The most compact bright radio-loud AGN – I. A new target sample selected for the space VLBI

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Abstract We investigated the archival ground-based VLBI images of the extragalactic radio sources included in both the *Wilkinson Microwave Anisotropy Probe (WMAP)* and the *Planck* catalogues, and selected 49 bright and compact sources as potential targets for space Very Long Baseline Interferometry (VLBI) observations at mm wavelengths. These sources have a flat radio continuum spectrum between 33 and 94 GHz. They are identified as core-dominated active galactic nuclei (AGN), located at declinations above $-40°$, and have never been observed with ground-based VLBI at 86 GHz. The radio properties of the 49 new sources are presented. We compare this new sample with similar samples of compact AGN available from earlier studies. The new candidates, together with the existing bright compact AGN sample identified from 86-GHz ground-based VLBI imaging surveys, form a catalogue of more than 160 AGN. These could be primary targets for mm-VLBI observations on the ground, as well as for future mm-wavelength space VLBI missions such as the project with two satellites currently under study in China.

Keywords galaxies: active – radio continuum: galaxies – surveys – techniques: high angular resolution – techniques: interferometric

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1 Introduction

Active galactic nuclei (AGN) are the most powerful non-transient objects in the Universe (Osterbrock & Ferland 2006). Their luminosity ranges from 10^{40} to 10^{47} erg s^{-1}. Blazars form a sub-class of AGN, containing optically violently variable (OVV) quasars, high-polarization quasars (HPQ) and BL Lacertae (BL Lac) objects. The latter are characterized by weaker or no emission lines and extreme variability (Antonucci 1993; Urry & Padovani 1995; Zensus 1997). Blazars are all radio-loud AGN and often show apparent superluminal motion in their jet components (see the recent review by e.g. Perlman 2013). The observed luminosity of blazars is significantly magnified by Doppler boosting, an effect of the relativistically beamed emission from the parsec-scale jet components (Blandford & Königl 1979; Kellermann & Pauliny-Toth 1981; Orr & Browne 1982; Lobanov 1998; Kellermann et al. 2004). This prominent character makes the blazars excellent laboratories to study AGN phenomena.

The tremendous energy release process of blazars is known to be associated with the accretion of material into a central supermassive black hole (SMBH) at the heart of the galaxy. It happens in an extremely compact region surrounding the SMBH. The radio properties of blazars are mostly manifested by highly relativistic jets launched from the vicinity of the central power engine (Rees 1971; Scheuer 1974). High-resolution radio observations of jetted outflows using the technique of Very Long Baseline Interferometry (VLBI, Whitney et al. 1971) shed light on the immediate environments of SMBHs, provide direct measurements of kinematic and magnetic properties of the jet flow (e.g. Hada et al. 2011; Doeleman et a. 2012), and allow testing jet models (e.g. Marscher & Gear 1985; Ferrari 1988; Marscher 2009; Potter & Cotter 2012).

Although blazars only account for a small fraction in the general AGN population, owing to their high observed luminosity, they often dominate the flux-density-limited AGN survey samples. VLBI surveys of radio-loud core-dominated AGN provide fundamental information on the statistical properties of the compact AGN jets and also form the basis for further detailed observations of individual objects. Several large VLBI surveys at various frequencies have been carried out in the past three decades or so, resulting in an imaging data base of several thousand AGN (for examples, see the references listed in Table 1). Ground-based VLBI at mm wavelengths provides a typical angular resolution of $\lesssim 0.2$ mas (at 7 mm), thus offering the best tool for imaging the fine radio structures of compact AGN jets on sub-parsec scales, approaching the site where the jet is launched and collimated.

