Catalog of Radio Galaxies with \( z > 0.3 \). II: Photometric Data

M.L. Khabibullina\(^a\), O.V. Verkhodanov\(^a\)
Special Astrophysical Observatory of the Russian AS, Nizhniy Arkhyz 369167, Russia

Received December 1, 2008; accepted April 4, 2009.

We describe the procedure of the construction of a sample of distant \( (z > 0.3) \) radio galaxies using the NED, SDSS, and CATS databases. We believe the sample to be free of objects with quasar properties. This paper is the second part of the description of the radio galaxies catalog we plan to use for cosmological tests. We report the photometric parameters for the objects of the list, and perform its preliminary statistical analysis including the construction of the Hubble diagrams.

PACS: 95.80.+p, 98.52.Eh, 98.54.Cm, 98.54.Gr, 98.62.Qz, 98.70.Dk, 98.80.-k

1. INTRODUCTION

The improved quality of observations and parameter simulation marks the approaching era of precision cosmology (as M. Longaire named it in 2000 in Manchester). The recent space and ground-based experiments \(^1\) \(^2\) have provided a wealth of data for measuring the parameters of the Universe and constructing a self-consistent cosmological mode. Nevertheless, checking whether the \( \Lambda \)CDM paradigm is compatible with other tests remains a priority task, as the current accuracy of the parameter determination \( (H_0, \Omega_L, \Omega_{DM}, \Omega_b, \Omega_k, \text{etc.}) \) still leaves the possibilities open for an existence of other models \(^3\). We place radio galaxies among the most interesting objects for independent tests of the above parameters. Radio galaxies are between the most luminous galaxies known, and can hence be studied at large redshifts, and thereby used to probe the state of the Universe in other epochs. Of great importance for the study of radio galaxies is the fact that their parent objects are giant elliptical galaxies (gE), which can be used as standard candles/rulers \(^4\) at the initial stage of selection. Identification with gE is important both for tracing the evolution of stellar systems at large redshifts \( (z \sim 4) \) \(^8\) \(^9\), which allows estimating the ages of the systems.

When constructed, a complete distribution of radio galaxies on their redshifts \( z \) can be used not only to study the luminosity function of these objects, but to investigate the formation of supermassive black holes at the galactic centers, and the dynamics of the expansion of the Universe. According to the observational data of Disney et al. \(^10\), the physical parameters of radio galaxies (total mass, baryon fraction, age, luminosity, etc.) are intercorrelated, and this fact should make it easier to use gE type galaxies in cosmological studies, provided that all these objects formed at the same epoch. However, to address such tasks, one needs the most complete sample of radio galaxies possible in different redshift intervals.

The aim of this paper is to construct a sample of radio galaxies in the redshift interval of \( z > 0.3 \). It is the second part of the catalog published after the Paper I \(^11\), and contains the catalogued optical data for radio galaxies adopted from other available sources.

Paper I describes the construction of the sample using the NED\(^1\) and CATS\(^2\) databases, and applying selection procedures, that results in singling out a total of 2442 objects. The list of ob-

\(^1\) http://nedwww.ipac.caltech.edu
\(^2\) http://cats.sao.ru
Figure 1: Sky positions of selected radio sources in Galactic coordinates. The circles indicate SDSS objects and the crosses mark all other sources.

In Paper I we as well constructed for our sample the “spectral index–redshift” (α(z)) relation, and other diagrams and distributions.

Herein we report similar statistical data for the results of optical observations initially catalogued in the NED and SDSS databases. Note that photometric estimates of the parameters of giant elliptical galaxies can be used for a number of cosmological tests, such as the Hubble diagram “magnitude–z” (K–z) [8], or the “age–z” diagram [21]. There are a number of tests that allow the parameters and evolutionary characteristics of the Universe to be estimated based on the radio data (see, e.g., [22, 23, 24]).

As we pointed out above, this is the second paper of the planned series of three papers dedicated to the construction of a sample, and to the statistical analysis of the catalog of radio galaxies, including the objects with spectroscopically measured z, emitting at radio frequencies, and having optical photometric data. In the future, we plan to use the physical parameters of the catalog objects to perform the cosmological tests mentioned in Paper I [11].

