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# Investigation of the Stellar Population of Several Polar Ring Galaxies

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Received: 29 November 2015; Accepted: 30 December 2015; Published: 5 January 2016
Academic Editors: José Alfonso López Aguerri, Enrichetta Iodice and Alexei Moiseev

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**Abstract:** We present results of our investigation of two multi-spin galaxies which were taken from the catalog of polar ring galaxies. All of them possess nucleus-like knots. An analysis of gas and stars kinematics and study of the stellar population were carried out for these objects. A complex structure and peculiar kinematics of both components were revealed. The observed distribution of the stellar age and metallicity in central parts of galaxies (radius is about 8″) and along directions through their knots helps us to understand the merging processes and make conclusion of the knots' nature in these objects.

**Keywords:** galaxies; peculiar galaxies; interaction of galaxies-kinematics; structure; stellar population; metallicity, age

**PACS:** 98.52.Sw, 98.54.Cm, 98.62.Dm, 98.62.Lv

## 1. Introduction

Multi-spin galaxies were discovered in past century. Since then they are investigated using different telescopes and there were obtained many observational data in a wide spectral range from X-ray to far-infrared (FIR). Most of these objects have an obvious signature of the interaction such as close companion(s). In addition to the complex morphology and kinematics, two galaxies under study (IC 883 and UGC 1198 taken from the catalog of polar ring galaxies [1]) have nucleus-like knots with the unclear origin.

## 2. Experimental Section

The observations of galaxies IC 883 and UGC 1198 were performed at the prime focus of the 6-m telescope of Special Astrophysical Observatory of the Russian Academy of Sciences (SAO RAS) with the SCORPIO multi-mode focal reducer [2] (in the "direct images", Fabry-Perot interferometer (FPI) and/or long-slit spectroscopy modes), as well as with the multi-pupil field spectrograph (see the SAO RAS web site [3,4]). Using FPI data, the two-dimensional surface brightness distributions of IC 883 in $H_\alpha$ and [NII]$\lambda$6584Å emission lines and in the continuum near these lines as well as the velocity and velocity dispersion fields in these lines were constructed. For IC 883, spectral observations in a "green" range (4428–5963ÅÅ) were made using the multi-pupil field spectrograph (MPFS). They allowed us to construct velocity and velocity dispersion fields of both gaseous and stellar components for the central region of the galaxy. The long-slit observations were performed for both galaxies in two spectral ranges. For IC 883, spectra in the "red" range (5700–7400ÅÅ) were obtained at three slit positions (along the

major PA = 139° and minor PA = 46° axes of the galaxy and at PA = 149°), and the spectra in the "green" range (3900–5700ÅÅ) were obtained only along the major axis. The long-slit observations of UGC 1198 were performed in "green" (3900–5700ÅÅ) and "red" (6100–7100ÅÅ) spectral ranges along the major axis (PA = 85°), at PA = 5° and PA = −68°. Line-of-sight velocity curves of the gaseous component and stars were constructed along these directions.

For the analysis of velocity fields we used the "tilted-ring" method [5,6]. It allows us to determine the positions of the dynamical center and the dynamical axis, to refine the galaxy's inclination to the plane of the sky, and to construct the rotation curve. The analysis of stellar metallicity and age was based on the comparison of the observed spectrum with a linear combination of some non-linear simple stellar population (SSPs) components. We adopt the Pegase-HR/Elodie3.1 (PE) stellar population models [7,8]. For this purpose, the University of Lyon Spectroscopic analysis Software (ULySS) [9] was used.

## 3. Results and Discussion

### *3.1. IC 883*

The galaxy IC 883 is an inclined peculiar disc galaxy with a long, almost linear southeastern tail and a faint diffuse southwestern tail (Figure 1). At the distance of ≈ 8.5″ (4 kpc) from the galaxy center to the southeastern direction, one can see a compact brightening indicated by the letter "B" in Figure 1. This feature presents in broadband optical and IR images too (see, for e.g., Figure 1) and coincides with the compact X-ray SE-source by the position [10]. The high infrared luminosity of IC 883 and the existence of two tidal tails are explained by the recent merging of two disc galaxies (e.g., [11]).

