UGC 7388: a galaxy with two tidal loops

M. Faúndez-Abans¹, V.P. Reshetnikov², M. de Oliveira-Abans¹, and I.F. Fernandez¹

¹ MCT/Laboratório Nacional de Astrofísica, Itajubá, Brasil
² St.Petersburg State University, Universitetskii pr. 28, Petrodvoretz, 198504 Russia

We present the results of spectroscopic and morphological studies of the galaxy UGC 7388 with the 8.1-m Gemini North telescope. Judging by its observed characteristics, UGC 7388 is a giant late-type spiral galaxy seen almost edge-on. The main body of the galaxy is surrounded by two faint ($\mu_B \sim 24.5$/$\arcsec$) and ($\mu_B \sim 25.5$/$\arcsec$) extended ($\sim 20–30$ kpc) loop-like structures. A large-scale rotation of the brighter loop about the main galaxy has been detected. We discuss the assumption that the tidal disruption of a relatively massive companion is observed in the case of UGC 7388. A detailed study and modeling of the observed structure of this unique galaxy can give important information about the influence of the absorption of massive companions on the galactic disks and about the structure of the dark halo around UGC7388.

Keywords: galaxies, interacting galaxies, morphology, kinematics.

1. Introduction

The more detailed the study of a particular galaxy is, the larger the number of formations and features of various kinds indicative of its preceding evolution are detected in its structure. These formations are discovered both in the central regions of galaxies (chemically and kinematically decoupled nuclei and circumnuclear structures; see, e.g., the review by Silchenko 2007) and in their outer regions (tidal structures, stellar and gaseous disk warps, star streams in galactic halos, etc. – see, e.g., Ibata et al. 2007; Martinez-Delgado et al. 2008).

Generally, the outer structures have a very low surface brightness and a relatively old age, $\geq 10^8$ yr. Their presence is usually attributed to the interactions and mergers of galaxies as well as to the absorption of relatively low-mass companions. The statistics of such relics of the hierarchical galaxy formation is an important test for the evolution models of extragalactic objects, while their characteristics (shapes, sizes, luminosities, etc.) can provide valuable information about the structure of dark halos and the star formation under unusual conditions (see, e.g., Dubinski et al. 1996; Reshetnikov and Sotnikova 2001).

In this paper, we present the results of our morphological and spectroscopic studies of the spiral galaxy UGC 7388. This galaxy has not been studied in detail previously, although a faint extended optical structure similar to those observed in several polar-ring galaxies has long been pointed out in its structure (Schweizer et al. 1983; Whitmore et al. 1990).

2. Observations

The observations of UGC 7388 were performed on April 8, 2005, with the 8.1-m Gemini North telescope (Hawaii, USA). We used the GMOS spectrograph in long-slit modes with the Red1 detector. The seeing during the observations was about 1.′′4 (FWHM). During the observations, we obtained two optical images of the galaxy (the r-G0303 filter with an effective wavelength of 630 nm), each with an exposure time of 5 min. These images (with a scale of 0.′′1454 per pixel) were used to analyze the morphology of the galaxy and to accurately set the slit for the subsequent spectroscopic observations.

¹ Request ID GN-2005A-Q-66.
² A description of the instrument can be found at [http://www.gemini.edu/sciops/instruments/gmos/gmos-Index.html](http://www.gemini.edu/sciops/instruments/gmos/gmos-Index.html)
The spectroscopic observations (with the R831+G5302 grating centered at 675 nm) were performed at two spectrograph slit positions, P.A.=49° (the major axis of the galaxy’s main body) and P.A.=109° (the major axis of the brighter inclined loop) – see Fig. 1. The spectral range was 5700–7800 Å, the spectral resolution was about 3000, and the scale of the spectra was 0.68 Å/pixel. At each position of the slit (its width and length were 0.75′′ and 1.8′′, respectively), we took three spectra, each with an exposure time of 15 min. Reproductions of the 2D spectra for the galaxy and the spectrum of its nucleus are shown in Fig. 2.

We reduced the data in a standard way using the IRAF and MIDAS packages.

3. Results

3.1. The morphological structure of UGC 7388

Figure 1 shows reproductions of the image for UGC 7388 at 630 nm. In the upper left panel, the object appears as an ordinary spiral galaxy seen at a large angle to the line of sight (nearly edge-on). A dust lane displaced by 2″ – 3″ from the center stretches along the entire NW edge of the galaxy. A straight structure extending beyond the NE edge of the galactic disk lies to the NW of this lane. The SW edge of the UGC 7388 disk is warped southward. The disk inclination was roughly estimated from its observed flattening ($b/a \approx 0.17$ from the SE half of the main body undistorted by absorption) and from the dust lane visibility conditions to be $i \geq 80°$.