The highest-resolution VLBI imaging currently available is at 86 GHz (e.g., Lee et al. 2008), although this may change in the fairly near future as 230-GHz observations with better baseline coverage become available (Krichbaum et al. 2013). The first single-baseline interference fringes demonstrating the feasibility of 3-mm VLBI were detected at 89 GHz (Readhead et al. 1983). Since then, a number of VLBI observations of individual sources and different samples have been conducted at 86 GHz (Beasley et al. 1997; Rantakyrö et al. 1998; Lonsdale, Doeleman & Phillips 1998; Lobanov et al. 2000; Lee et al. 2008, and references therein). These observations have led to the detection of 126 sources in total, of which 114 have high (∼10 microarcsecond-level) resolution images (Rantakyrö et al. 1998; Lobanov et al. 2000; Lee et al. 2008). In fact, these sources constitute a group of the *brightest and most compact* radio AGN.

Apart from increasing the observing frequency, the angular resolution can also be improved by expanding the maximum baseline length of the VLBI network. This basic idea led to the development of space VLBI (SVLBI) which involves one or more radio telescopes installed on Earth-orbiting spacecraft. The ground-based VLBI stations and the space radio telescope(s) together form a space–ground VLBI network (Burke 1984). Currently, ground-only VLBI does not have sufficient resolving power to study the regions closest to the SMBHs where the jets are created and collimated. The extension of VLBI baselines into space offers the unique opportunity to probe these central regions of AGN by direct imaging.

In the 1980s, the first SVLBI experiments were successfully performed with a geostationary Tracking and Data Relay Satellite (TDRS) and some ground radio telescopes at 2.3 and 15 GHz (Levy et al. 1986; Linfield et al. 1989, 1990). The first dedicated SVLBI mission was the VLBI Space Observatory Programme (VSOP) led by Japan (Hirabayashi et al. 2000a). The *HALCA* satellite carrying an 8-m diameter radio telescope on board was launched in 1997 (Hirabayashi et al. 1998). The space radio telescope worked at 1.6 and 5 GHz. The apogee altitude of HALCA was 21 400 km, providing an angular resolution up to three times higher than available with the ground-only VLBI at the same observing frequency. The VSOP conducted an extensive 5-GHz AGN survey targeting a sample of 402 sources above 1 Jy flux density (Hirabayashi et al. 2000b). The results indicate that the AGN cores have an average diameter of 0.2 mas, and 14 per cent of the cores are smaller than 0.04 mas (Horiuchi et al. 2004; Scott et al. 2004).

In order to explore the innermost jets of the extremely compact AGN, SVLBI at higher frequency and with increased apogee height is required. Initial studies of a second-generation Japanese SVLBI mission VSOP-2 including observations at 8, 22 and 43 GHz and providing a maximum resolution of 38 microarcseconds (38 μas; Hirabayashi 2000c; Tsuboi 2009) were carried out, but it was decided not to take the project forward due to technical difficulties in meeting some of the required specifications. Currently the *RadioAstron* mission led by Russia is operational (Kardashev et al. 2013). The satellite, launched with a 10-m orbiting radio telescope in 2011, provides baselines up to ∼300 000 km to the ground radio telescopes. This in principle allows a resolution of ∼7 μas at the highest of the four observing frequencies (0.3, 1.6, 5 and 22 GHz). Such a fine resolution could be obtained when the spacecraft is at around its apogee. However, the imaging capability of RadioAstron is rather limited because a large fraction of the orbital period is spent at around the apogee due to the very eccentic elliptical orbit.

Future SVLBI missions would leap forward in the direction of improving both the resolution and the imaging capability. For instance, Russia is planning a millimeter-wavelength space-VLBI project named *Millimetron*, including a 12-m space radio telescope working at the highest frequency of 4700 GHz (Kardashev et al. 2007; Wild et al. 2009). Recently, the Shanghai Astronomical Observatory (SHAO) of the Chinese Academy of Sciences (CAS) started studying such a program (Hong et al. 2014). The objective is to achieve ultra-high angular resolution (a few μas) to image the immediate vicinity of the SMBHs, to study the black hole physics and to test the general relativity in strong gravity field. The first phase of the program involves two satellites, each carrying a 10-m radio telescope, operating at the highest frequency of 43 GHz. The proposed apogee height of the satellites is ∼60 000 km. The two space telescopes, working together with ground-based VLBI stations, could provide angular resolution as fine as 20 μas, together with a favourable (u, v) coverage for imaging.

