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Radio Spectra of Giant Radio Galaxies from RATAN-600 Data

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Abstract—Measurements of the flux densities of the extended components of seven giant radio galaxies obtained using the RATAN-600 radio telescope at wavelengths of 6.25 and 13 cm are presented. The spectra of components of these radio galaxies are constructed using these new RATAN-600 data together with data from the WENSS, NVSS, and GB6 surveys. The spectral indices in the studied frequency range are calculated, and the need for detailed estimates of the integrated contribution of such objects to the background emission is demonstrated.

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1. INTRODUCTION

Giant radio galaxies (GRGs) are the largest radio sources in the Universe, with linear sizes of more than 1 Mpc. Studies of these objects began with 3C 236 [1]. They display primarily morphological type FR II [2], and are identified with giant elliptical galaxies and quasars. GRGs are rare compared to ordinary radio galaxies, hindering statistical studies and detailed studies of their formation as a population. Several groups are undertaking studies of their properties, aimed at explaining their huge sizes [3–12]. As was noted by Jamrozy et al. [10], the influence of GRGs on the surrounding environment could be more extensive than for ordinary radio galaxies, whose sizes are an order of magnitude smaller. It is an important fact that GRGs have sizes that are comparable to or larger than the dimensions of groups of galaxies. Therefore, they are believed to play an important role in the formation of the large-scale structure of the Universe [10].

One possible explanation for the large sizes of GRGs is that they are an effect of orientation. However, the idea that these sizes could represent a maximum projection onto the plane of the sky, compared to ordinary radio galaxies, is not confirmed by observations with the Effelsberg telescope [4]. Analyzing various properties of radio sources (asymmetry, energy densities in the lobes, variation in the lobe pressure with redshift, spectral age, ambient density), Schoenmakers et al. [4] showed that the asymmetry of the arm lengths for GRGs is somewhat higher than for 3CR radio galaxies having smaller dimensions, which is difficult to explain with orientation effects.

There are currently two main views about the origin of the large sizes of GRGs: (1) they are related to properties of the energy released by the jets emerging from their nuclei; (2) they are determined by the properties of the ambient medium in the local group of galaxies. Schoenmakers et al. [4] suggest that the latter effect is most important. They concluded that GRGs may represent the oldest, comparatively powerful members of a group of radio sources, whose radio emission has continued to develop. Their spectral analysis indicated that the lobes of GRGs have higher pressures than the ambient medium, and that the redshift dependence of the lobe pressures could also be due to selection effects. The conclusions of [4] are supplemented by the analysis of radio and optical (SDSS, APM) data for radio galaxies and quasars carried out by Komberg and Pashchenko [13], who found that, in addition to the influence of the surrounding medium, the sizes of giant radio sources can be explained by the presence of a population of long-lived, radio-loud active nuclei, which, in turn, can evolve into GRGs.

It is also of interest to investigate how various characteristics of GRGs (size, shape, orientation) affect maps of the microwave background radiation [14]. Although their contribution to maps of the millimeter background are modest, their angular sizes (to 10′) create problems in connection with distinguishing components due to spectral-index variations at the locations of the extended radio lobes of these galaxies. Therefore, it is of interest to estimate and take into account the possible contribution of GRGs to anisotropy of the background radiation, due

Table 1. Main parameters of observed giant radio galaxies

Source name	Coordinates RA/Dec (J2000.0)	Redshift	Type	Angular size, arcmin	Flux density (1.4 GHz), mJy
GRG 0139+3957	013930+395703	0.211	II	5.7	801.1
GRG 0912+3510	091252+351016	0.249	II	6.2	157.4
GRG 1032+2759	103214+275600	0.085	II	11.0	284.1
GRG 1343+3758	134255+375819	0.227	II	11.3	131.0
GRG 1400+3017	140040+301700	0.206	II	10.8	451.9
GRG 1453+3308	145303+330841	0.249	II	5.7	455.5
GRG 1552+2005	155209+200524	0.089	II	19.6	2385.6
GRG 1738+3733	173821+373333	0.156	II	6.5	236.0