The extended ringlike structure is slightly displaced to the NE of the galactic center and crosses the galactic plane at an angle of $\sim 55°$ (the major axis of the ring is 47″ or 20 kpc; its apparent flattening is $b/a \approx 0.6$). Previously, the presence of this feature allowed UGC 7388 to be considered as a probable candidate for polar-ring galaxies (Whitmore et al. 1990).

As the image contrast increases, the ring-like structure becomes increasingly distinct (the lower left frame in Fig. 1). However, the second, fainter and more extended, ring elongated from the north to the south also shows up (see also the upper right frame). This ring crosses the galactic plane at an angle of about 150° (so that the ring-like structures are almost orthogonal to each other); its major axis is 78″ (34 kpc) and its apparent flattening is $b/a \approx 0.7$

A faint diffuse feature stretching to the NW from the NE edge of the galactic disk can be seen in the upper right frame of Fig. 1. This feature and the two loops described above probably form a single continuous structure wound around the edge-on galactic disk. The galaxy as a whole is embedded in a faint, almost circular (in projection) envelope $\sim$60 kpc in diameter.

Many of the features of UGC 7388 described above are clearly traceable on the contour map shown in Fig. 3.

3.2. Photometric characteristics of UGC 7388

The main characteristics of the galaxy that we found and those taken from the literature are summarized in the table. To estimate the apparent magnitude of
UGC 7388 in the $B$ band\textsuperscript{3} and its $B - V$ color index, we used photometric data from the SDSS survey (Adelman-McCarthy et al. 2007) recalculated to the $B$ and $V$ bands (Blanton and Roweis 2007). Note that the estimated apparent magnitude of the galaxy, $B = 15.25$, is brighter than that in the LEDA\textsuperscript{4} (16.18 ± 0.5) by almost one magnitude.

The total luminosity of the loop system and the outer envelope is comparable to the observed luminosity of the central galaxy (within the faintest isophote shown in Fig. 3, the observed ratio of the luminosity of the outer structures to the luminosity of the central galaxy reaches ~0.8). However, the central galaxy is seen nearly edge-on and its luminosity should be corrected for internal extinction. Following the recommendations by Tully et al. (1998), we estimated that the central galaxy seen face-on should be brighter by ~ 1\textsuperscript{m} (in the $R$ filter). Thus, the relative luminosity of the outer structures decreases to ~ 20 – 30\% of the luminosity of the central galaxy.

Using an approximate calibration of our frames (based on the SDSS apparent magnitude of UGC 7388), we found that the brightest parts of the smaller ring have a surface brightness from $\mu_R \approx 22.9\text{m}/\square''$ (the E and SE regions of the ring) to $\mu_R \approx 22.3\text{m}/\square''$ (the W edge). Below, the surface brightnesses are given without their units of measurement. The southern region of the more extended loop exhibits a lower brightness, $\mu_R \approx 24.0 – 24.4$. The corresponding $B$-band brightnesses (for $B - R$ color indices of the loops from +1.0 to +1.5) are $\mu_B \approx 23.3 – 24.4$ and $\mu_B \approx 25.0 – 25.9$ for the smaller and larger rings.

The galaxy has no distinct bulge and the brightness distribution along its major axis can be described by an exponential disk with a radial scale length of 3.0 kpc. The color index of UGC 7388 ($(B - V)_0 \approx +0.5... + 0.6$ corrected for the inclination) and the relative abundance of neutral hydrogen

---

\textsuperscript{3} All magnitudes are given here in the AB system of magnitudes.

\textsuperscript{4} Lyon–Meudon Extragalactic Database.
(M(III)/$L_B \approx 0.2 - 0.3$) are also consistent with the fact that it is a late-type galaxy.

The vertical $R$-band brightness distribution of the galactic disk is distorted by the dust lane. The $J$-, $H$-, and $K$-band images of UGC 7388 taken from the 2MASS survey[5] are more symmetric. In the $K$ band, the ratio of the exponential scale lengths found along the minor and major axes of the disk is $h_z/h \approx 0.4$. Such a large apparent flattening may suggest that the galactic plane is significantly inclined to the line of sight ($i \leq 70^\circ$ for the galaxy’s true flattening $\leq 0.15$), but the relatively small observed displacement of the dust lane (see above) is apparently in conflict with this assumption. The large observed ratio $h_z/h$ probably suggests that the stellar disk of UGC 7388 is intrinsically thick.

