Ultra-steep spectrum decametric sources for cosmological researches

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Abstract: Radio galaxies is one of the main probes in observational cosmology to test physical conditions in the different epoch of the Universe. Selection of distant galaxies is one of main tasks in activity. We consider the problems of decametric source identification and prepare a list of ultra steep spectrum radio sources being candidates to distant radio galaxies using the CATS database.

1. Introduction

There are several cosmological tests based on the observational data of the radio galaxies (Verkhodanov, Parijiskij, 2003, 2008). Namely, they are:

- radio source counts (Condon, 1984),
- a diagram *K-z* (Willott et al., 2003),
- clustering of radio sources (Blake & Wall, 2002),
- a radio galaxy angular size (Gurvits et al., 1999; Guerra et al., 2000; Jackson, Jannetta, 2006),
- gravitational lensing (Chae et al., 2002),
- age of radio galaxies (Jimenez, Loeb, 2002; Verkhodanov, Parijskij & Starobinsky, 2005),
- the Sunyaev-Zeldovich effect (Sunyaev, Zeldovich, 1972; De Zotti et al., 2005),
- the Sachs-Wolfe effect (Sachs, Wolfe, 1967; McEwen et al., 2007),
- a search for neutralino in halo (Colafrancesco & Mele, 2001).

Most of these tests need to have a distance scale till the high z ($z > 3$) to form a cosmological grid using the same type objects. Radio galaxies are among the best ones for this goal. They are identified with giant elliptical galaxies which started to form from the very beginning of the Universe. The giant elliptical (gE) galaxies with high radio luminosity and with the old stellar population are the most suitable objects for estimating the age of stellar systems. They are placed as a rule in the center of clusters and proclusters being the brightest galaxies. The present-day models predict fast enough (during 1 billion years) formation of such systems at $z \sim 4$ (Pipino & Mantencci, 2004), which enables application of photometric methods to their investigation. The efficiency of selecting such galaxies with the aid of radio astronomy methods beginning from moderate redshifts ($z > 0.5$) is confirmed by several groups (Pedani, 2003). A combined diagram of Hubble "K-z" for radio galaxies and field galaxies (Jarvis et al. 2001; De Breauk et al. 2002) shows that radio galaxies have the highest luminosity at any redshift $0 < z < 5.2$ (Reuland et al., 2003). Besides, radio galaxies have supermassive black holes whose mass is generally proportional to a stellar bulge one ($M_{BH} \sim 0.006\ M_{buldge}$, Maggorrian et al., 1998), and this fact is additional evidence of the presence of an already formed stellar population. Note that the estimate of the age of distant galaxies is also of interest in connection with searching for primeval black holes with masses 10^3 - 10^6 $M_\odot$.

To select the distant radio galaxies, ultra steep spectrum (USS) source ($\alpha \leq -1.1$, $S \sim \nu^\alpha$) catalogues are used. The observational fact is that a chance to find a high redshift radio source is higher when an object has USS. The most distant radio galaxies have been detected using this approach at $z=4.514$ (Kopylov et al., 2006) and $z = 5.19$ (van Breugel et al., 1999). To collect USS sources, one should have observational data in the wide range of radio frequencies. The low frequencies ($\nu < 1400$ MHz) play very important role in this selection. One of the most full collection of radio astronomical catalogs are stored in the database CATS (Verkhodanov et al., 2005b). Among them, the decametric catalog (Braude et al. 1978-2002) has the lowest frequencies range (10-25 MHz).

2. Decametric objects

A radio survey obtained with the UTR telescope (Kharkov, Ukraine) at frequencies 10-25 MHz has resulted in a catalog of 1822 sources (Braude et al., 1978-1994). Covering about 30% of the sky north of -13°, declination, this survey is presently the lowest-frequency source catalog of its size, and thus provides an ideal basis to study the little known optical identification content of sources selected at decametric frequencies. In the original version of the UTR-2 catalog (UTR in what follows) there is no radio identification at other frequencies for 7% of the sources, and for 81% there is no optical identification. Our goal is to identify all UTR sources with known radio sources and to search for optical counterparts on the Digitzed Sky Surveys.

To the first lists of Braude et al. (1978-1994) stored in the CATS, we have added another catalog Braude et al. (2002) of 487 sources in the range of declinations $30° < \delta < 40°$, which was processed in the same way as the previous ones to prepare a list of USS sources.