Table 2. Observed regions of the GRGs

Source name	Section[1]	Coordinates of center of observed region[2]	Number of transits N_t
GRG 0139+3957	c	013927.4+395653	1
GRG 0912+3510	n	091252.0+351231	5
	s	091250.0+350631	1
GRG 1032+2756	n	103212.5+275925	3
	c	103214.4+275555	3
	s	103215.1+275115	1
GRG 1343+3758	c	134255.0+375819	2
GRG 1400+3017	n	140045.0+302214	3
	s	140038.4+301325	3
GRG 1453+3308	n	145302.0+331046	4
	c	145303.0+330856	2
	s	145301.4+330556	1
GRG 1552+2005	c	155209.0+200524	8
GRG 1738+3733	n	173820.6+373658	2
	c	173821.0+373333	2
	s	173821.8+373108	1

[1] The indicated sections are central (c), northern (n), and southern (s).

[2] The coordinates of the component centers (Right Ascension and Declination) refer to epoch J2000.0.

both to their millimeter radiation and to effects arising during the identification of components on the scales of multipoles $\ell \geq 500$ in various frequency ranges.

We present here the first RATAN-600 measurements of the centimeter- and decimeter-wavelength flux densities of seven giant radio galaxies. Note that radio galaxies of arcmin size had been observed earlier by Soboleva with RATAN-600 [15] in cm/mm wavelength range. It was detected that morphological structures had approximately same spectral indices.

2. RATAN-600 DATA

2.1. Observations on the RATAN-600

The observations of the GRGs were carried out on the northern sector of the RATAN-600 in mid-December 2008, using continuous-spectrum radiometers at the primary feed, operating at wavelengths of 1.38, 2.7, 3.9, 6.25, 13, and 31 cm [16]. Unfortunately, due to the presence of various types of interference during the observing period, only the data at 6.25 and 13 cm were suitable for our analysis. The dimensions of the antenna beam in the central section at the observed elevations were 43″ and 90″. Fortunately, both wavelengths had spectral-analyzer subchannels, making it possible to effectively combat interference. The subchannels at 31 cm proved not as useful in this sense. Due to the short observing times, the required sensitivity (<20 mK) was not achieved at wavelengths shorter than 6 cm. A list of the observed sources is given in Table 1, and a journal of the observations in Table 2. Despite the fact that the GRG 1343+3758 was observed twice, it was not possible to achieve a sufficient signal-to-noise ratio to detect this source.

Depending on the position angle of the radio structure, from one to three cross-sections through the source were made (Table 2). The number of transits of the objects through the telescope beam was limited by the total observing time granted for the project.

Table 3. Flux densities of the components (in mJy) according to the RATAN-600, WENSS, NVSS, and GB6 data

Source Component	6.25 cm RATAN	13.5 cm RATAN	92 cm WENSS	21 cm NVSS	6.25 cm GB6
0139+3957 w	470	857	–	2120	656
c	139	252	–	744	317
e	82	212	–	133	–
0912+3510 n	30	< 120	160	56	< 20
s	73	166	512	101	20
1032+2759 n	66	< 120	–	92	< 20
c	52	< 120	–	75	59
s	106	148	–	138	56
1400+3017 n	63	212	1258	333	73
s	46	194	1053	155	37
1453+3308 n	85	109	420	245	< 20
c	123	226	593	149	131
s	109	116	488	89	< 20
1552+2005 w	82	212	–	133	< 20
e	139	252	–	744	317
ee	470	857	–	2120	656
1738+3733 n	54	160	152	64	< 20
c	63	174	720	117	93
s	50	123	133	58	< 20

2.2. Reduction

To tie the flux densities to the international scale [17], we carried out observations of calibrator sources from the RATAN-600 standard list [18, 19]. The transit curves for the sources were analyzed in the FADPS standard reduction system [20, 21]. When analyzing each component in the recordings, we subtracted a low-frequency trend obtained with an 8′ smoothing window. We estimated the flux densities using the integrals beneath the curves for the transits of the sources through the RATAN-600 beam, approximated by sets of Gaussians. The noise levels in the recordings for single transits at an elevation of 76° were 8.1, 5, 36, 3.3, and 65 mK/s$^{1/2}$ at 1.38, 2.7, 3.9, 6.25, and 13 cm, respectively. The 6.25 and 13-cm flux densities are presented in Table 3, together with the integrated flux densities in the measured components (marked in Fig. 1) calculated from the NRAO VLA Sky Survey (NVSS) maps [22], Westerbork Northern Sky Survey (WENSS) maps [23], and data from the Green Bank GB6 catalog [24]. We also used the CATS database [25] to identify objects and estimate the parameters of components.