To fulfil the scientific objectives of the SVLBI array, it is essential to have a sample of AGN that are sufficiently compact and bright for successful detection and imaging. Assembling a fundamental target list is vital for several reasons: calibration of the space telescope (pointing, sensitivity), investigations of jet physics (formation and acceleration of the relativisitic jets, magnetic fields in inner jets, transverse structure of jet flow, etc.), and studies of the statistical properties of the most compact AGN cores. The goal of this paper is to supplement the AGN lists known from previous 86-GHz ground-based VLBI surveys with potential new compact targets that have never been imaged at this frequency. The frequency of 86 GHz was chosen because *(i)* this is currently the highest where VLBI imaging data on a sufficiently large sample of sources are available, and *(ii)* the angular resolution of the ground-only VLBI networks is almost as high as the resolution of the proposed space–ground array at 43 GHz. A sample of compact and bright radio sources, to be confirmed with ground-based 86-GHz VLBI imaging, offers a good basis for a sample to be targeted later with 43-GHz SVLBI imaging.

With the recent release of high-frequency all-sky AGN flux density data bases, such as the point source catalogues of the *Wilkinson Microwave Anisotropy Probe* (*WMAP*, Bennett et al. 2003) and the *Planck* (Planck Collaboration 2011a) space telescopes, it became possible to search for more candidates. The single-dish flux densities measured at several high-frequency bands, together with public VLBI imaging data at lower frequencies, allow us to identify new bright and compact AGN suitable as targets for the future mm-wavelength SVLBI. On the other hand, ground-based VLBI imaging of these sources at 86 GHz would significantly extend the samples available at present. In Section 2, we describe the sample selection method and give the result. Section 3 presents some statistical properties of our new sample. Section 4 gives a summary of the findings and outlines our plans for continuing this work.

Table 1 Major VLBI imaging surveys of radio-loud AGN, with the 86-GHz surveys at the bottom.

Survey	ν (GHz)	N	Ref.
PR	5	37	1
CJF	1.6, 5	293	2–7
VSOP PLS	5	374	8
VSOP	5	242	9–11
VCS	2.3, 8.4	5756	12–17
RRFID	2.3, 8.4	782	18–20
VIPS	5	1127	21
VLBA 2cm / MOJAVE	15	259	22–27
CRF	24, 43	274	28
mJIVE-20	1.4	>4300	29
Rantakyrö+	86	13	30
Lobanov+	86	17	31
Lee+	86	109	32

Notes. Col. 1: abbreviated survey name, Col. 2: observing frequency in GHz, Col. 4: number of sources imaged, Col. 4: references 1. Pearson & Readhead (1988); 2–7. Polatidis et al. (1995); Thakkar et al. (1995); Xu et al. (1995); Taylor et al. (1994); Henstock et al. (1995); Pollack, Taylor & Zavala (2003); 8. Fomalont et al. (2000); 9–11. Hirabayashi et al. (2000b); Scott et al. (2004); Dodson et al. (2008); 12–17. Beasley et al. (2002); Fomalont et al. (2003); Petrov et al. (2005, 2006); Kovalev et al. (2007); Petrov et al. (2008); 18–20. Fey, Clegg & Fomalont (1996); Fey & Charlot (1997, 2000); 21. Helmboldt et al. (2007) 22–27. Kellermann et al. (1998); Zensus et al. (2002); Kovalev et al. (2005); Lister & Homan (2005); Lister et al. (2009, 2013); 28. Charlot et al. (2010); 29. Deller & Middelberg (2014); 30. Rantakyrö et al. (1998); 31. Lobanov et al. (2000); 32. Lee et al. (2008).

2 The sample selection

An important practical question about the future SVLBI, in particular the proposed Chinese mm-SVLBI array, is how many targets can be detected above 100 mJy ($\sim 7\sigma$) at the highest frequency band (43 GHz) on the longest achievable space–ground baselines of ∼70 000 km, assuming state-of-the-art receivers and a maximum bandwidth of 256 MHz (Kellermann et al. 2013). An analysis of the results of earlier VLBI surveys, and eventually a dedicated pre-launch AGN survey using ground-based VLBI arrays at the highest possible frequencies should yield a realistic estimate to answer this question.