The rather large uncertainties of UTR positions (~ 0.7°) require an iterative process for finding radio counterparts at successively higher frequencies (and thus higher positional accuracy). In this we aided ourselves by selecting previously cataloged sources from the CATS database (Verkhodanov et al., 2005b) in a box of RA x DEC = $40' \times 40'$ centered on the nominal UTR position. The "raw" spectra given by these fluxes were refined using computer charts of source locations around UTR positions. All counterparts from TXS, GB6 and PMN catalogs within circles of $1'$ radius were considered one source. Groups of sources lying further apart were assigned separate spectra, each with the UTR flux as upper limit. We fitted spectra of 3170 radio counterparts to 2308 UTR sources with either straight (S), convex (C^-), or concave (C^+) curves in the lg ν - lg S plot (see also Verkhodanov et al., 2000a,b, 2001, 2003). The resulting catalog includes information from a large number of electronically available catalogs of radio, infrared, optical and X-ray sources.

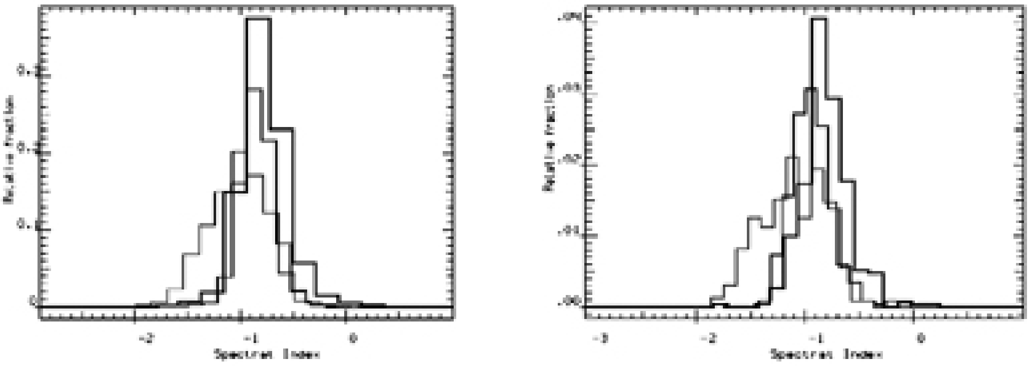

Fig.1 Distributions of spectral indices of 3170 radio counterparts of UTR sources, fitted at frequencies 80, 365 (fat line) and 1400 MHz (fattest line). Left: 2762 high Galactic latitude sources (|b|>10°); right: 408 sources at low Galactic latitudes (|b|<10°).

Table 1: Distribution of radio counterparts to UTR sources by spectral type, where $X=\log_{10}$ (frequency/MHz), and $Y=\log_{10}$ (flux density in Jy)

Spectral class	Fitting function	N	%
Straight (S)	Y = +A+B*X		39
Convex (C^+)	$Y = +A \pm B*X - C*X^2$		8
Concave (C^-)	$Y = +A - B*X + C*X^2$		50
or	Y = ±A±B*X+C*EXP(-X)		3

In our catalog of 3170 radio counterparts (the full list will be published in a forthcoming paper) there are 639 S-type sources with "very-steep spectrum" (VSS), and for the present work we selected from these a subsample of 199 "ultra-steep spectrum" (USS) objects ($\alpha \leq -1.2$). To further increase the radio-positional accuracy, we searched for radio counterparts of USS sources in the FIRST catalog (White et al.,1997). Parts of these sources are presented in Table 2. If a UTR source has more than one acceptable counterpart in FIRST, we label these components with letters a, b, c, etc. Only one of the FIRST components (labeled GR1527+51 b) is truly unresolved by the FIRST beam of ~ $5''$ (i.e. has a major and minor axis of $< 2''$), while all other objects have a multi-component or extended structure. We checked the sources also in the lower resolution NVSS at 1.4 GHz (Condon et al. 1998). Usually, the larger is the source complex, the larger is the NVSS/FIRST flux ratio. Radio spectra of some of the source complexes are shown in Fig. 2.