2. THE CATALOG

2.1. Description of the Catalog

In this paper we describe the second part of the list of radio galaxies, which contains optical magnitudes. The data are listed in the Table presented in the Appendix. The columns of the table give the names of the objects and their magnitudes. The complete catalog is available from the CATS database, and CDS database.

In the table we use standard designations for the passbands in which the magnitudes are measured: the SDSS filters u, g, r, i, and z; the passbands of the Johnson and UKIDSS systems: R, U, B, V, G, H, I, J, K, R, and Z; the Gunn system filters r_G and i_G; the Hubble Space Telescope’s filters F160W, F775W, F850LP, F702W, F606W and F814W; the ultraviolet filters FUV and NUV with the 1150–1700˚ A and 1575–3110˚ A passbands, respectively; and the Palomar Atlas photographic magnitudes of the blue and red plates O and E.

The coordinates of the selected radio galaxies are listed in the Table presented in the Appendix to Paper I. Figure 1 shows the positions in the sky for these objects.

2.2. Statistical Analysis of the Sample

We already pointed out in Paper I that our list of galaxies is neither complete in terms of sky coverage, nor homogeneous in terms of sensitivity and

---

3 ftp://cats.sao.ru/pub/CATS/RLIST
4 ftp://cdsarc.u-strasbg.fr/pub/cats/J/other/AstBu/64.276
5 http://cdsarc.u-strasbg.fr/cgi-bin/VizieR?-source=J/other/AstBu/64.276
6 The SDSS magnitudes are given in the AB system as defined by Petrosian [25].
frequency intervals, as the sample contains objects drawn from different catalogs and unconnected sky areas. Figure 1 demonstrates the positions of the selected galaxies in the sky. The most complete and homogeneous subsample of the list contains objects from the SDSS survey, highlighted in Fig. 1 with a different marker. The SDSS radio galaxies (the NVSS [26] and FIRST [27] radio data) include many objects with small redshifts ($z < 0.5$) and small fluxes ($S < 15 \text{ mJy}$), making this subsample distinguish itself quality-wise among other subsamples.

We performed a preliminary statistical analysis of our list and present the results in Figs. 2 and 3. Figure 2 shows the histograms of the magnitude distribu-
Figure 3: Left to right, top to bottom: the “magnitude–z” Hubble diagrams for the H, I, J, K, R, and V passbands. The galaxies from groups (1) and (2) are marked with crosses and
| Redshift | g      | i      | r      | u      | z      |
|----------|--------|--------|--------|--------|--------|
| 1.6      | 17     | 18     | 19     | 20     | 21     |
| 1.8      | 16     | 17     | 18     | 19     | 20     |
| 2.0      | 15     | 16     | 17     | 18     | 19     |
| 2.2      | 14     | 15     | 16     | 17     | 18     |
| 2.5      | 13     | 14     | 15     | 16     | 17     |

Figure 4: Left to right, top to bottom: the “magnitude–z” Hubble diagrams for the g, i, r, u, and z passbands. The galaxies from groups (1) and (2) are marked with crosses and circles, respectively. Regression relations \( \text{mag}(z) \) are derived for the g, i, r, and z-band magnitudes.
tion in the H, I, J, K, R, V, g, i, r, u, and z passbands.

It is evident from this figure that the magnitudes of the objects have different distributions in different filters. However, the fact that for many radio galaxies there exist measurements in more than three filters will make it possible in the future to estimate the age of the stellar populations in these galaxies. In our analysis of the sample we subdivided the sources into two groups: (1) those with the semimajor axes greater than 29′′, and (2) those with the semimajor axes smaller than 29′′ (data adopted from the NVSS catalog). Here 29′′ is the median semimajor axis (according to NVSS) of the sources of our sample. In Figs. 3 and 4, the galaxies from groups (1) and (2) are marked with crosses and circles, respectively. We made such division in order to search for eventual physical differences between radio galaxies depending on their radio sizes, what could be of help in the studies of giant radio galaxies [28]. However, it is evident from the figures that the diagrams for the subsamples selected based on this parameter differ insignificantly.

