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Three low surface brightness dwarfs discovered around NGC 4631

Igor D. Karachentsev[1], Dirk Bautzmann[2], Fabian Neyer[2], Robert Pölzl[2], Peter Riepe[2], Thorsten Zilch[2], and Bruno Mattern[2]

[1] *Special Astrophysical Observatory of the Russian Academy of Sciences*

[2] *TBG group in the German amateur association*⋆

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ABSTRACT

We report the discovery of three low surface brightness companions to the spiral galaxy NGC 4631, made with small amateur telescopes. Assuming their distances to be 7.4 Mpc, the same as that of NGC 4631, the absolute magnitudes and linear diameters of the dwarfs are ranged within [-12.5, -9.6] mag and [4.7 - 1.3] kpc, respectively. These new three dwarfs, together with the discovered by us diffuse structure called "bridge", look like parts of a tidal filament directed towards NGC 4656 at total extended over 100 kpc.

Key words: galaxies: dwarf, galaxies: groups, galaxies: interactions

1 INTRODUCTION

Wide-field surveys of the halo of the Andromeda galaxy performed with 3-meter class telescopes designed with the CCD-mosaics led to the discoveries of many ultra-faint dwarf companions and low surface brightness (LSB) stellar streams (Ibata et al. 2007; Martin et al. 2009; Ibata et al. 2014). A similar survey of wide surroundings of another nearby giant spiral galaxy M 81 (Chiboucas et al. 2009, 2013) also demonstrated the presence around it of many dwarf satellites of very low surface brightness, SB$\sim (26-28) m/\square''$. Diffuse objects having

⋆ TBG is a group in the German amateur association "Vereinigung der Sternfreunde e.V. " called "Tief Belichtete Galaxien", which performs the project "Very long exposed galaxies".

a surface brightness of $\sim 1\%$ above the moonless night sky are usually indistinguishable on the photographic plates of sky surveys POSS-I, POSS-II, ESO-SERC and reveal themselves only being resolved into stars.

The brightness limit of SB$\sim 27m/\Box''$ is easily reachable for the telescopes designed with modern CCD mosaics under a long enough exposure time and accurate flat-fielding. Because the surface brightness of a galaxy does not depend on its distance, a search for new very LSB objects can be successfully performed with a telescope of small diameter ($\sim 0.1-1$ meter) having a wide field of view. For instance, a deep image of a galaxy situated at a distance of 10 Mpc, carried out with a ~ 1 Mega-pixel camera under a resolution of $\sim 3''$/pixel, covers with its field of view $\sim 1^\circ$ the sky region of ~ 100 kpc, comparable with the size of the halo of a giant galaxy. Hereby, the image of a dwarf companion having a typical diameter of ~ 1 kpc (or $20''$) contains a number of resolution elements (~ 50), which is sufficient to reliably detect the object.

According to the standard cosmological paradigm, luminous galaxies are building up from dwarf galaxies via their consecutive merging. Due to this, the far periphery of nearby giant galaxies looks like a screen where one can see stellar streams as a result of dwarf galaxy merging, and a population of LSB dwarfs missed by the photographic sky surveys.

These apparent considerations were set as a ground for different projects which directed astronomy amateurs, having small-gauge telescopes, to perform a systematic survey of the vicinities of nearby luminous galaxies. The efficiency of such a strategy was demonstrated by (Martinez-Delgado et al. 2008, 2010, 2012) whose project "Dwarf Galaxy Survey with Amateur Telescopes = DGSAT" led to the discovery and study of tidal stellar streams around several nearby spiral galaxies.

