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The Active Galaxy NGC 3862 in a Compact Group in the Cluster A1367

A. A. Lipovka[1], N. M. Lipovka[2], I. V. Gosachinskiĭ[2], and E. Chavira[3]

[1]*Center of Physical Research, Sonora University, Aptdo. Postal 5-088, Hermosillo, Sonora, Mexico*

[2]*St. Petersburg Branch of the Special Astrophysical Observatory, Russian Academy of Sciences, Pulkovskoe sh. 65, St. Petersburg, 196140 Russia*

[3]*National Institute of Astronomy, Optics, and Electronics, Tonanzintla, Aptdo. Postal 51 y 216, Pueblo, Pueblo, Mexico*

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Abstract—We study a compact group of 18 galaxies in the cluster A1367 with redshifts $z = 0.0208{-}0.025$. The group's center of activity in the radio is the galaxy NGC 3862, whose radio flux is an order of magnitude stronger than for the other members of the group. We present coordinates derived from the Palomar plate archive together with recessional velocities, and analyze other characteristics of the group's galaxies. The results of 1400 MHz observations of NGC 3862 with the RATAN-600 radio telescope are presented. These observations indicate that the galaxy's radio emission is variable.

1. INTRODUCTION

The evolution of galaxies and their clusters is a central topic of modern astrophysics. Interest in these questions comes from attempts to follow the evolution of galaxies and explain the formation of galaxies and clusters of galaxies, as well as from possibilities for deriving information on the physical conditions in clusters, galaxies, and galactic nuclei. To achieve progress in these areas, it is important to study isolated, compact groups of galaxies in clusters together with their morphology, radio and optical spectra, and X-ray emission.

It is also interesting in its own right to study active galactic nuclei that display activity over a wide wavelength range, from the X-ray to the radio. This study deals with a compact group containing an active galaxy. We have already presented preliminary studies of galaxies in the clusters A569 [1], A1185 [2], A2151 [3], and a cluster in Cetus [4]. In those studies, we found and identified a number of radio objects with known radio spectra, whose optical properties are of considerable interest. Some 45% of these radio sources were identified with compact galaxies, and a large fraction have their strongest radio emission in their active nuclei.

Here, we study a compact group of galaxies surrounding NGC 3862 in the cluster A1367. The second section presents a catalog of the galaxies, while the third section discusses the radio properties of the galaxies based on our RATAN-600 observations and published data together with their optical properties.

2. THE CATALOG

A compact group of galaxies with a low velocity dispersion is present in the cluster A1367, in the vicinity of NGC 3862 (Fig. 1). The group is interesting because of its morphology, because it is distinct from the rest of the cluster members, and also because NGC 3862 is an active galaxy with one of the few known galactic optical jets.

When compiling the catalog, we used coordinates for the galaxies calculated at the Institute of Optics and Electronics (INAOE, Mexico) based on glass copies of the Palomar Sky Atlas plates using a blink comparator and the technique described in [5]. The rms uncertainties in the coordinates were calculated using reference stars from the PPMN catalog, and are $\Delta RA = \pm 1.5''$, $\Delta DEC = \pm 2.0''$.

The table presents the resulting coordinates of the galaxies, along with their optical characteristics, measured using an Automatic Plate Measuring facility [6]. The columns of the table present (1) a running number for each galaxy; (2, 3) the equatorial coordinates for equinox 2000.0; (4) the magnitude from [6]; (5) the angular size of the galaxy's major axis (calculated by us using data from [6], in arcseconds); (6) the ellipticity, $1 - b/a$, where a and b are the major and minor axes [6]; (7) the position angle, PA [6]; (8) the radial velocity from the NASA Extragalactic Database [7]; and (9) the galaxy's name [7]. Note that galaxies 12 and 13 are considered a single galaxy in [6], and we determined the sizes of these galaxies from the Palomar images.