Undoubtedly, the pre-launch AGN survey sample should contain the brightest and most compact sources known. Several large VLBI surveys of AGN were carried out in the past, working at cm and mm wavelengths (see the reviews in e.g. Frey 2006; Kovalev et al. 2009). All of them were limited to a certain flux density, thus preferentially targeting the bright AGN. The improved sensitivity of the instruments with time led to lower flux density limits and the increase in the sample sizes. Table 1 lists some representative AGN imaging surveys and gives references for their details. The 86-GHz surveys are listed at the end of the table.

The number of VLBI-imaged sources at mm wavelengths is small compared to the sample sizes of cm surveys. The moderate size of the presently known 86-GHz AGN sample can partly be attributed to technical difficulties: the small number and the limited availability of VLBI telescopes operating at 3 mm, the relatively poor baseline sensitivity, and the short atmospheric coherence time at 86 GHz. On the other hand, the continuum radio spectra steepening at high frequencies contribute to the decrease of suitably strong targets.

So far, VLBI surveys at 86 GHz resulted in images of just over 100 bright and most compact AGN. A first step towards an enlarged sample suitable for observations with a future mm-SVLBI array is to find further candidates which can then be confirmed as compact radio AGN using ground mm-VLBI observations. To this end, we turned to the *WMAP* and *Planck* point source catalogues.

The *WMAP* performed its all-sky survey at five different frequency bands from 23 to 94 GHz, from 2001 August to 2010 August. The primary goal of the mission was to study the properties of the Cosmic Microwave Background (CMB) radiation. To remove the foreground radio emission, a catalogue of discrete sources had to be created (e.g. Chen & Wright 2009). The *Planck* spacecraft complemented the CMB survey with improved angular resolution, sensitivity and frequency coverage, from 2009 August to 2013 October. The *Planck* covered a broader frequency range, in 9 different bands from 30 to 857 GHz. The range of the upper four frequency bands of the *WMAP* overlapped with the lowest four bands of the *Planck*.

Recently, Chen et al. (2013) compared the *WMAP* point source data from the first 7 years and the early release of the *Planck* compact source catalogue (Planck Collaboration 2011b). They compiled a list of 198 extragalactic sources detected with both space telescopes. The identification was based on the matching positions, no flux density limit was set, and the distribution of the sources is uniform over the whole sky (the sources within 5°of the Galactic plane were excluded to avoid confusion). Thus the Chen et al. (2013) list can be regarded as an unbiased sample of bright extragalactic radio sources at mm wavelengths. The 198 sources include 161 blazars (135 flat-spectrum radio quasars and 26 BL Lacertae objects), 28 non-blazar AGN, 2 galaxies, and 7 unidentified radio sources (Chen et al. 2013).

To define a new sample of bright and compact AGN potentially suitable for mm-wavelength SVLBI, we applied the following four selection criteria:

(a) A flat radio continuum spectrum (flux density $S_\nu \propto \nu^\alpha$, with a spectral index $\alpha \geq -0.5$) between 33 and 94 GHz.

(b) The object is classified as either a flat-spectrum radio quasar or a BL Lac object (Chen et al. 2013). Other types of sources such as starburst galaxies, normal galaxies, extended radio galaxies, and Galactic objects are ruled out this way.

(c) The declination is at least $-40°$, for the sake of good imaging together with the ground-based VLBI telescopes mostly located in the northern hemisphere.

(d) The source has never been imaged with ground-based VLBI at 86 GHz.