A similar project, called TBG (Tief Belichtete Galaxien) was started by the German amateur association "Vereinigung der Sternfreunde e.V.", which has several workgroups, the "Fachgruppe Astrofotografie" being one of them. In 2011 this group started a project in collaboration with professional astronomers from the Bochum University. The project is called TBG, which stands for the German expression "Tief Belichtete Galaxien" (meaning "very long exposed galaxies"). All the selected targets are the galaxies from the Local Volume. Initially, the project's aim was to detect new stellar streams. As shown by the first results, the wide-field photography made by the team also allows to reveal other interesting details: the tidal interaction phenomena between galaxies, as well as the dwarf galaxies of very low surface brightness. Meanwhile, the TBG team reached SB of $\sim 27m/\Box''$, which is deeper than that of the Sloan Digital Sky Survey = SDSS (Abazajian et al. 2009). In autumn 2013 the TBG aims were redefined and the cooperation with professional astronomers was also exchanged. In terms of the public outreach, there will soon be a TBG website for the presentation of the team results. Today the group of amateur astrophotographers counts about 30 members. The telescopes in use range from the small refractors (4 inch) to the reflectors with apertures up to 44 inches. To get very deep and high quality image data, high-end off-the-shelf CCD cameras of well-known manufacturers are used. All the images are carefully calibrated by dark frame subtraction and flat field correction before the further processing is applied. The framework of the TBG group activities is conceived by Peter Riepe (conceptional work) and Thorsten Zilch (organization).

2 THE GROUP OF GALAXIES AROUND NGC 4631

According to Makarov & Karachentsev (2011), a group of galaxies around NGC 4631 accounts 28 members with a wide range of absolute magnitudes M_B from -20^m till -10^m. The group is characterized by the mean radial velocity of +635 km/s in the rest frame of the Local Group, the velocity dispersion of 90 km/s, and the mean harmonic radius of 243 kpc. The total stellar mass of the group members amounts to $\log(M_*/M_\odot) = 11.12$, and the virial (projected) mass of the group is equal to $\log(M_p/M_\odot) = 12.98$, what is 72 times the stellar mass. The brightest group member is a spiral late-type galaxy NGC 4631 seen nearly edge-on. On its northern side, an elliptical galaxy NGC 4627 is projected, and on the southern side at the separation of $32'$ there is another bright late-type spiral galaxy NGC 4656 showing strong distortions of the disk shape. Radburg-Smith et al. (2011) determined the distance to NGC 4631 as 7.38 Mpc, via the Tip of Red Giant Branch using the ACS camera aboard the Hubble Space Telescope. With this distance, NGC 4631 has a linear Holmberg diameter of 33.7 kpc and an absolute magnitude of $M_B = -20\overset{m}{.}28$.

The moderately wide interacting pair NGC 4631/4656 with the linear projected separation of 69 kpc was a subject of investigations by various authors. Rand (1994) performed a 21-cm survey of the pair using the WSRT radio telescope with a resolution of $\sim 30''$ and found four wide HI-tails. Two of them extend from NGC 4631 towards NGC 4656 and two others are directed to the north and north-east from NGC 4631. Apart from them, a ring-like structure consisting of low-density HI-clouds was detected. These features look like a tidal bridge with tails created during a tight encounter of two spiral galaxies. Judging from their projected separation and radial velocity difference of 55 km/s, this event happened $\sim$ 1 Gyr ago.

Donahue et al. (1995) imaged the NGC 4631/4656 pair with a narrow ($\sim$ 30Å) filter centered on the Balmer $H\alpha$ line. They found a broad field of faint $H\alpha$ emission, occupying a space between the pair components and also extending north from NGC 4631. The discovery of a faint emission envelope around the pair has again confirmed the presence of rudimental tidal features remaining from the encounter.

3 DISCOVERY OF THREE NEW DWARF GALAXIES NEAR NGC 4631

To test the own capabilities, the TBG members concentrated their initial photographic efforts on the already known objects, i.e. the objects imaged by the group of David Martinez-Delgado and his amateur astronomers (Martinez-Delgado et al. 2008). As the second step they decided to establish a new list of targets from the NGC/IC catalog by a systematic examination of potential candidates using the Deep Sky Survey (DSS). To identify the possible candidates, a heavy contrast enhancement for all the images was applied. Applying this method, some dozens of galaxies, showing suspicious features like possible stellar streams were selected. Due to the limited magnitude of the DSS, the target candidates were compared with the SDSS images, whenever available. The galaxy NGC 4631 turns out to be among the first targets in the project.

