interacting pairs, UGC 4703–UGC 4703B and LMC–SMC, are $\approx 5:1$.

Although the tidal features of the LMC–SMC pair are quite prominent in gas structure, recent observations have revealed the presence of stellar substructure in the outskirts of the SMC (Belokurov & Koposov 2016; Besla et al. 2016; Belokurov et al. 2017). The presence of a gaseous bridge between the LMC and SMC proves that they must have had at least one close encounter in the recent past (Kallivayalil et al. 2013). Additionally, Nidever et al. (2013) identified a $\approx 55$ kpc stellar stream located to the east of the SMC, a likely stellar counterpart of the H I Magellanic Bridge that was tidally stripped from the SMC (Subramanian et al. 2017). In comparison to the stellar streams observed in the LMC–SMC pair, the stellar streams around UGC 4703 pair are more prominent. We also find a star-forming region (the putative TDG) in the stellar bridge that has a stellar mass log$(M_\star//M_\odot) = 7.25$ and a star formation rate $8.9 \times 10^{-3} M_\odot$ yr$^{-1}$. Overall, the stellar bridge is significantly bluer than both the dwarfs (UGC 4703, UGC 4703B) and is fairly aligned with the H I bridge. This suggests that at least some, if not all, stellar population in the bridge may have formed very recently from the tidally stripped gas. Evidence of a young stellar population has also been identified around the gaseous bridge connecting the LMC–SMC (Belokurov & Koposov 2016; Belokurov et al. 2017).

As far as our detection limit permits no sign of an extended H I tail is observed around the UGC 4703 pair, unlike the LMC–SMC system where a long trailing gaseous stream (known as the Magellanic Stream, MS) is prominent. The origin of the MS is debated, and a frequent, but not conclusive, explanation is that it is a product of tidal interactions between either LMC–SMC–MW or only LMC–SMC (Fujimoto & Sofue 1976; Gugglielmo et al. 2014). There are other scenarios, such as ram-pressure stripping, that could also explain the origin of the MS (Meurer et al. 1985; Moore & Davis 1994) if the interacting pair had already crossed the MW outer disk at some point in their past orbit. Even in a purely tidal interaction model, it is not clear how much MW potential affects the dynamical history of the pair or, in other words, whether the pair is bound to MW or not. The lack of three-dimensional distance of the NGC 2718 and UGC 4703 pair prevents us from estimating if UGC 4703 and UGC 4703B are bound to NGC 2718 or not.

We find that UGC 4703B is relatively gas-poor and the H I map shows that the gas distribution is displaced from its optical counterpart, while both LMC and SMC relatively are gas-rich. This may be a hint that the interaction between UGC 4703 and UGC 4703B is relatively advanced compared to LMC–SMC. Being the minor companion, UGC 4703B has experienced tidal stretching from UGC 4703, which probably has displaced most of the gas mass and deformed the stellar disk, creating a stellar bridge. One main difference in the geometry of LMC–SMC

| Galaxy   | R.A.       | Decl.  | FUV (mag) | NUV (mag) | $u$ (mag) | $g$ (mag) | $r$ (mag) | $i$ (mag) | $z$ (mag) | [3.6] (mJy) | [4.5] (mJy) | log(SFR) ($M_\odot$ yr$^{-1}$) | log($M_\star$) ($M_\odot$) |
|----------|------------|--------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|---------------------------------|-------------------|
| UGC 4703 | 08:58:29.869 | 06:19:17.07 | 17.1 | 16.8 | 16.31 | 15.60 | 15.26 | 15.19 | 15.08 | 2.060 | 1.540 | −0.64 | 9.27 |
| UGC 4703B | 08:58:25.024 | 06:20:06.44 | 19.6 | 18.9 | 18.25 | 17.10 | 16.76 | 16.50 | 16.38 | 0.390 | 0.230 | −1.49 | 8.74 |
| TDG      | 08:58:28.424 | 06:19:34.76 | 20.4 | 20.3 | 20.05 | 19.25 | 19.32 | 19.20 | 19.30 | 0.010 | 0.005 | −2.05 | 7.28 |

Note. The UV magnitudes are from the GALEX images and the optical are from the SDSS. Spitzer Space Telescope images are used to derive IR flux. UV and optical magnitudes are corrected for galactic extinction. We used the Schlafly & Finkbeiner (2011) extinction map, and we calculated the extinction in UV using Seibert et al. (2005). The stellar masses are derived from the Spitzer [3.6] and [4.5] channel flux, and star formation rates are derived from the GALEX FUV flux.

| Galaxy | R.A.       | Decl.  | FUV (mag) | NUV (mag) | $u$ (mag) | $g$ (mag) | $r$ (mag) | $i$ (mag) | $z$ (mag) | [3.6] (mJy) | [4.5] (mJy) | log(SFR) ($M_\odot$ yr$^{-1}$) | log($M_\star$) ($M_\odot$) |
|--------|------------|--------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|---------------------------------|-------------------|
and UGC 4703–UGC 4703B is the relative line of sight velocity between the pair, where the later has a significantly lower value, i.e., 15 km s\(^{-1}\). In contrast to the previous hypothesis, this may also suggest that the encounter in UGC 4703–UGC 4703B is slower than the encounter in LMC–SMC and that leads to a stronger tidal distortion of participating galaxies in UGC 4703–UGC 4703B compared to relatively fast interacting LMC–SMC. However, a comparative study with a result of numerical simulation with full orbital histories of interactions is required to make a firm conclusion.

In summary, we present the UGC 4703 pair–NGC 2718 system as an LMC–SMC–MW analog. Both of the systems have similar physical (geometry, star formation rate, total gas mass, and stellar mass) and morphological properties. Our GMRT observations detected \(\text{H} \text{i}\) in NGC 2718 and the UGC 4703 pair, as well as in the bridge between the dwarf pair.

Table 2

| Galaxy       | \(M_B\)  | \(D\)  | \(M_d\)   | SFR   | \(H_\text{max}\) |
|--------------|---------|--------|-----------|-------|------------------|
| MW           | −21.17  | 0      | \(5 \times 10^{10}\) | 0.68–1.45 | 8 \times 10^7 |
| LMC          | −18.60  | 50     | \(2.3 \times 10^9\) | 0.2   | 4.4 \times 10^8 |
| SMC          | −17.20  | 60     | \(5.3 \times 10^8\) | 0.04  | 4 \times 10^8   |
| NGC 2718     | −21.01  | 0      | \(7 \times 10^{10}\) | 0.97  | 1.12 \times 10^{10} |
| UGC 4703     | −18.0   | 81     | \(1.8 \times 10^9\) | 0.2   | 1.4 \times 10^8 |
| UGC 4703B    | −16.5   | 104    | \(5.4 \times 10^8\) | 0.03  | ...              |

**Note.** \(D\) is distance from the host galaxy to the dwarfs. In our case, it is sky-projected, while the values for LMC and SMC are three-dimensional. The LMC and SMC parameters are obtained from D’Onghia & Fox (2016).

}\(^a\) Combined \(\text{H} \text{i}\) mass of UGC 4703 and UGC 4703B.
However, no extended H I, similar to the MS, is detected between NGC 2718 and the UGC 4703 pair. We also detected star-forming regions along the UGC 4703/4703B bridge with stellar masses exceeding $10^7 M_\odot$. A comparison of optical and H I morphology of interacting dwarfs pairs (UGC 4703–4703B and LMC–SMC) suggests interaction between UGC 4703 and UGC 4703B is either slow or at a relatively advanced stage compared to the LMC–SMC interaction.

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