The flatness of the radio spectrum used for criterion (a) is believed to result from the superposition of several compact sub-components in the AGN "core" (i.e. the base of the compact jet) which are synchrotron self-absorbed with different turnover frequencies. Therefore the flat overall spectrum is a good indication of the compactness of the radio structure. The selection criteria (c) and (d) are the same as used for previous studies (Lobanov et al. 2000; Lee et al. 2008). Here we do not directly apply a lower flux density threshold, as was done e.g. by Lee et al. (2008) who constrained their sample to $S_{86} > 0.3$ Jy. Note however, that the combined *WMAP–Planck* sample of Chen et al. (2013) does have an implicit lower threshold of the flux density (somewhat below 1 Jy) because of the point-source detection limits of the space telescopes.

After applying the four filters above, 49 sources remain from the total of 198 *WMAP–Planck* objects (Chen et al. 2013). Table 2 lists the basic information of these 49 sources: the source names derived from the J2000 and B1950 coordinates, respectively, right ascension (α_{J2000}), declination (δ_{J2000}), spectroscopic redshift (z), and type (BLL means BL Lac, FSRQ abbreviates flat-spectrum radio quasar). The coordinates and the redshifts are taken from the NASA/IPAC Extragalactic Database[1] (NED). The object types are adopted from Chen et al. (2013).

In their recent work, Geréb & Frey (2011) selected 37 compact AGN as potential SVLBI calibrators from the five-year WMAP point source catalogue of Chen & Wright (2009). They used three selection criteria: a total flux density limit of $S_{86} > 1$ Jy, declination above $-40°$, and no previous 86-GHz VLBI observation of the sources. The last two criteria are the same as we applied in (c) and (d), respectively. Among the 37 sources of Geréb & Frey (2011), 14 overlap with our sample. The differences in the sample size and content could arise from the different parent catalogues, and the other selection criteria: the flux density limit used by Geréb & Frey (2011) on the one hand, and the flat radio spectrum required in our paper on the other.

3 Properties of the sample

Except for J0629−1959, all the sources in the sample are prominent optical AGN with measured spectroscopic redshift available in the literature (Table 2). The lowest redshift is 0.049 (for J1517−2422, also known as AP Lib), the highest value is 2.680 (for J0242+1101), the median redshift is 1.0. The histogram of the redshift distribution is shown in Fig. 1 shown as filled bars. The data of the 86-GHz global VLBI imaging survey (Lee et al. 2008) are also displayed with open bars. The comparison indicates that the redshift distribution of the new sources is in good agreement with those already shown to be suitable for 86-GHz VLBI observations. There is a generally decreasing trend with increasing z, as a natural consequence of the flux-density-limited samples. From the largest cosmological distances, only the few most luminous sources enter in the sample. At high redshifts, which also correspond to the era preceding the period of the peak AGN activity in the Universe (at z between ∼0.5 and 2), the number of sources gradually declines.

Our sample contains 7 BL Lacs (14 per cent) and 42 flat-spectrum radio quasars (86 per cent). The percentage of the BL Lacs is consistent with that in the parent *WMAP–Planck* sample (16 per cent, Chen et al. 2013). It is comparable to the 19 per cent found in the 86-GHz VLBI sample of Lee et al. (2008). Interestingly, another large VLBI imaging survey, the MOJAVE 15-GHz sample (Lister et al. 2013) with a total of 183 radio-loud AGN also contains 16 per cent BL Lacs. The ratio of BL Lac objects in the radio-selected blazar samples is an important input for understanding the difference between BL Lacs and FSRQs (e.g. Giommi et al. 2012). Based on the *Planck* flux densities interpolated to the four *WMAP* frequency bands by Chen et al. (2013), we calculated the spectral index α of each source by fitting a power-law continuum using the measured flux densities at 33, 41, 61 and 94 GHz. This parameter was then used to select the flat-spectrum sources with $\alpha \geq -0.5$ as described in Section 2.

Figure 2 shows the distribution of the spectral index in the present sample, compared with others. The maximum spectral index in our sample is $\alpha = 0.13$, the corresponding radio source (J0719+3307) shows a rising spectrum from cm to mm wavelengths. The median spectral index in the sample is -0.22. The spectral indices in the Lee et al. (2008) sample (right panel of Fig. 2) show a broader distribution, while its peak is consistent with that of the present sample, although we filtered out the steep-spectrum sources with selection criterion (a). The objects with steep spectra typically correspond to the radio galaxies in Lee et al. (2008).