The g, i, r and z-band magnitudes show linear dependencies \( \text{mag}(z) \), which we derived based on the mean values averaged inside the \( \Delta z = 0.5 \) wide bins. The regression relation can be described by the law \( z = p + qx \), where \( z \), \( p \) and \( q \) are the redshift, intercept, and slope of the linear relation, respectively. The Table above lists the parameters of the regression relation for the g, i, r, and z filters. We see no variation of redshift with magnitude changes in the u-band. Moreover, two populations of objects characterized by different regression relations can be identified in the g and z filters (see Fig. 5).

Below we list the radio galaxies that do not fit within the general relation in the Hubble diagrams:

| Filter | \( p \) | \( q \) |
|--------|--------|--------|
| g\(_1\) | -2.15  | 0.12   |
| g\(_2\) | 0.08   | 0.02   |
| i      | -2.34  | 0.15   |
| r      | -2.20  | 0.14   |
| z\(_1\) | -2.01  | 0.14   |
| z\(_2\) | 0.43   | 0.003  |

Table 1: Table. Parameters of the regression relation for the g, i, r, and z filters. Two populations denoted by subscripts 1 and 2, are identified for the g and z passbands, respectively.

| Filter       | \( p \)                | \( q \)            |
|--------------|------------------------|--------------------|
| 2MASX        | J15542080+2712295       | \( z=1.439 \)      |
| TXS          | 0828+193                | \( z=2.572 \)      |
| SDSS         | J162626.28+371441.6     | \( z=2.656 \)      |
| SDSS         | J110245.80+602830.6     | \( z=2.111 \)      |
| SDSS         | J143631.27+431124.7     | \( z=4.261 \)      |
| SDSS         | J082907.43+064546.0     | \( z=2.224 \)      |
| SDSS         | J074324.07+233626.0     | \( z=2.480 \)      |
| SWIRE        | J104528.29+591326.7     | \( z=2.310 \)      |

Figure 5: The Hubble diagrams for the g- (left) and z-band (right) filters. The galaxies from groups (1) and (2) are marked with crosses and circles, respectively. The regression lines emphasize the two object populations identified.
3. CONCLUSIONS

We report the second part of the radio galaxies catalog with redshifts $z > 0.3$, which contains complete information on the magnitudes of the objects. The catalog is based on lists of objects from the NED and CATS databases. Our sample includes the SDSS objects, and the objects from the “Big Trio” program. We perform a preliminary statistical analysis of the distributions of individual magnitudes. The catalog will serve as a basis for further studies of the ages of distant radio galaxies. We constructed the Hubble diagrams for 11 filters, and determined the parameters of linear regression for the $g$, $i$, $r$, and $z$ filters of the SDSS survey. In addition, two populations of objects characterized by different regression relations can be identified in the $g$- and $z$-band filters.

Acknowledgments.

This research has made use of the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. We also made use of the CATS databases. Our sample includes the SDSS objects, and the objects from the “Big Trio” program.

References

[1] G. Hinshaw, J. L. Weiland, R. S. Hill, et al., ApJS 180, 225 (2009), arXiv:0803.0732.
[2] P. Schneider, P. B. Hall, G. T. Richards, et al., AJ 134, 102 (2007).
[3] E. Komatsu, J. Dunkley, M. R. Nolta, et al., ApJS 180, 330 (2008), arXiv:0803.0547.
[4] N. S. Soboleva, Doctoral Dissertation in Mathematics and Physics (Special Astrophysical Observatory, St.-Petersburg, 1992).
[5] O. V. Verkhodanov, A. I. Kopylov, Yu. N. Parijskij, et al., Astrophysical Bulletin 48, 41 (1999), astro-ph/9910559.
[6] O. V. Verkhodanov, Yu. N. Parijskij, N. S. Soboleva, et al., Physical Bulletin 52, 5 (2001), astro-ph/0203522.
[7] O. V. Verkhodanov, A. I. Kopylov, O. P. Zhelenkova, et al., Astron. Astrophys. Trans. 19, 663 (2000), astro-ph/0012359.