Table 1. The FIRST counterparts to 23 USS sources (α ≤ - 1.2), being part of 199 USS decametric objects, from the UTR catalog. We list the UTR name, the size of the source complex (or deconvolved size if a single component) from NVSS and FIRST, respectively, the FIRST RA & Dec, the peak and integrated component flux at 1.4 GHz from FIRST, their deconvolved major and minor axes, and major axis position angle (N through E) from FIRST.

UTR name (B1950)	VSS size(")	FIRST size(")	RA (J2000) Dec	S_p (mJy)	S_i mJy)	Maj (")	Min (")	PA (°)
GR0002+00 b	16.	7.4	000650.56 + 003648.4	47.6	75.9	7.4	1.1	154
GR0135 - 08	28.	20.	013714.87 - 091155.4	5.2	44.3	30.8	7.5	98
			013715.08 - 091203.3	10.2	36.9	15.6	4.3	90
			013715.45 - 091155.8	8.2	25.7	13.0	5.4	148
			013716.22 - 091149.5	10.0	39.3	11.3	9.3	119
GR0257 - 08 a	< 18.	4.5	025919.15 - 074501.2	162.5	211.9	4.5	1.3	59
GR0257 - 08 b	80.	83.	030040.22 - 075302.2	18.4	52.8	15.6	3.0	174
			030040.56 - 075259.6	10.1	122.8	30.7	13.1	163
			030042.99 - 075413.8	7.0	34.2	16.2	8.4	32
			030042.99 - 075358.0	13.6	47.8	12.3	7.4	152
			030043.60 - 075418.3	6.4	22.0	11.2	7.6	85
			030043.75 - 075407.2	6.6	22.4	15.6	4.8	174
GR0723+48 b	47.	3.1	072651.18 + 474041.5	23.8	29.1	3.1	2.0	175
			072655.0 + 474051.0	51.8	75.7	5.6	1.1	85
GR0818+18	24.	22.	082032.48 + 192731.3	31.1	49.2	6.1	1.7	174
			082032.73 + 192709.0	76.4	98.5	3.9	1.6	8
GR0858 - 02 b	70.	55.	085935.06 - 015842.1	11.7	27.2	10.2	3.2	122
			085936.10 - 015851.8	9.8	15.9	6.2	2.8	128
			085938.21 - 015908.1	20.2	43.6	8.1	4.5	133
GR0910+48	36.	29.	091359.00 + 482738.0	26.9	88.6	11.6	5.2	100
			091401.83 + 482729.2	39.6	110.2	10.9	3.9	106
GR0922+42 b	< 19.	2.7	092559.66 + 420335.3	199.7	244.1	2.7	2.4	98
GR0942+54	14.	8.	094618.12 + 543003.8	51.1	57.1	2.5	0.9	36
			094618.53 + 543010.1	75.3	80.6	1.7	1.1	16
GR1149+42	< 17.	5.0	115213.58 + 415344.9	83.7	115.4	5.0	1.0	18
GR1214 - 03	70.\,?	3.2	121755.30 - 033722.0	176.9	208.9	3.2	1.2	111
GR1223 - 00	25.	25.	122722.97 - 000813.8	5.8	13.6	8.4	5.0	100
			122724.54 - 000821.1	8.4	16.9	7.1	4.6	116
GR1243+04	< 18.	6.8	124538.38 + 032320.1	249.4	379.9	6.8	1.3	158
GR1318+54	25.	23.	132202.81 + 545758.1	30.3	90.3	9.5	5.9	82
			132205.33 + 545805.3	8.6	35.9	10.7	8.6	55
GR1320+43	< 19.	3.3	132232.32 + 425726.5	129.3	154.6	3.3	1.0	81
GR1355+01 c	< 19.	10.	135821.64 + 011442.0	77.0	88.4	2.9	1.4	42
			135822.08 + 011449.4	169.9	180.9	1.6	1.3	32
GR1447+57	< 19.	4.5	144630.04 + 565146.8	75.2	99.2	4.5	0.7	148
GR1527+51 b	< 19.	1.4	152828.36 + 513401.4	203.9	212.8	1.4	0.8	140
GR1539+53 b	< 18.	6.4	154144.69 + 525054.5	87.0	136.7	6.4	0.8	66
GR1613+49	< 19.	3.0	161631.16 + 491908.2	56.1	66.2	3.0	1.3	10
GR1731+43	42.	40.	173333.87 + 434318.6	32.9	57.9	6.3	3.0	164
			173334.26 + 434300.8	22.8	27.3	3.1	1.5	173
			173334.41 + 434251.4	12.3	15.8	3.3	2.4	159
			173334.58 + 434239.8	27.3	51.0	7.5	2.3	150
GR2211 - 08 b	< 19.	8.6	221519.65 - 090005.8	75.2	125.0	8.6	1.4	176