Using publicly available[2] calibrated visibility data from earlier VLBI surveys (Table 1), we investigated the compactness of the 49 sources listed in Table 2. We used the highest-frequency data available for a given object, at 8, 15, 24 or 43 GHz. Among the possible methods to assess the compactness, we adopted the one applied by Lee et al. (2008), by calculating the ratio of the core flux density to the total flux density of the CLEAN components obtained during the imaging, $R = S_{\mathrm{core}}/S_{\mathrm{CLEAN}}$. We obtained S_{core} by fitting the brightest core component with a circular Gaussian brightness distribution model in DIFMAP (Shepherd 1997), and S_{CLEAN} by integrating the flux density contained in the visible emission region in the VLBI image. Since the source compactness obviously depends on the observing frequency (e.g. Charlot et al. 2010), and the structures tend to be smaller at higher frequencies, the heterogeneous R values obtained at different frequencies are not directly comparable in our sample. However, for most of the sources, the core dominance was at least 90 per cent (Fig. 3), indicating that the members of the present sample are indeed compact radio-loud AGN. The minimum and median values for R were 0.76 and 0.95, respectively. By visual inspection, the overall

[1] http://ned.ipac.caltech.edu/

[2] http://astrogeo.org

core dominance of the objects in the sample is consistent with the appearance of the sources in the lower-frequency VLBI images, where they all show compact core–jet structures or naked cores, typical for radio-loud core-dominated AGN.

4 Summary and outlook

We selected a complementary sample of 49 bright and compact radio AGN as potential targets for future mm VLBI and SVLBI observations. The sources were drawn form the common *WMAP–Planck* source list compiled by Chen et al. (2013), having flat radio spectrum and declination above $-40°$. The latter criterion ensures their visibility from northern-hemisphere VLBI arrays. The new candidates have never been imaged with ground-based VLBI at the highest observing frequency used for large AGN surveys (86 GHz). Based on their optical identification, continuum spectral properties, and compactness in lower-frequency VLBI surveys, these sources appear promising candidates for successful VLBI detection with ground-based VLBI at 86 GHz or SVLBI at 43 GHz in the future. This study is a part of the efforts to define a target sample for a proposed Chinese SVLBI mission involving two spaceborne radio telescopes, operating at frequencies up to 43 GHz (Hong et al. 2014).

The sample presented in this paper would increase the number of extragalactic objects covered in past 86-GHz VLBI surveys (Rantakyrö et al. 1998; Lobanov et al. 2000; Lee et al. 2008) by nearly 40 per cent. The next immediate step is to perform VLBI fringe detection tests with these objects, and eventually long-baseline imaging observations to confirm their compactness. In the near future, further improvement in selecting new candidates is expected from the use of the final release of the *Planck* catalogue of compact sources which comprises more sources and more accurate flux density measurements. The selection criteria applied in the present paper could be adopted to find additional compact AGN candidates with somewhat lower flux densities.

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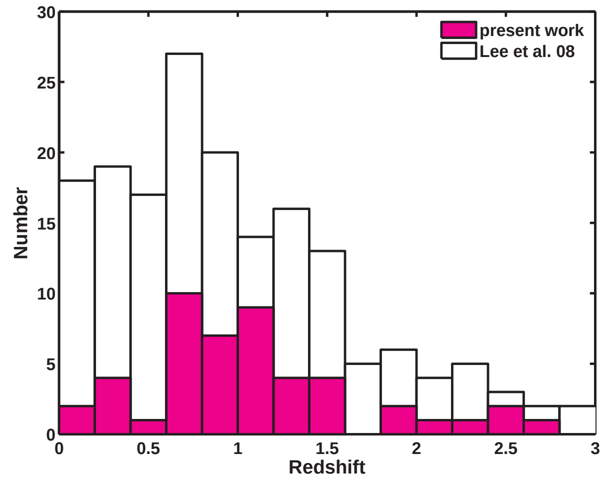

Fig. 1 Histogram of the redshift distribution for the 86-GHz global VLBI imaging survey (Lee et al. 2008, open bars) combined with our present sample of 48 candidate compact sources (filled bars).