The uncertainties in the 6.25-cm RATAN-600 flux densities for sources with flux densities >50 mJy are ∼10%, and for sources with flux densities <50 mJy 13% at wavelength of 6.25 cm. The undertainties at 13 cm are 10% for sources with flux densities >180 mJy and 15% for sources with flux densities <180 mJy.

2.3. Spectra

We constructed spectra for the radio components using the data in Table 3. We described the spectra using the parametric formula $\log S(\nu) = A + Bx +$

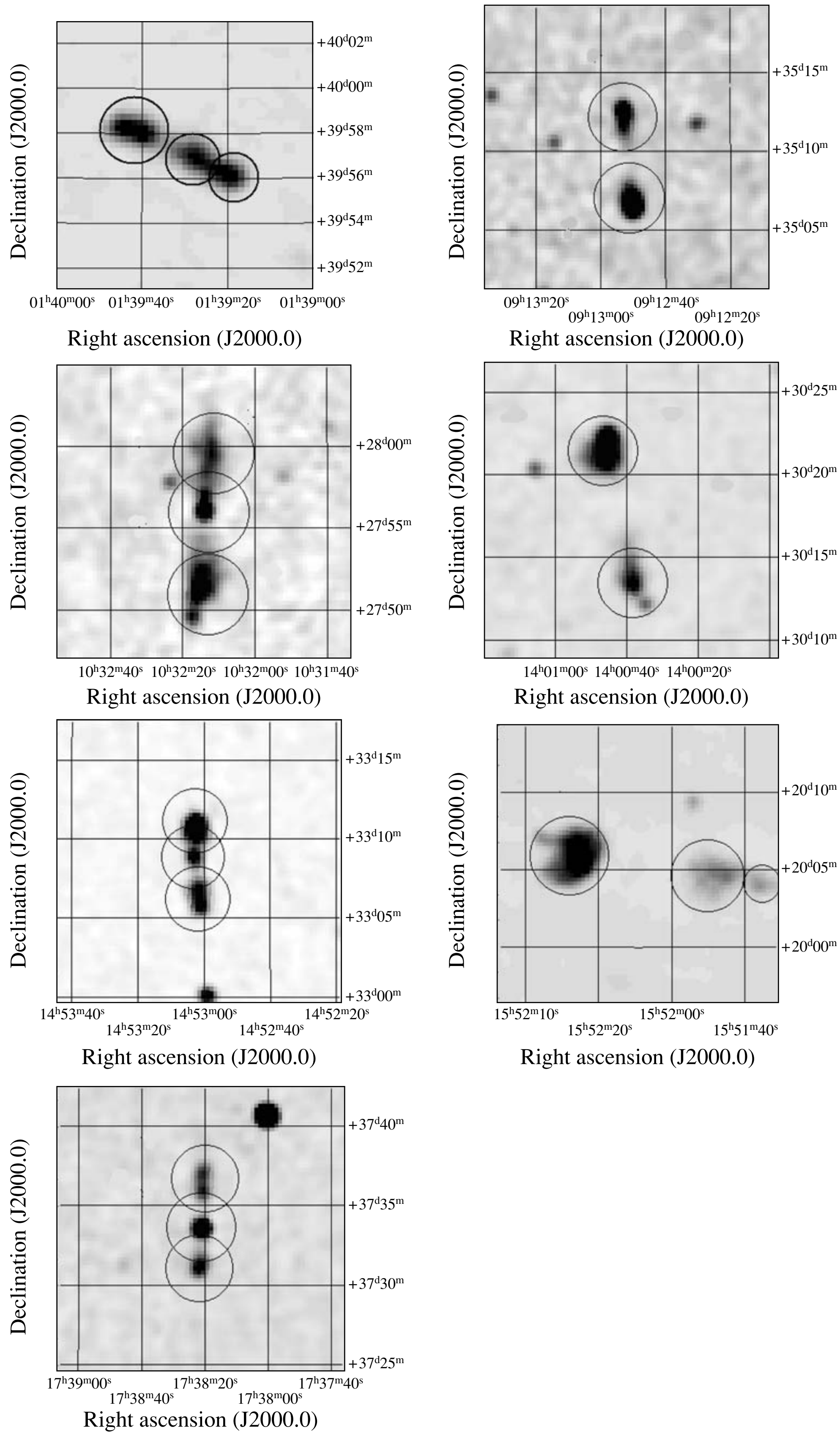

Fig. 1. Radio images of the GRGs from the NVSS survey. The circles mark the components observed on the RATAN-600.

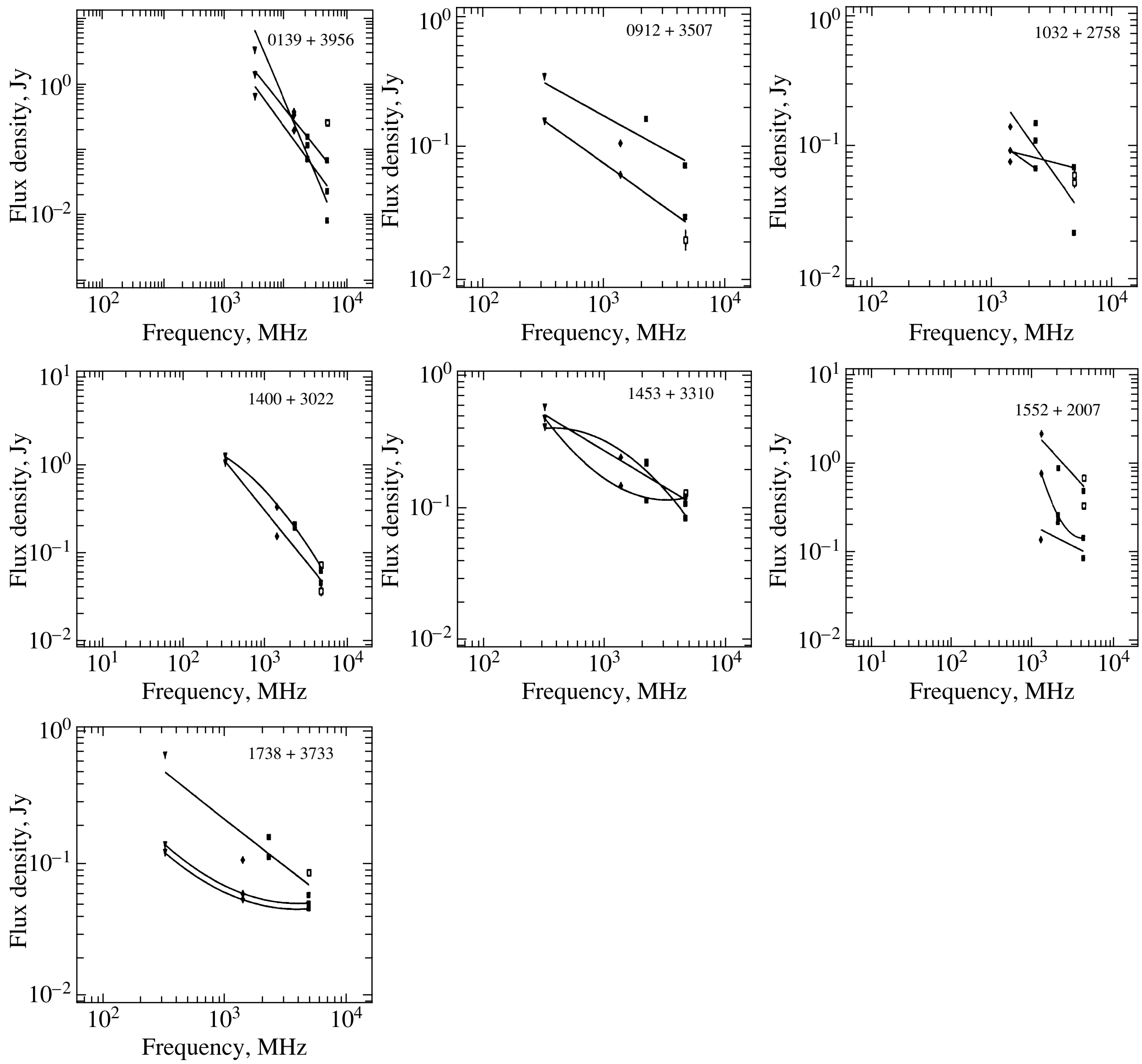

Fig. 2. Radio spectra of the GRG components constructed using the RATAN-600, GB6, NVSS, and WENSS data (Table 3).