At first, a wide-field image of the galaxy was derived by Dirk Bautzmann. A diffuse feature 20' northwest from NGC 4631 unknown before was revealed. It is marked by the bars in Figure 1. Then, Bruno Mattern from Hamburg identified this feature on his deep wide-field frame obtained earlier. Later, Robert Pölzl and Fabian Neyer took follow-up images of this region. The stacked image of them is presented in Figure 2. The diffuse object was confirmed again. We called it N4631dw1. About 5' north of the NGC 4631 core and 3' north-north-east of NGC 4627, another diffuse object was found, smaller in size and likely an extremely faint dwarf galaxy, called N4631dw2. About 10' south-east of the NGC 4631 centre, yet a third faint object is visible, N4631dw3, looking like a dwarf spheroidal galaxy. At least, on the opposite side of NGC 4631, compared to N4631dw1, a larger structure of extremely low surface brightness can be recognized just south of the N4631dw3 object. This elongated feature seems to point in the direction of NGC 4656, situated in the zone of the HI and $H\alpha$ bridge, found by Rand (1994) and Donahue et al. (1995).

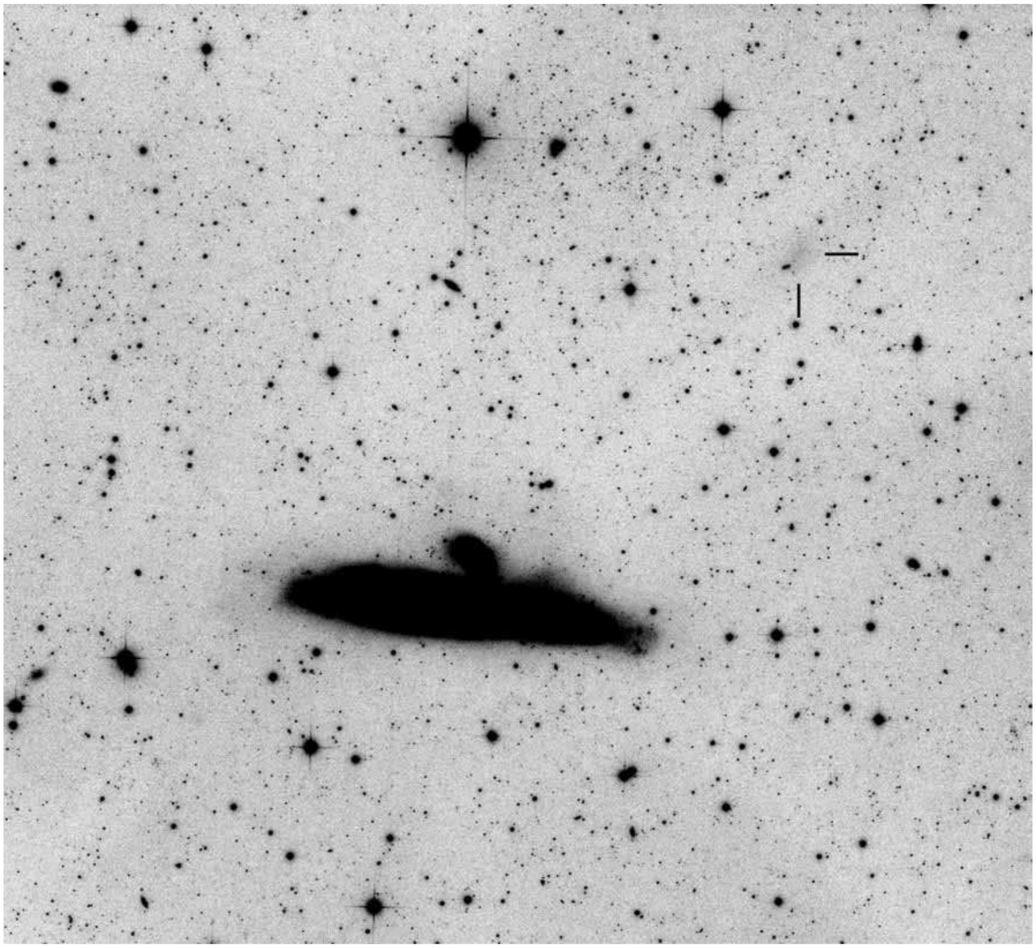

Figure 1. NGC 4631 and N4631dw1 (arrows) taken in March 2013 by Dirk Bautzmann. Telescope: PlaneWave CDK 12.5 (f/8) on the ASA DDM85 mount, camera: Apogee U16M with LRGB+$H\alpha$ filters. Total exposure: 13 h 05 min, FWHM about $2''.6$, field of view: $41' \times 37'$.

Table 1. Properties of three low surface brightness dwarfs discovered around NGC 4631

Object	RA (J2000.0) DEC	a'	b/a	B_T	M_B	m_{FUV}	Type
N4631dw1	12 40 57.0 +32 47 33	2.2	0.60	16.8	−12.5	22.00	Ir
N4631dw2	12 42 06.8 +32 37 15	0.9	0.90	18.5	−10.8	22.64	Ir
N4631dw3	12 42 52.5 +32 27 35	0.6	0.85	19.7	−9.6	—	Sph

Table 1 presents some basic properties of the objects, assuming their apparent membership in the NGC 4631 group: (1) — the object name, (2) — equatorial coordinates for the epoch (J2000.0), (3) — angular diameter in arcmin, (4) — axial ratio, (5) — total blue magnitude as estimated by eye-ball, (6) — absolute magnitude, (7) — magnitude in the far ultraviolet band acquired by the GALEX (http://galex/stsci.edu/GalexView/), which is useful under the morphological classification of the objects, (8) — morphological type of the dwarf: Ir — irregular, Sph — spheroidal.

As follows from these data, all three new dwarf galaxies have luminosities typical for the