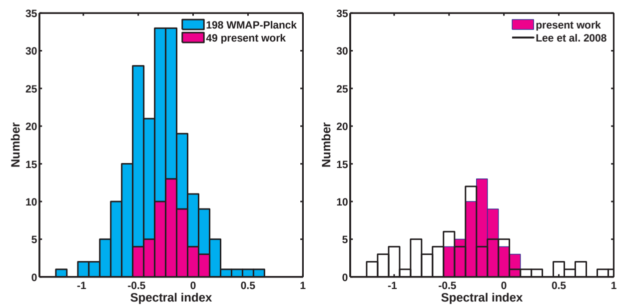

Fig. 2 Plots of the spectral index distribution in our sample of 49 blazars (red) overlapped with the parent *WMAP–Planck* sample (Chen et al. 2013, blue, left panel). The spectral index distribution for the Lee et al. (2008) 86-GHz VLBI sample is also shown as open bars in the right panel, with the data adopted from Geréb & Frey (2011).

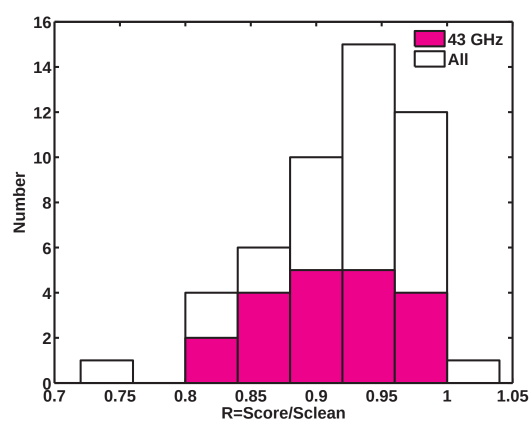

Fig. 3 Histogram of the source compactness parameter $R = S_{\rm core}/S_{\rm CLEAN}$ in our sample. The measurements at 43 GHz are marked with red colour.

Table 2 The catalogue of 49 new candidate compact blazars for mm-SVLBI observations.