As we noted above, this compact group is characterized by a relatively low velocity dispersion ($V_{mean} =$

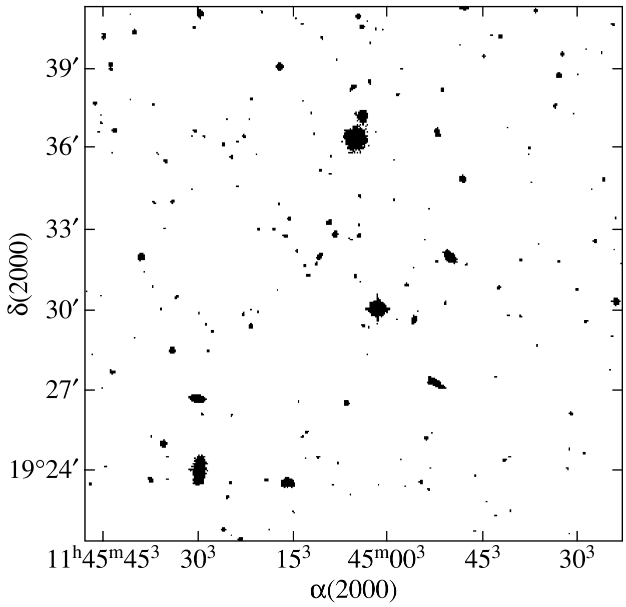

Fig. 1. The compact group of galaxies in the cluster A1367.

6450 ± 511 km/s), confirmation that the group galaxies are close together in space. Another interesting feature is displayed by the spatial positions of the galaxies: they form a chain-like curve, which can be fit with high significance. To estimate the probability for such an arrangement to occur by chance, we approximated the curved path with a second-order polynomial. The square deviation of the galaxy positions from the approximating curve is an order of magnitude lower than the density of galaxies in the vicinity of the compact group, providing evidence that the group is real and confirming that the arrangement of the galaxies in the plane of the sky is not random. The galaxies may have formed along the ridge of an expanding front, or might be the result of the ejection of matter from NGC 3862 that moved along the path now traced by the galaxy positions, gradually sweeping up matter and causing the galaxies to grow. This last possibility is supported by the fact that the galaxies' sizes increase and their color indices change systematically with increasing distance from the central galaxy in the group, NGC 3862: the closer to NGC 3862, the redder the galaxies' colors. On average, the colors of the galaxies that are closest to NGC 3862 are 0.6^m redder than the colors of galaxies at the group periphery, providing evidence for strong extinction in the neighborhood of NGC 3862. To conclude this section, we note that the statistical mean magnitude for this group of galaxies is $12.2^m \pm 2.5^m$ and the mean size is $30'' \pm 18.0''$ [6], corresponding to a mean galaxy size of 12 kpc for a mean recessional velocity of 6450 km/s. The size of NGC 3862 is 17.8 kpc for its recessional velocity of 6511 km/s and $H = 75$ km s^{-1}Mpc^{-1}.

3. THE RADIO PROPERTIES OF NGC 3862 AND OUR RATAN-600 RADIO OBSERVATIONS

Weak 21-cm radio emission was found for galaxies 2 and 4 in the group (with the fluxes being 111.9 and 81.5 mJy, respectively) [8]; weak radio emission for galaxy 5 with a flux of 10 mJy was also reported in [9]. The group's radio activity center is NGC 3862, for which an abundance of radio data are available [7–9].

It was found in 1968 [10] that the size of the radio source 3C 264 (NGC 3862) increased with decreasing frequency, which was interpreted as a spectral-index gradient across the galaxy. Further higher-resolution studies [11] at 11 cm ($\theta = 12'' \times 34''$) and 6 cm ($\theta = 6.5'' \times 19''$) revealed the presence of a large-scale asymmetry in the galaxy's radio-brightness distribution to the northeast, leading to the galaxy's classified as a head–tail radio galaxy.

Further observations [12] at 1465 MHz with even higher resolution, $\theta = 2.7'' \times 4''$, demonstrated that NGC 3862 has a nucleus that is $<3''$ in size and an extended component elongated towards the northeast. Bridle and Vallee [12] explained the large-scale structural asymmetry of NGC 3862 as the result of the diffusion of relativistic electrons that were left behind the moving galaxy. However, later observations [8, 9] demonstrated the presence of two features towards the northeast which, in our opinion, are related to the activity of NGC 3862 and represent periodic ejections of matter towards PA $= 32°–37°$.