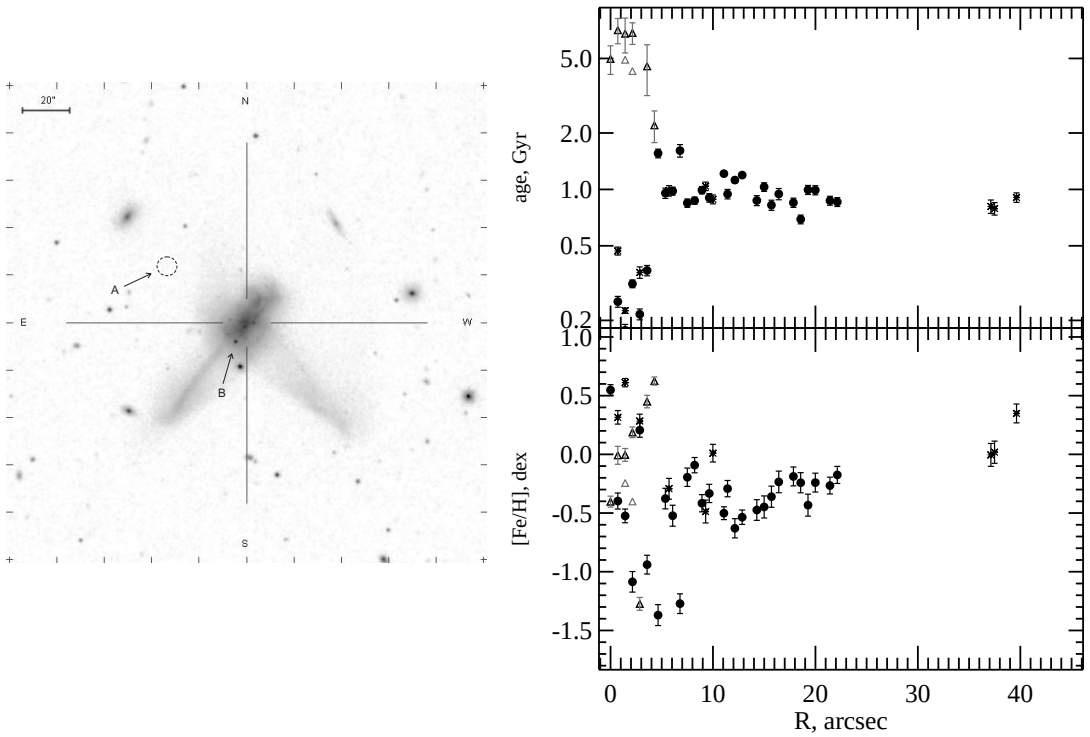


**Figure 1. Left**: the *gri* image of IC 883 from the Sloan Digital Sky Survey (http://www.sdss.org/). Arrows indicate the "A" and "B" regions discussed in the paper. North is up and east is to the left. 1″ corresponds to 0.5 kpc, $H_0$ = 72 km/s/Mpc, the distance to the galaxy is 97.4 Mpc. **Right**: Dependences of age (**top**) and metallicity (**bottom**) of the stellar population on distance along the major axis of IC 883: △—old stellar population; ∗—young stellar population in the SE-side; •—young stellar population in the NW-side.

As a result of the analysis of the large amount of our material for IC 883, it was ascertained the following. The detailed results of observations and their analysis will be published in [12].

In general, the velocity field of the main body is typical for disc galaxies: the ionized gas and the stars rotate around the galaxy minor axis. The position difference of dynamic axes of the stellar and the gaseous disks was found. This indicates that the system is still in the perturbed state. Regions with signs of shock waves in a gas medium ([NII]/$H_\alpha$ > 1.5) are observed in the main body of IC 883 along the minor axis. The processes of star formation are going on all over the disk of the galaxy. The youngest stellar population (2–5 $\times$ $10^8$ years) has the metallicity +0.3 $\pm$ 0.1 dex and belongs to the circumnuclear region (Figure 1). The age and metallicity of the stellar disk at r $\geq$ 5″ are 1 $\pm$ 0.1 Gyr and $-0.4 \pm 0.3$ dex.