No.	Name (J2000)	Name (B1950)	α_{J2000}	δ_{J2000}	z	α	Type
1	J0137−2430	0135−247	01 37 38.3465	−24 30 53.886	0.838	−0.06	FSRQ
2	J0242+1101	0239+108	02 42 29.1709	+11 01 00.728	2.680	−0.25	FSRQ
3	J0406−3826	0405−385	04 06 59.0353	−38 26 28.042	1.285	−0.23	FSRQ
4	J0428−3756	0426−380	04 28 40.4243	−37 56 19.581	1.110	−0.22	BLL
5	J0449+1121	0446+112	04 49 07.6711	+11 21 28.596	1.207	−0.14	FSRQ
6	J0453−2807	0451−282	04 53 14.6468	−28 07 37.327	2.559	−0.18	FSRQ
7	J0457−2324	0454−234	04 57 03.1792	−23 24 52.020	1.003	−0.18	FSRQ
8	J0607−0834	0605−085	06 07 59.6992	−08 34 49.978	0.872	−0.23	FSRQ
9	J0629−1959	0627−199	06 29 23.7619	−19 59 19.724	...	−0.29	BLL
10	J0634−2335	0632−235	06 34 59.0010	−23 35 11.957	1.535	−0.33	FSRQ
11	J0719+3307	0716+332	07 19 19.4197	+33 07 09.709	0.779	0.13	FSRQ
12	J0725−0054	0723−008	07 25 50.6400	−00 54 56.544	0.128	0.01	BLL
13	J0757+0956	0754+100	07 57 06.6429	+09 56 34.852	0.266	0.01	BLL
14	J0808−0751	0805−077	08 08 15.5360	−07 51 09.887	1.837	−0.16	FSRQ
15	J0824+3916	0821+394	08 24 55.4839	+39 16 41.904	1.216	−0.22	FSRQ
16	J0920+4441	0917+449	09 20 58.4585	+44 41 53.985	2.186	−0.32	FSRQ
17	J0921−2618	0919−260	09 21 29.3539	−26 18 43.386	2.300	−0.28	FSRQ
18	J0927+3902	0923+392	09 27 03.0139	+39 02 20.852	0.695	−0.47	FSRQ
19	J0927−2034	0925−203	09 27 51.8243	−20 34 51.233	0.347	0.05	FSRQ
20	J1033+4116	1030+415	10 33 03.7079	+41 16 06.233	1.118	−0.39	FSRQ
21	J1037−2934	1034−293	10 37 16.0797	−29 34 02.813	0.312	−0.03	FSRQ
22	J1056+7011	1053+704	10 56 53.6175	+70 11 45.916	2.492	0.06	FSRQ
23	J1058+0133	1055+018	10 58 29.6052	+01 33 58.824	0.890	−0.30	FSRQ
24	J1127−1857	1124−186	11 27 04.3924	−18 57 17.442	1.050	−0.41	FSRQ
25	J1130−1449	1127−145	11 30 07.0526	−14 49 27.388	1.184	−0.12	FSRQ
26	J1146+3958	1144+402	11 46 58.2979	+39 58 34.304	1.090	−0.38	FSRQ
27	J1337−1257	1334−127	13 37 39.7828	−12 57 24.693	0.539	−0.23	FSRQ
28	J1357+1919	1354+195	13 57 04.4367	+19 19 07.372	0.720	−0.28	FSRQ
29	J1517−2422	1514−241	15 17 41.8131	−24 22 19.476	0.049	−0.17	BLL
30	J1626−2951	1622−297	16 26 06.0208	−29 51 26.971	0.815	−0.07	FSRQ
31	J1637+4717	1636+473	16 37 45.1306	+47 17 33.831	0.740	−0.31	FSRQ
32	J1727+4530	1726+455	17 27 27.6508	+45 30 39.731	0.717	−0.32	FSRQ
33	J1734+3857	1732+389	17 34 20.5785	+38 57 51.443	0.970	−0.13	FSRQ
34	J1751+0939	1749+096	17 51 32.8186	+09 39 00.728	0.322	−0.21	BLL
35	J1801+4404	1800+440	18 01 32.3148	+44 04 21.900	0.663	−0.50	FSRQ
36	J1849+6705	1849+670	18 49 16.0723	+67 05 41.680	0.657	−0.17	FSRQ
37	J1911−2006	1908−201	19 11 09.6529	−20 06 55.109	1.119	−0.12	FSRQ
38	J1923−2104	1920−211	19 23 32.1898	−21 04 33.333	0.874	−0.06	FSRQ
39	J1957−3845	1954−388	19 57 59.8193	−38 45 06.356	0.630	−0.50	FSRQ
40	J2000−1748	1958−179	20 00 57.0904	−17 48 57.673	0.650	−0.30	FSRQ
41	J2006+6424	2005+642	20 06 17.6946	+64 24 45.418	1.574	−0.44	FSRQ
42	J2031+1219	2029+121	20 31 54.9943	+12 19 41.340	1.215	−0.33	BLL
43	J2101−2933	2058−297	21 01 01.6600	−29 33 27.836	1.492	−0.06	FSRQ
44	J2148+0657	2145+067	21 48 05.4587	+06 57 38.604	0.990	−0.45	FSRQ
45	J2203+1725	2201+171	22 03 26.8937	+17 25 48.248	1.075	−0.08	FSRQ
46	J2229−0832	2227−088	22 29 40.0843	−08 32 54.436	1.560	−0.04	FSRQ
47	J2232+1143	2230+114	22 32 36.4089	+11 43 50.904	1.037	−0.35	FSRQ
48	J2246−1206	2243−123	22 46 18.2320	−12 06 51.278	0.632	−0.23	FSRQ
49	J2311+3425	2308+341	23 11 05.3288	+34 25 10.906	1.817	−0.17	FSRQ

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