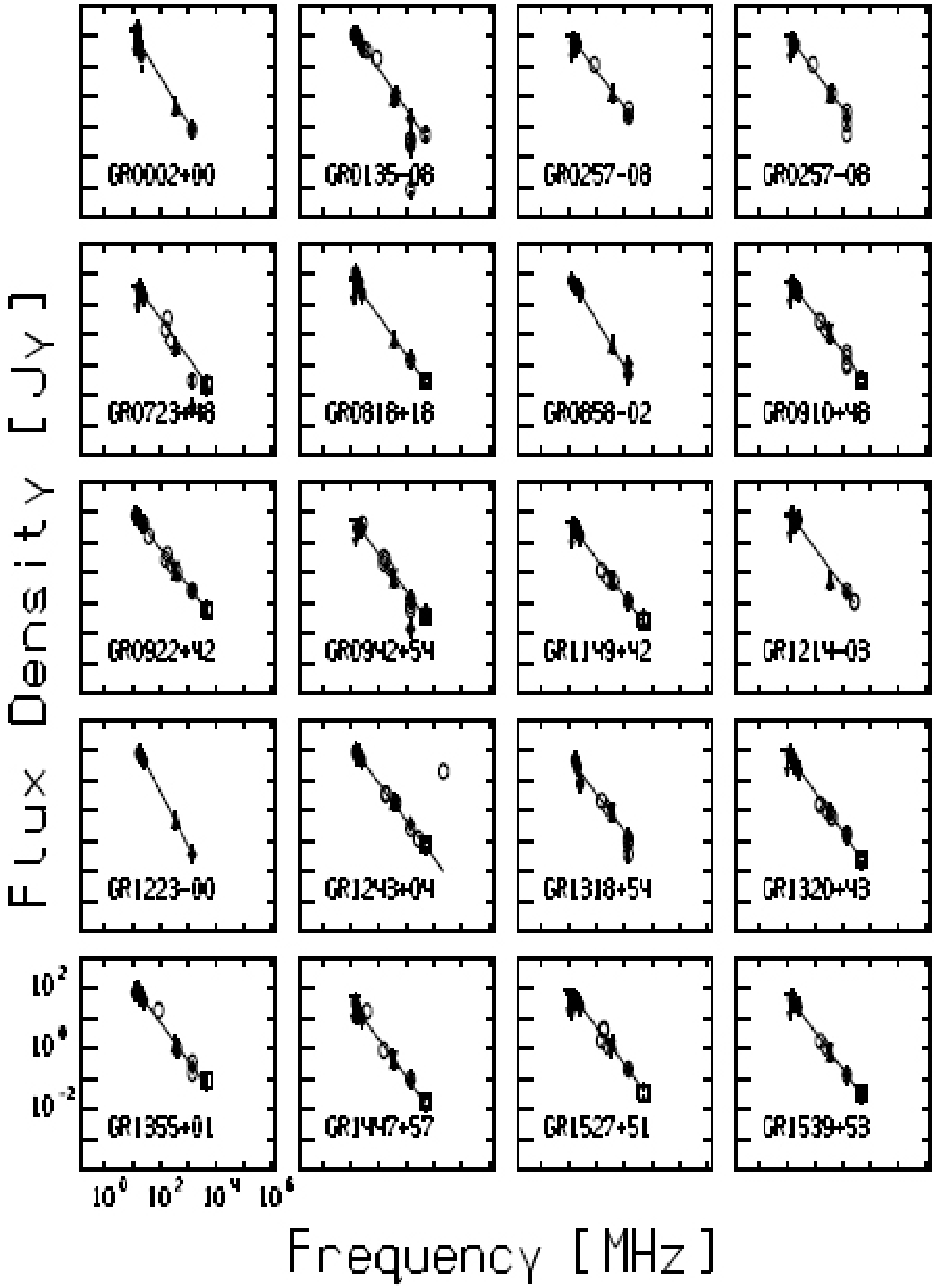

Fig. 2. Radio spectra of 20 USS sources from UTR, identified with FIRST sources.}