The complete radio spectrum of NGC 3862 is presented in Fig. 2. Note the scatter of the flux densities over a wide frequency range.

Jointly analyzing the data with various resolutions, we can distinguish and construct the spectra for the corona and a nuclear region about $3''$ in size (marked "A" in Fig. 2). In Fig. 2, measurements from 1964 to 1980 are displayed using circles, whereas measurements obtained after 1980 are shown by crosses. The flux density appears to slowly decrease with time.

To confirm earlier suspicions of radio variability of NGC 3862, we obtained observations with $160''$ resolution using the RATAN-600 radio telescope in March 2003. Our flux-density measurements at 21 cm were obtained using feed cabin 2 of the northern sector of the RATAN-600 radio telescope. We carried out seven independent observations to improve the accuracy of our 21-cm flux measurements.

Parameters of the studied galaxies

No.	RA (2000.0)	DEC (2000.0)	R	θ	$1-a/b$	PA	v, km/s	Galaxy name
1	$11^h44^m47.61^s$	$19°34'59.7''$	12.68^m	23.5°	0.07	7°	6256	
2	11 44 49.79	19 32 4.5	9.53	49.1	0.38	46	6255	NGC 3857
3	11 44 51.76	19 36 39.4	12.10	29.0	0.36	14	6556	
4	11 44 51.91	19 31 55.2	17.31	12.3	0.38	125		
5	11 44 52.08	19 27 21.7	9.49	61.2	0.65	59	5468	NGC 3859
6	11 44 55.56	19 29 41.9	12.58	24.5	0.35	172	6457	
7	11 45 2.60	19 38 37.5	15.63	14.2	0.17	23		
8	11 45 3.69	19 37 20.0	10.94	29.3	0.13	46	6908	IC 2955
9	11 45 4.43	19 41 1.4	13.70	17.2	0.05	34		
10	11 45 4.83	19 36 32.6	9.38	41.5	0.08	96	6511	NGC 3862
11	11 45 4.89	19 37 26.4	19.32	8.5	0.20	117		
12	11 45 4.96	19 38 26.8		10				
13	11 45 5.43	19 38 20.0		8				
14	11 45 15.17	19 23 34.5	9.94	41.7	0.28	84	6997	NGC 3864
15	11 45 29.38	19 24 7.1	9.40	75.1	0.72	175	7457	NGC 3867
16	11 45 29.80	19 26 44.9	9.68	47.5	0.49	80	6386	NGC 3868
17	11 45 34.91	19 25 6.0	12.99	22.0	0.08	21		
18	11 45 36.94	19 23 41.5	14.36	18.2	0.25	35		

The system noise temperature was ≈70 K, the continuum bandwidth 10 MHz, and the time constant 6 s. We used 3C 123, which has a flux of 46.61 Jy at 21 cm, as a reference source. The observations and data reduction were done using standard software written at the RATAN-600 radio-spectrometry complex. The effective area of the telescope at the elevation of 3C 123 was 982 m^2, and the right-ascension correction was found to be -0.38^s.

We reduced the observations using the standard RATAN-600 software for the reduction of spectroscopic data. We measured the observational parameters using code designed to carry out a Gaussian analysis of the transit curves after correction for smoothing by the output device of the continuum channel. The resulting mean parameters for five observations were RA(2000.0) $= 11^h45^m06.12^s \pm 0.2^s$ and the flux at 21 cm $P = 4.70 \pm 0.1$ Jy.

Previous observations at 21 cm obtained in 1981 and 1995 yielded $P = 5.94 \pm 0.17$ Jy [13] and $P = 5.45 \pm 0.12$ Jy [14]. Our 2003 RATAN-600 flux, $P = 4.70 \pm 0.1$ Jy, is 1.24 ± 0.27 Jy lower than the value observed in 1981, representing a decrease by about 20% in 22 years.

Let us now estimate the characteristic magnetic fields for the two emitting regions: the corona and plane of the galaxy.