We have found that forbidden lines are very intensive and the $H_\alpha$ line is in absorption in the center of the compact "B" region. Furthermore, it has been ascertained the kinematic decoupling of this area—its counter-rotation with respect to the main body with a velocity range ~120 km/s. We determined its age and metallicity (4–8 Gyr and $-1.7$- $-1.$ dex), as well as a lower mass estimation of this region within a radius of 1″.5 (8.4 $\times$ $10^8$ $M_\odot$). Our analysis of kinematics, age, metallicity, and mass of the "B" region indicates that it is neither globular cluster nor HII region of the galaxy main body, but represents a separate system and can be a dwarf Im galaxy or a remnant of spiral companion galaxy destroyed during the merging.

The velocities in the southeastern tail do not correspond to the circular rotation around the minor axis of the galaxy, therefore this structure can be either a remnant of a destroyed satellite or a fragment of the unwound bent spiral arm. The second variant seems to us the most likely. The similarity of the chemical composition of the galaxy main body and the southeastern tail as well as simulations of similar structures [13] evidence in favor of this assumption.

On the continuation of the northeastern protrusion the weak region "A" radiating in emission lines but invisible in broadband images of IC 883 was detected.

The observed peculiar structure of the object under study was, probably, formed as a result of the merger of two galaxies. Based on our results one can say that the "A" region, SW-tail, and NE- and SW-protrusions apparently form a system of the ionized gas which has a complex knotty appearance and a large spread of line-of-sight velocities and moves approximately along the minor axis of the galaxy. Perhaps, this gas was pulled off from a companion galaxy. The resulting cumulative distribution of velocities in this structure does not allow to say that there is a formed polar ring in the galaxy; thus, at present IC 883 does not belong to the class of galaxies with polar rings. The "B" region is perhaps a dwarf Im galaxy or a remnant of spiral companion galaxy destroyed during the merging.

### *3.2. UGC 1198*

UGC 1198 is a small galaxy which shows a slight enhancement along the minor axis in the inner region, especially toward the north [1], and two linear structures elongated approximately along the main body of the galaxy (Figure 2).

A slight dust lane is present on the east side. A bright spot (indicated by the letter "A" in Figure 2) is observed at 5″ to the north approximately along the minor axis. A faint elliptical object (the letter "B" in Figure 2) is located 17″ NW of the galaxy center. The observed morphology and the B–V color index distribution of UGC 1198 suggest that the slight enhancement along the minor axis can be an almost edge-on warped disk or ring (see the photometric study of the galaxy by [14]).

The long-slit observations were performed in "green" and "red" spectral ranges along the major axis (PA = 85° ), the slight enhancement and "A" region (PA = 5° ), and through the faint elliptical object "B" (PA = $-68°$ ). The analysis of the line-of-sight velocity curves of the ionized gas and stars along these directions has shown that the main body of the galaxy is poor of gas. The ionized gas belongs to the peculiar structure, which is elongated almost along the minor axis and is possibly a disc. The ionized gas of this disc rotates approximately around the major axis of UGC 1198, *i.e.*, this disc is polar. The radiation of the ionized gas arises as a result of the photoionization.