[8] C. J. Willott, S. Rawlings, M. J. Jarvis, and K. M. Blundell, MNRAS 339, 173 (2003).
[9] O. V. Verkhodanov, A. I. Kopylov, Yu. N. Parijskij, et al., Astronomy Lett. 31, 221 (2005), arXiv:0705.3040.
[10] M. J. Disney, J. D. Romano, D. A. Garcia-Appadoo, et al., Nature 455, 1082 (2008), arXiv:0811.1554.
[11] M. L. Khabibullina and O. V. Verkhodanov, Astrophys. Bull. 64, 123 (2009), arXiv:0911.3741.
[12] D. Dagkesamanskii, Nature, 226, 432 (1970).
[13] G. Blumenthal and G. Mile, A&A 80, 13 (1979).
[14] Yu. N. Parijskij, W. M. Goss, A. I. Kopylov, et al., Bull. SAO 40, 5 (1996).
[15] Yu. N. Parijskij, W. M. Goss, A. I. Kopylov, et al., Astron. Astrophys. Trans. 18, 437 (1999).
[16] C. breuck, V. van Breugel, H. J. A. Röttgering, and G. Miley, A&AS 143, 303 (2000).
[17] G. Miley and C. De Breuck, Astron. Astrophys. Rev. 15, 67 (2008).
[18] C. De breuck, V. van Breugel, S. A. Stanford, et al., AJ 123, 637 (2002).
[19] A. I. Kopylov, W. M. Goss, Yu. N. Parijskij, et al., Astron. Astrophys. Lett. 32, 433 (2006), arXiv:0705.2971.
[20] M. A. Jarvis, H. Teimourian, C. Simpson et al., accepted to MNRAS, arXiv:0907.1447.
[21] O. V. Verkhodanov, Yu. N. Parijskij, and A. A. Starobinsky, Bull. SAO 58, 5 (2005), arXiv:0705.2776.
[22] O. V. Verkhodanov and Yu. N. Parijskij, Bull. SAO 55, 66 (2003).
[23] O. V. Verkhodanov and Yu. N. Parijskij, in Particles and Cosmology, Proc. 14th Internat. School, Ed. by S. V. Demidov, V. A. Matveev, and V. A. Rubakov, p. 109 (2008).
[24] O. V. Verkhodanov and Yu. N. Parijskij, Radio Galaxies and Cosmology, (Fiz. Mat. Lit., Moscow, 2009) [in Russian].
[25] D. P. Schneider, P. B. Hall, G. T. Richards, et al., AJ 134, 102 (2007).
[26] J. J. Condon, W. D. Cotton, E. W. Greisen, et al., AJ115, 1693 (1998).
[27] R. L. White, R. H. Becker, D. J. Helfand, and M. D. Gregg, ApJ 475, 479 (1997).
[28] O. V. Verkhodanov, M. L. Khabibullina, M. Singh, et al., in Practical Cosmology, Proc. Internat. Conf. “Problems of Practical Cosmology”, Ed. by Yu. Baryshev, I. N. Taganov, and P. Teerikorpi, Russian Geog. Soc., St. Petersburg, V.II, 247 (2008).
[29] O. V. Verkhodanov, S. A. Trushkin, H. Andernach, and V. N. Chernenkov, in Astronomical Data Analysis Software and Systems VI, Ed. by G. Hunt and H. E. Payne, ASP Conf. Ser., 125, 322 (1997), astro-ph/9610262.
[30] O. V. Verkhodanov, S. A. Trushkin, H. Andernach, and V. N. Chernenkov, Bull. SAO 58, 118 (2005), arXiv:0705.2950.
[31] O. V. Verkhodanov, in Astronomical Data Analysis Software and Systems VI, Ed. by G. Hunt and H. E. Payne, ASP Conf. Ser., 125, 46 (1997).

http://sed.sao.ru/~vo/fadps_e.html
[32] O. V. Verkhodanov, B. L. Erukhimov, M. L. Monosov, et al., Bull. SAO 36, 132 (1993).