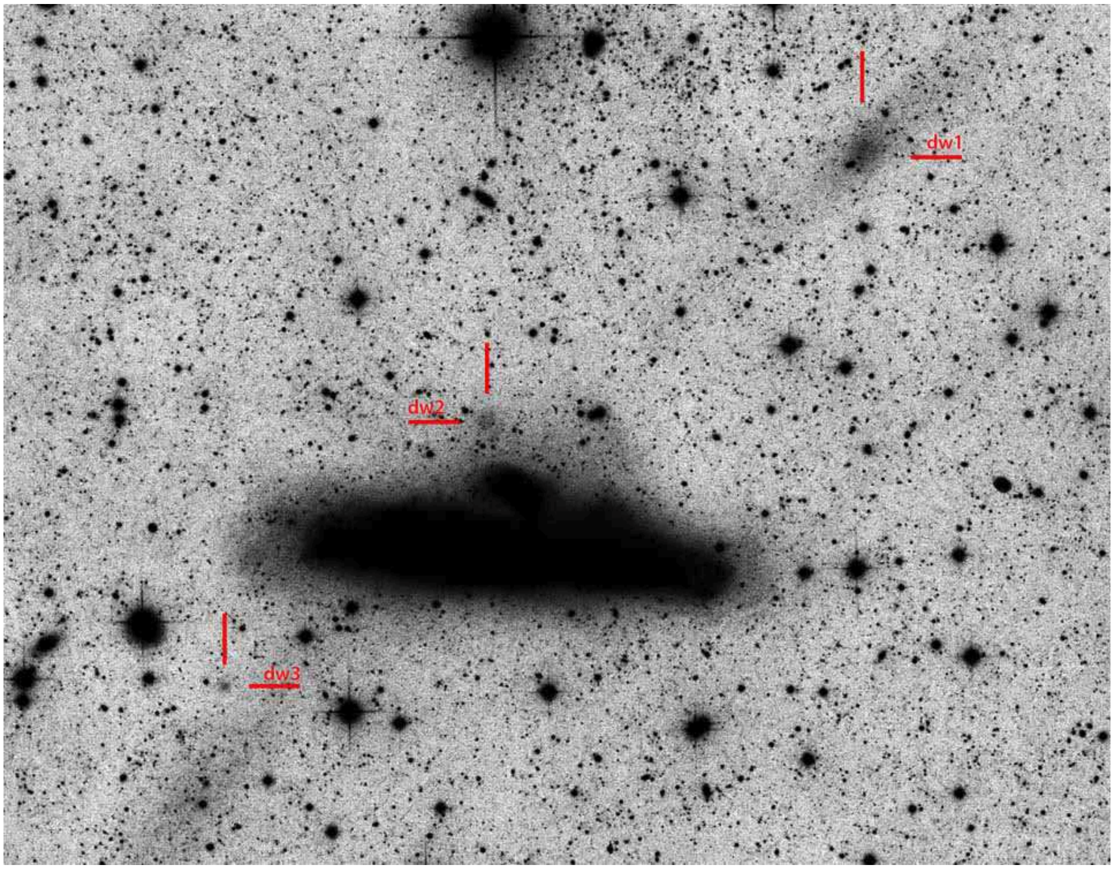

Figure 2. The stacked image of NGC 4631 and three neighboring LSB dwarfs derived from 75 individual images with a total exposure time of 23.9 hours. The data consists of: 3.25 hours (only L filter) taken from Dirk Bautzmann in March 2013 with PlaneWave CDK 12.5 (f/8) on ASA DDM85 mount and Apogee U16M camera + 5.67 hours taken from Robert Pölzl in May and June 2013, with 14.5 Newton f/3.8 on ASA DDM85 mount and FLI ML 8300 camera + 15 hours taken from Fabian Neyer in February and March 2013 with 5.5 TEC APO refractor (f/7.2) on AP900GoTo mount and STL-11000M camera. The average FWHM is 3.0 arcsec, resampled at $1.80''$/pixel, FOV of about $42' \times 32'$, North is up. Processing by Fabian Neyer. From upper right to lower left the objects: N4631dw1, N4631dw2, and N4631dw3 are marked. South of the object N4631dw3, the the mentioned LSB "bridge" directed to the NGC 4656 can be seen.

dwarfs of the Local Group and other nearby groups. Under the scale of $1' = 2.15$ kpc, linear diameters of the new objects are also similar to the dwarf population of the nearby groups. We do not list the extremely LSB structure, called the "bridge" among the dwarfs as its large linear dimensions, 16×7 kpc, are unusual for the known dwarf systems.

4 CONCLUDING REMARKS