### 3.3. Results of spectroscopic observations

The spectrum of the galactic nucleus is typical of HII regions (Fig. 2). The systematic velocity of the galaxy that we found (see the table) is in a good agreement with the results of previous spectroscopic observations (NED, the NASA/IPAC Extragalactic Database) and radio observations (O’Neil et al. 2004).

Figure 4 presents the distribution of radial velocities measured from the [OI]$_{\lambda 6300}$, H$\alpha$, [NII], and [SII] emission lines along the major axis of UGC 7388. The errors of individual velocity measurements do not exceed 10 km/s in the central region of the galaxy and increase to 20–30 km/s on its periphery. The lower panel in Fig. 4 shows the velocity distribution averaged relative to the galaxy’s dynamical center. The maximum observed rotation velocity, $V_{\text{max}} = 220$ km/s, is close to the FWHM of the HI profile corrected in a standard way (see, e.g., Bottinelli et al. 1990; Tully and Fouque 1985) for instrumental broadening and turbulent gas motion ($W_{20}^{corr}/2 = 224$ km/s).

We see from Fig. 4 that the observed rotation curve within $15'' - 20''$ of the galactic center can be represented by an exponential disk (the figure shows the so-called maximal disk, whose contribution to the observed rotation curve in the central region of the galaxy is at a maximum). However, the last point of

---

[5] http://www.ipac.caltech.edu/2mass/
Table 1. Main characteristics of UGC 7388

| Characteristic                        | Value                      |
|--------------------------------------|----------------------------|
| Morphological type                   | Sc:                        |
| Apparent magnitude, $B$              | 15.25                      |
| $B - \text{V}$                       | +0.8                       |
| Diameter ($\mu R = 25.5$)           | 120" (52 kpc)              |
| Extinction in our Galaxy, $A_B$      | 0.05                       |
| Heliocentric radial velocity         | 6442 ± 11 km/s             |
| Photometric distance                 | 93.8 Mpc                   |
| Scale                                | 0.435 kpc/1"               |
| Absolute magnitude of central galaxy, $M_B^0$ | −20.4:                     |
| Radial scale length of brightness distribution, $h$ | 6.9" (3.0 kpc)          |
| Maximum rotation velocity, $V_{max}$ | 220±20 km/s                |
| Observed HI profile width, $W_{20}$  | 471 km/s                   |
| $M_{HI}$                             | $6.3 \times 10^9 M_\odot$  |
| $L_{FIR}$                            | $1.4 \times 10^{10} L_\odot$ |
| SFR$_{FIR}$                          | $7 M_\odot$/yr             |

* – NASA/IPAC Extragalactic Database

The rotation curve at $r = 23'' = 10$ kpc (or, in units of the exponential scale length, $3.3h$), deviates from the exponential fit, suggesting the existence of a dark halo in which the optical disk is embedded. Within $r = 23''$, the contribution from the hidden mass is relatively small – the ratio of the dark halo mass to the stellar disk mass is $\sim 1/3$. This estimate of the contribution from the dark halo is most likely a lower limit – if the galactic disk is not maximal and/or if the exponential scale length of the density distribution in the disk is smaller than our adopted value (e.g., 2MASS images are indicative of lower values of $h$), then the contribution from the dark halo can be considerably larger.

The radial-velocity distribution for the Hα and [NII] lines at P.A.=109° is shown in Fig. 5. Obviously, the ring-like structure (the brighter and more compact of the two structures described above) shows evidence of a large-scale rotation relative to the central galaxy: the W part of the ring recedes from us with a relative velocity of $\sim 100$ km/s, while its E part approaches us with a velocity of $\sim 50–100$ km/s. Thus, UGC 7388 could have been classified as a kinematically confirmed polar-ring galaxy, but the presence of a second loop-like structure and the noncoincidence of the loop centers with the galactic nucleus are in conflict with the classical definition of this type of galaxies (Whitmore et al. 1990).

In general, the radial-velocity distribution of the emitting gas along the major axis of the loop appears non-monotonic: a local velocity maximum is observed at a distance of $10''–15''$ to the east of the nucleus. This feature may be related, for example, to the interaction between the gas subsystems of the loop and the main galaxy. In addition, to all appearances, the general velocity field of UGC7388 is a complex, multi-component one, since it reflects the capture and disruption of a relatively massive companion (see the subsequent discussion).