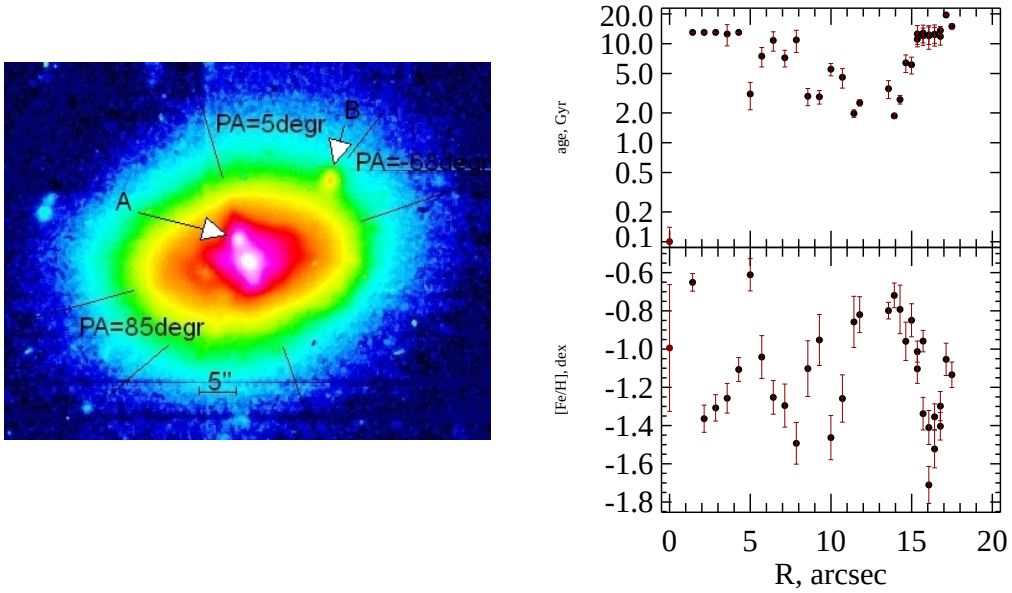


**Figure 2. Left**: The image of UGC 1198 in *B*-band taken from: http://www.astro.spbu.ru/PolarRing/prg.html. The positions of the slit during our observations are shown. Arrows indicate the "A" and "B" objects discussed in the paper. North is up and east is to the left. 1″ corresponds to 0.9 kpc, $H_0 = 72$ km/s/Mpc . **Right**: Dependences of age (**top**) and metallicity (**bottom**) of the stellar population of UGC 1198 on distance along PA = $-68°$ .

We analyzed spectra in the "green" range to obtain the age and metallicity of the stellar population of UGC 1198. The old stellar population $10 \pm 2.5$ Gyrs with the metallicity $-1.4$ dex prevails in the central region of the main disc of the galaxy (Figure 2). The age and the metallicity of the stellar population of the "B" object is close to the values of the nucleus of the host galaxy and is about $12 \pm 2.5$ Gyr and $-1.5 \pm 0.3$ dex. Moreover, line-of-sight velocities of its stars do not correspond to the rotation of the main stellar disc at the same distance. Distance to this object, calculated by the Hubble's law, is father out 800 pc from the galaxy center. Thus it can be a nuclear of a projected dwarf galaxy (dE), perhaps, a companion. The age and metallicity decoupling was found for the bright spot "A". Values of these parameters ($1.5 \pm 0.2$ Gyrs and $+0.4 \pm 0.3$ dex) correspond to ones of spiral galaxies [15,16].

The observed peculiar structure and kinematics of UGC 1198 is a result of the merger of two galaxies. At present UGC 1198 has the inner polar disc and two companions: the faint elliptical object located 17″ NW of the galaxy center is, perhaps, the nuclear of a dwarf galaxy and the bright spot at 5″ to the north along the minor axis is a spiral galaxy which, most likely, was a gas donor for the polar disc.

**Acknowledgments:** This work is supported by the St.Petersburg State University under grant No. 6.38.335.2015. The observations obtained using the 6-m telescope of the SAO RAS were carried out with the financial support of the Ministry of Education and Science of the Russian Federation (contract No. 16.518.11.7073 and 14.518.11.7070). Also we thank the Large Telescope Program Committee for the allocation of the observational time at the 6m telescope, V.L. Afanasiev (SAO RAS) for the allocation of the Multi Pupil Fiber Spectrograph for our observations, A.N. Burenkov, D.I. Makarov, and A.V. Moiseev, who performed imaging, FPI and long-slit observations at the 6-m telescope.

**Author Contributions:** All authors have participated in both the analysis and the scientific discussion.

**Conflicts of Interest:** The authors declare no conflict of interest.

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