As was noted by (Kroupa et al. 2010; Ibata et al. 2013; Pawlowski et al. 2013), a significant part of dwarf satellites around the Andromeda galaxy and the Milky Way are situated in flat disk-like structures. The origin of these planar structures is usually explained as a result of tidal interactions between the luminous galaxies, whose tails and bridges are transformed after the fragmentation into ordinary dwarfs. In the case of an interacting pair NGC 4631/4656, three LSB dwarf galaxies discovered, along with the diffuse "bridge" structure form a filament (or a planar system seen edge-on) that extends over 100 kpc. This is just one more example illustrating the idea that "tidal dwarfs" may be making up a noticeable fraction in the dwarf galaxy population. Herein, Kroupa et al. (2010) stress the following piquancy: tidal dwarfs principally differ from the ordinary (relic) dwarfs, because the luminous matter, rather than the dark matter is their dominating component.

Considering suites of dwarf galaxies around the nearby luminous galaxies, (Karachentsev et al. 2013a) noticed that the number of dwarf companions tightly correlates with the luminosity (mass) of the principal galaxy. Among the objects of the "Updated Nearby Galaxy Catalog" by Karachentsev et al. (2013b), most of the galaxies with absolute magnitude brighter than -18.5^m possess dwarf companions. There are about 100 bright enough galaxies in this catalog, whose surroundings are still poorly investigated. A systematic search of low-contrast signs of interaction and LSB companions around them using the deep exposures at the amateur telescopes is an important and actual task of the extragalactic astronomy.

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