4. Discussion

The data from the table and the preceding discussion show that UGC7388 is a typical giant spiral galaxy. It is similar to the Milky Way Galaxy in luminosity, maximum rotation velocity, and exponential scale length of the brightness distribution. The main differences between UGC7388 and the Milky Way are the absence of a prominent bulge and a slightly higher HI abundance.

The most remarkable feature of UGC 7388 is that it is surrounded by two faint extended loop-like structures (Figs. 1 and 3). The existence of the brighter structure with $\mu_B \sim 24$ has already been known (its presence was the reason why the galaxy was included in the list of candidate polar-ring galaxies); the fainter structure ($\mu_B \sim 25.5$, the diameter exceeds 30 kpc) is described here for the first time.

One of the standard scenarios for the formation of outer structures in galaxies is the tidal capture
Fig. 4. Top: Observed radial-velocity distribution along the major axis of UGC 7388 (different symbols indicate individual measurements from three different spectrograms). Bottom: Averaged rotation curve of the galaxy (crosses); the dashed line indicates the rotation curve for an exponential disk with a scale length of 6.9" and flattening $b/a = 0.2$ (Monnet and Simien 1977); the horizontal bar indicates the FWHM of the corrected HI profile.

An upper limit on the mass of the companion being disrupted can be roughly estimated from the observed luminosity of the structures outside the disk of the main galaxy to be 20–30% of the main galaxy’s mass. This is a gross overestimate, since the matter of the central galaxy itself snatched away during the interaction with the companion can also contribute to the luminosity of the outer structures. In addition, the observed (at least in the brighter loop, Fig. 2) emission lines can also contribute to the observed $R$ band luminosity of the outer structures. These effects are fairly difficult to take into account. Therefore, as a rough estimate, we assume that the relative mass of the companion can reach $\sim 0.2 \pm 0.1$ of the main galaxy’s mass.

As for the interaction geometry, the companion most likely approached the NE edge of the galaxy from the NW (see Fig. 1); it described initially the larger (fainter) loop and subsequently the smaller (brighter) one. In general, the companion’s orbit traced by the tidal structures is very similar to the results of numerical simulations presented by Villalobos and Helmi (2008) (see Fig. 3 in their paper). The time it takes for the companion to be disrupted is $\sim 1$ Gyr (estimated from the total length of the loops and the velocity of the companion, 200 km/s).

What suggests that a prolonged interaction of two galaxies is observed in the case of UGC 7388? First of all, it is the fact that the main galaxy has a perturbed structure. For example, a linear structure, which may
be a tidal tail seen nearly edge-on, stretches along its NW edge. The SW edge of the disk is strongly warped (the warp of the opposite part of the disk is probably masked by the previously mentioned straight structure and the dust lane). The existence of such deformations of the stellar disks in galaxies is often related to their interactions and the presence of close companions (Reshetnikov and Combes 1998, 1999). There is evidence of an excess in thickness of the stellar disk in UGC 7388 (see above), which is also a standard consequence of the gravitational interaction between galaxies (Reshetnikov and Combes 1997). Additional signatures of the absorption of a companion include the presence of an extended, nearly spherical envelope $\sim 60$ kpc in diameter surrounding the galaxy and the relatively high infrared luminosity of UGC 7388 (see the table).

Very few objects similar to UGC 7388 (spiral galaxies surrounded by extended loop-like structures of low surface brightness visible in the optical range) are known to date. As the closest example, we can mention the Milky Way Galaxy, whose disk is crossed by an extended star stream produced by the dwarf galaxy Sgr I being disrupted (Ibata et al. 1995). Another example is the nearly edge-on galaxy NGC 5907, whose main body is surrounded by a very faint ($\mu_R \approx 27 - 28$) loop-like structure $\sim 40$ kpc in diameter (Shang et al. 1998). The observed morphology of this loop is well described as the remnant of a disrupted low-mass ($\sim 10^{-3}$ of the main galaxy’s mass) companion (Reshetnikov and Sotnikova 2000). A large-scale system of faint ($\mu_R \approx 27$) tidal loops has recently been discovered around the spiral galaxy NGC 4013, which is also seen nearly edge-on (Martinez-Delgado et al. 2008).