Combined with the higher-resolution observations [8, 9, 15], our RATAN-600 data can be used to separate out the individual radio-emitting components and reveal the nature and character of the radio emission from these components. The galaxy's corona is responsible for more than 40% of the radio emission, and has a spectral index of $\alpha = 0.95$, whereas the spectral index of the radio emission from the galactic plane is $\alpha = 0.67$.

We can use the known flux density, size of the emitting region, and distance to the galaxy to estimate the magnetic-field strength (see, for example, [16]). Our estimated magnetic-field strength in the plane of NGC 3862 is $H(\mathrm{pl}) = 3.5 \times 10^{-6}$ Oe for $\alpha = 0.67$, with the field in the corona being $H(\mathrm{cor}) = 0.86 \times 10^{-6}$ Oe for $\alpha = 0.95$.

It is also of interest to compare the jet's physical parameters derived from optical data with those we have estimated from the radio emission. For this purpose, we use recent data on the optical activity of the jet of NGC 3862. Hubble Space Telescope

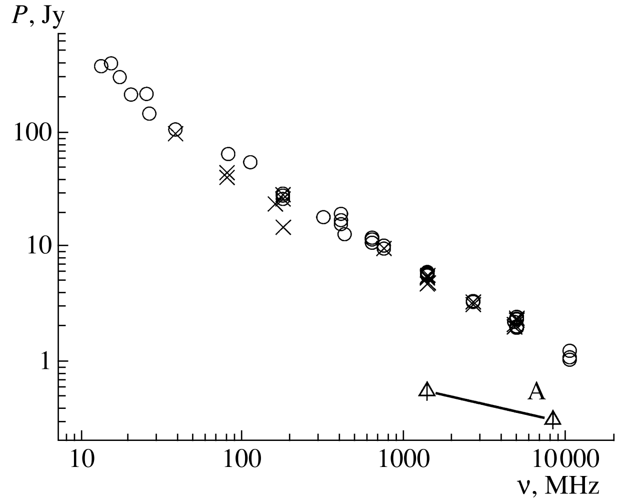

Fig. 2. Radio spectrum of NGC 3862; the spectrum of the compact nucleus is marked "A."

high-resolution optical measurements at 3400 Å and 4850 Å [17] display a compact core and a 270-pc-long jet in position angle PA = 37°, close to the direction of the radio jets [8, 9]. Crane *et al.* [17] conclude that the optical jet emission is synchrotron radiation with a spectral index of 1.4, and that the emission from the nucleus has a spectral index of $\alpha = 1.2$.

Using the standard known formulas for synchrotron radiation [16], we find that the 3400 Å and 4850 Å radiation will be emitted by relativistic electrons with energies of $E = 1.8 \times 10^4 - 1.8 \times 10^6$ MeV in a magnetic field of $H = 5 \times 10^{-4}$ Oe, with the density of the relativistic electrons being $K = 10^{-9} - 10^{-11}$ erg/cm^3. The life times of such electrons will be about 10^3 years, in a good agreement with the size of the optical jet.

4. CONCLUSIONS

We have studied a compact group of galaxies in the vicinity of NGC 3862 in the cluster A1367 ($z = 0.0208 - 0.025$). We measured the coordinates of the 18 members of the group with the blink comparator of the Institute of Optics and Electronics using the coordinates of reference stars. Four group members have been found to have radio emission, with the most active galaxy in the radio being NGC 3862, which may be ejecting matter in position angle PA = 32°–37°, observed as a jet in both the radio and optical. By analyzing this galaxy's radio emission observed with various resolutions over a wide wavelength range, we were able to separate out the radio emission from the galaxy's nucleus, plane, and corona. We find a flattening of the radio spectrum towards the nucleus. We had earlier obtained a similar result based on analysis of a large amount of data for the cluster A569 [1].

Our RATAN-600 observations of NGC 3862 demonstrate that the 21-cm emission is time-variable, with the 21-cm flux currently decreasing by approximately 70 mJy per year. Given the small uncertainties in the measured fluxes, we consider this result to be firm. Since the radio structure is associated with a jet, we suggest that the activity of NGC 3862 is periodic.

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