$Cf(x)$, where S is the flux density in Jy, x the logarithm of the frequency ν in MHz, and $f(x)$ one of the following functions: $\exp(-x)$, $\exp x$, or x^2. We used the "spg" system to analyze the spectra [26]. The spectra of the components are shown in Fig. 2. Analytical fits of the curves representing the continuous spectra of the GRG components are presented in Table 4.

3. DISCUSSION

The constructed GRG spectra (Fig 2) display a variety of properties. It is obvious that the spectral indices and spectral shapes of the observed GRG components differ appreciably, from very steep spectra, as in GRG 0139+3957, to fairly flat spectra, as in GRG 1738+3733.

For each component of the studied GRGs, we calculated the spectral indices as the tangent of the slope of the curve approximating the spectrum at the given frequency. The results for 6.25 and 13 cm are presented in Table 5.

GRG 1738+3733 stands out among the observed sources, due to the similarity of the radio spectra and spectral indices for both its extended components.

Note that the variation of the spectral indices of GRGs with distance from the center of the galaxy was noted earlier in [4]. This is due to the variation of the particle energy in the components with distance from

Table 4. Approximate dependences for the continuous radio spectra of the GRG components from 92 to 6.25 cm

Source component	Radio spectrum
0139+3957 w	$3.182 - 1.294x$
c	$6.409 - 2.237x$
e	$3.135 - 1.182x$
0912+3510 n	$0.847 - 0.653x$
s	$0.771 - 0.508x$
1032+2759 n	$3.264 - 1.275x$
c	$-0.299 - 0.237x$
s	$0.961 - 0.636x$
1400+3017 n	$-0.914 + 1.406x - 0.400x^2$
s	$2.928 - 1.150x$
1453+3308 n	$-4.053 + 2.841x - 0.550x^2$
c	$1.110 - 0.555x$
s	$6.626 - 4.288x + 0.608x^2$
1552+2005 w	$0.695 - 0.463x$
e	$34.372 - 19.175x + 2.609x^2$
ee	$3.394 - 0.997x$
1738+3733 n	$3.496 - 2.681x + 0.374x^2$
c	$1.559 - 0.728x$
s	$3.685 - 2.754x + 0.383x^2$

Table 5. Spectral indices for the GRG components at 6.25 and 13 cm

Source component	Spectral index	
	6.25 cm	1.3 cm
0139+3957 w	−1.29	−1.29
c	−2.24	−2.24
e	−1.18	−1.18
0912+3510 n	−0.65	−0.65
s	−0.51	−0.51
1032+2759 n	−1.27	−1.27
c	−0.24	−0.24
s	−0.64	−0.64
1400+3017 n	−1.54	−1.28
s	−1.15	−1.15
1453+3308 n	−1.21	−0.86
c	−0.56	−0.56
s	0.19	−0.20
1552+2005 w	−0.46	−0.46
e	0.03	−1.63
ee	−1.00	−1.00
1738+3733 n	0.07	−0.17
c	−0.73	−0.73
s	0.07	−0.18

the host galaxy due to variations in the pressure of the gas flowing around the lobes, i.e., the pressure of the surrounding medium.

Note also that the RATAN-600 observations have made it possible to refine the spectra of the GRG components and, via extrapolation of the radio spectra, estimate their fluxes at millimeter wavelengths. These extrapolated flux densities exceed 0.6 mJy. With an expected total number of GRGs of several hundred [14], their contribution to the background radiation can, in principle, lead to a bias in calculations of the level of fluctuations of the background, as well as problems in distinguishing the background signal. To estimate this bias, we have begun composing a catalog of GRGs with modest flux densities (<100 mJy) over the entire sky.

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