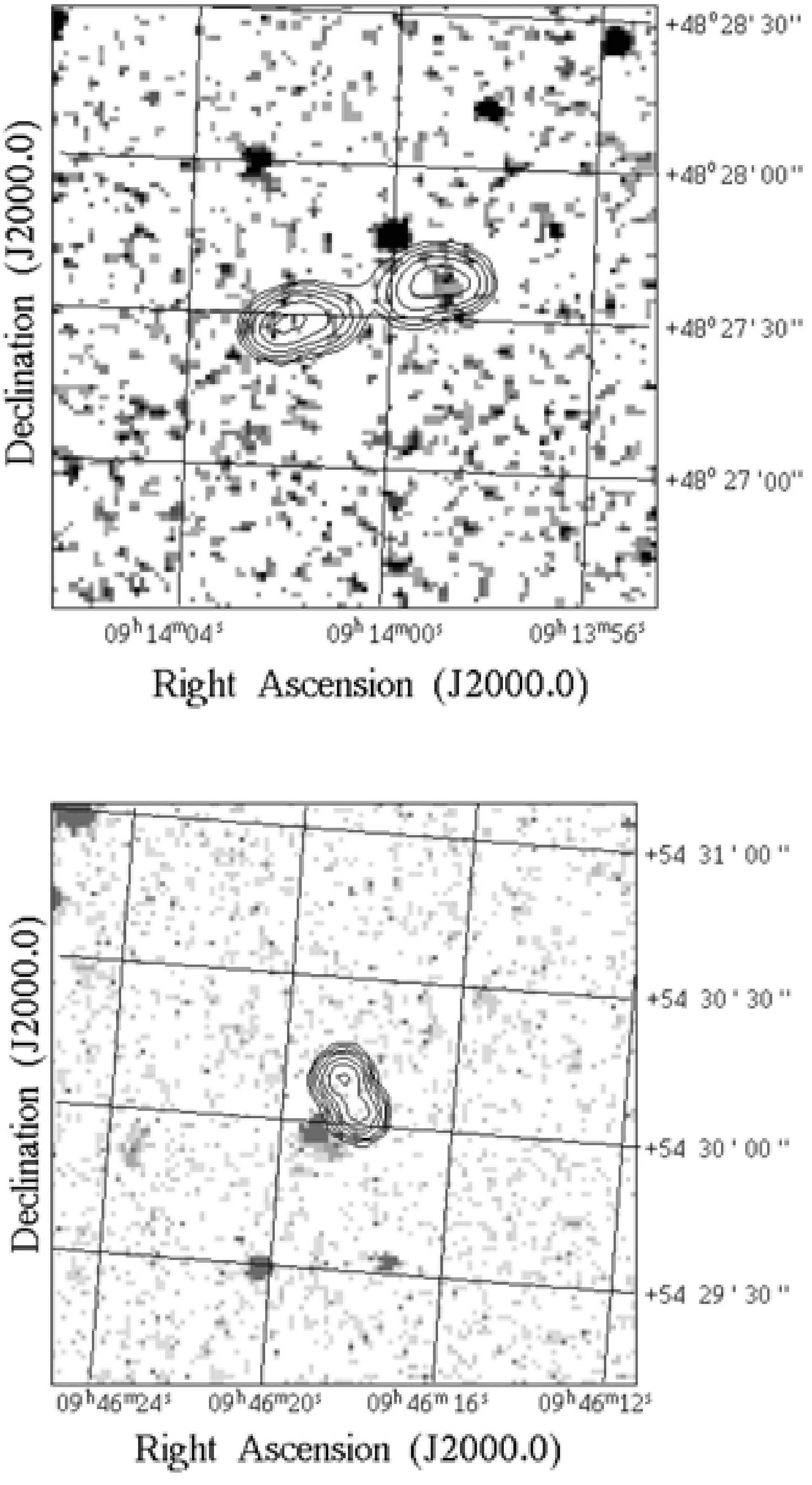

Fig.3 Examples of two FIRST maps of multicomponent objects GR0910+48 (upper panel) and GR0942+54 (lower panel) overlaid on DSS-2 images. There are no optical counterparts above the plate limit at the symmetry center of these radio doubles.

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