The three galaxies (NGC 5907, NGC 4013, and UGC 7388) share several common features. First, they are all seen at a large angle to the line of sight, edge-on. Such a preferential orientation is undoubtedly the result of observational selection, since the outer structures in galaxies with a smaller inclination to the line of sight will be projected onto their main bodies and will remain undetectable. Second, all three galaxies are relatively isolated objects. This peculiarity probably stems from the fact that the presence of nearby galaxies can disrupt the thin, “coherent” outer structures. Third, all three galaxies exhibit large-scale warps of their stellar and/or gaseous disks. As was noted above, such deformations of the galactic disks can be caused by their gravitational interaction with the companions being absorbed.

An important difference between UGC 7388 and other similar objects is that the disruption of not a dwarf, but of a relatively massive companion is observed in this galaxy. Accordingly, the tidal loops have a rather high surface brightness, which allows their geometry and even kinematics to be investigated without any special tricks. This turns UGC 7388 into a unique laboratory for studying such topical questions as the disruption of a companion in the gravitation field of a massive galaxy and the influence of a companion on the structure of the main galaxy (vertical heating of the stellar disk, the formation of its large-scale warp, triggered star formation, etc.). Realistic numerical simulations of UGC 7388 could allow the extent, mass, and, possibly, shape of the dark halo in this galaxy to be estimated.

Acknowledgments

This work is based on the observational data obtained at the Gemini Observatory, which is operated by the Association of Universities for Research in Astronomy (AURA) under a cooperative agreement with NSF on behalf of the Gemini Union: NSF (USA), STFC (United Kingdom), NRC (Canada), CONICYT (Chile), ARC (Australia), CNPq (Brazil), and SECYT (Argentina). The observations were performed under ID GN-2005A-Q-66. The study was supported by the Russian Foundation for Basic Research (project no. 06-02-16459).

REFERENCES

1. J.K. Adelman-McCarthy, M.A. Agueros, S.S. Allam, et al., Astrophys. J. Suppl. Ser. 172, 634 (2007).
2. M.R. Blanton and S. Roweis, Astron. J. 133, 734 (2007).
3. L. Bottinelli, L. Gouguenheim, P. Fouque, and G. Paturel, Astron. Astrophys. Suppl. Ser. 82, 391 (1990).
4. Ch. Brocca, D. Bettoni, and G. Galletta, Astron. Astrophys. 326, 907 (1997).
5. J. Dubinski, J. Mihos, and L. Hernquist, Astrophys. J. 462, 576 (1996).
6. R.A. Ibata, G. Gilmore, and M.J. Irwin, Mon. Not. R. Astron. Soc. 277, 781 (1995).
7. R. Ibata, N.F. Martin, M. Irwin, et al., Astrophys. J. 671, 1591 (2007).
8. D. Martinez-Delgado, M. Pohlen, R.J. Gabany, et al., [arXiv:0801.4657v1 (2008).]
9. G. Monnet and F. Simien, Astron. Astrophys. 56, 173 (1977).
10. K. O’Neil, G. Bothun, W. van Driel, and D. Monnier Ragaigne, Astron. Astrophys. 428, 823 (2004).
11. V. Reshetnikov and F. Combes, Astron. Astrophys. 324, 80 (1997).
12. V. Reshetnikov and F. Combes, Astron. Astrophys. 337, 9 (1998).
13. V. Reshetnikov and F. Combes, Astron. Astrophys. Suppl. Ser. 138, 101 (1999).
14. V.P. Reshetnikov and N.Ya. Sotnikova, Pis’ma Astron. Zh. 26, 333 (2000) [Astron. Lett. 26, 277 (2000)].
15. V.P. Reshetnikov and N.Ya. Sotnikova, Astron. Astrophys. Trans. 20, 111 (2001).
16. F. Schweizer, B.C. Whimore, and V.C. Rubin, Astron. J. 88, 909 (1983).
17. Zh. Shang, Zh. Zheng, E. Brinks, et al., Astrophys. J. 504, 23L (1998).
18. O.K. Silchenko, Astronomy: Traditions, Present, Future Ed. by V.V. Orlov, V.P. Reshetnikov, and N.Ya. Sotnikova (St.-Petersburg State University, St. Petersburg, 2007), p. 63.
19. R.B. Tully and P. Fouque, Astrophys. J. Suppl. Ser. 58, 67 (1985).
20. R.B. Tully, M.J. Pierce, J.-Sh. Huang, et al., Astron. J. 115, 2264 (1998).
21. A. Villalobos and A. Helmi, arXiv:0803.2323v1 (2008).
22. B.C. Whitmore, R.A. Lucas, D.B. McElroy, et al., Astron. J. 100, 1489 (1990).