

## THE FIFTH VLBA CALIBRATOR SURVEY: VCS5

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### ABSTRACT

This paper presents the fifth part of the Very Long Baseline Array (VLBA) Calibrator Survey (VCS), containing 569 sources not observed previously with very long baseline interferometry in geodetic or absolute astrometry programs. This campaign has two goals: (1) to observe additional sources that, together with previous survey results, form a complete sample, and (2) to find new strong sources suitable as phase calibrators. This VCS extension was based on three 24 hr VLBA observing sessions in 2005. It detected almost all extragalactic flat-spectrum sources with correlated flux density greater than 200 mJy at 8.6 GHz above declination  $-30^\circ$  that were not observed previously. Source positions with milliarcsecond accuracy were derived from astrometric analysis of ionosphere-free combinations of group delays determined from the 2.3 and 8.6 GHz frequency bands. The VCS5 catalog of source positions, plots of correlated flux density versus projected baseline length, contour plots, and FITS files of naturally weighted CLEAN images, as well as calibrated visibility function files, are available on the World Wide Web.

*Key words:* astrometry — catalogs — surveys

*Online material:* machine-readable tables

### 1. INTRODUCTION

This work is a continuation of the survey search for bright compact radio sources. Several major applications require an extended list of sources with positions known at the nanoradian level: geodetic observations, including space navigation; very long baseline interferometry (VLBI) phase referencing of weak targets; and differential astrometry. For satisfying the needs of these applications, 878 sources were observed under various geodetic and astrometric programs from 1979 through 2002, and over 80% of them were detected. Results of these observations were presented in the International Celestial Reference Frame extension 2 (ICRF-Ext. 2; Fey et al. 2004), which contains the positions of 776 sources. In addition, 2952 flat-spectrum sources were observed in nineteen 24 hr sessions from 1994 through 2005 in the Very Long Baseline Array (VLBA) Calibrator Survey (VCS) program. The positions of 2505 sources were determined from the observations of the VCS project: VCS1 (Beasley et al. 2002), VCS2 (Fomalont et al. 2003), VCS3 (Petrov et al. 2005), and VCS4 (Petrov et al. 2006). Since 364 sources are listed in both the ICRF-Ext. 2 and the VCS catalogs, the total number of sources for which positions were determined with VLBI in the International VLBI Service for Astrometry and Geodesy (IVS) and VCS1–VCS4 experiments is 2917. Among them, 2468 sources, or 85%, are considered acceptable calibrators, having at least eight successful observations at both the X band (central fre-

quency 8.6 GHz) and the S band (central frequency 2.3 GHz), and the semimajor axis of the error ellipse of their coordinates being less than 25 nrad ( $\approx 5$  mas). When observations from both the geodetic programs and VCS1–VCS4 are combined, the overall catalog provides fairly good sky coverage. The probability of finding a calibrator within  $4^\circ$  of any target north of declination  $-40^\circ$  is 98.1%.

In this paper we present an extension to the VCS catalogs, called the VCS5 catalog. It concentrates on the brightest flat-spectrum sources north of declination  $-30^\circ$  not previously observed with VLBI under geodetic and absolute astrometry programs. VCS5 is different from the previous campaigns, since its prime goal is to collect data needed for astrophysical analysis of active galactic nuclei (AGNs; see § 2).

Since the observations, calibration, astrometric solutions, and imaging are similar to those of VCS1–VCS4, most of the details are described by Beasley et al. (2002) and Petrov et al. (2005) and are not repeated here. In § 2 we discuss the scientific objectives for the VCS5. In § 3 we describe the strategy for selecting the 675 candidate sources observed in three 24 hr VCS5 sessions with the VLBA based on analysis of the available multifrequency non-VLBI continuum radio measurements. The same strategy was successfully applied by us earlier to select 100 objects with the strongest estimated flux density at 8.6 GHz in the framework of the VCS4 survey. Sixty-seven of these 100 VCS4 candidates showed X-band-correlated flux density greater than 0.2 Jy (Petrov et al. 2006). In § 4 we briefly outline the observations and data processing. We present the VCS5 catalog in § 5, and we summarize our results in § 6.

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## 2. SCIENTIFIC OBJECTIVES FOR THE VCS5

There are two main scientific objectives for the VCS5. We would like to perform a statistical analysis of the physical properties of a deep sample of compact AGNs on the basis of milliarcsecond-scale images measured simultaneously at the S band and X band with the VLBA. A cursory analysis of the sample of the 2917 VCS/ICRF sources observed with the VLBA in the S/X mode revealed that it is nearly complete down to 0.5 Jy but becomes incomplete at lower flux densities. As a result, possible usage of this largest collection of VLBI data for statistical analysis of the properties of AGNs at milliarcsecond scales is limited. The first goal of the current VCS5 project is to observe the remaining bright sources with expected correlated flux densities in the range 200–600 mJy to create a statistically complete sample of extragalactic flat-spectrum radio sources with integrated flux density at milliarcsecond scales greater than 200 mJy at the X band. This will make the results of the VCS significantly more useful for astrophysical applications. The uniformity of VCS data reduction, as well as the completeness and homogeneity of the source sample, will guarantee robust results from further statistical studies.

The second goal is to find more compact sources and to precisely measure their positions for use in geodetic applications, including space navigation, VLBI phase referencing of weak targets, and differential astrometry. Many applications prefer a more distant, bright calibrator to a nearby but weaker calibrator, since more time can be spent on the target. The VCS5 observations cover almost all the remaining *bright* calibrators with correlated flux density at or greater than 200 mJy.

## 3. SOURCE SELECTION

Our source selection goal was to find all flat-spectrum radio sources brighter than 0.2 Jy at 8.6 GHz that were missing from the VCS1–VCS4 and ICRF-Ext. 2 catalogs. We define a “flat radio spectrum” as having a spectral index  $\alpha > -0.5$  ( $S \sim \nu^\alpha$ ). To compile a list of missing objects, we first selected all the sources from the NRAO VLA Sky Survey (NVSS) catalog (Condon et al. 1998) with a flux density at 1.4 GHz of  $S > 50$  mJy, a declination  $\delta > -30^\circ$ , and a Galactic latitude  $|b| > 1.5^\circ$  and that were not identified with Galactic objects. Since the NVSS catalog is more than 99% complete for flux density  $S > 50$  mJy, it is unlikely that sources with highly inverted spectra and flux density  $S > 200$  mJy at 8.6 GHz have been missed.

We then searched the CATS database (Verkhodanov et al. 1997) containing almost all radio catalogs to find flux density measurements at other radio frequencies for the selected NVSS sources. These data were supplemented by the results of the 1–22 GHz instantaneous broadband spectra measurements of  $\sim 3000$  extragalactic flat-spectrum radio sources, which we performed in transit mode with the 600 m ring radio telescope RATAN-600 of the Russian Academy of Sciences (see, e.g., Kovalev et al. 1999). The collected data were then analyzed semiautomatically, and bad data points, wrong identifications, and multiple data points corresponding to different components of the same extended object were flagged. We found that we could compile a complete sample of sources with a total flux density spectrum flatter than  $\alpha = -0.5$  and with an estimated total flux density of  $S > 170$  mJy at 8.6 GHz. In this complete sample there were 675 candidates not previously observed in geodetic VLBI mode, and these were the sources selected for VCS5 observations. Figure 1 presents examples of plots of the total flux density spectra collected by the CATS database that we used for source selection.

Our analysis of the multifrequency catalogs and RATAN observations used for selection indicates that we have found

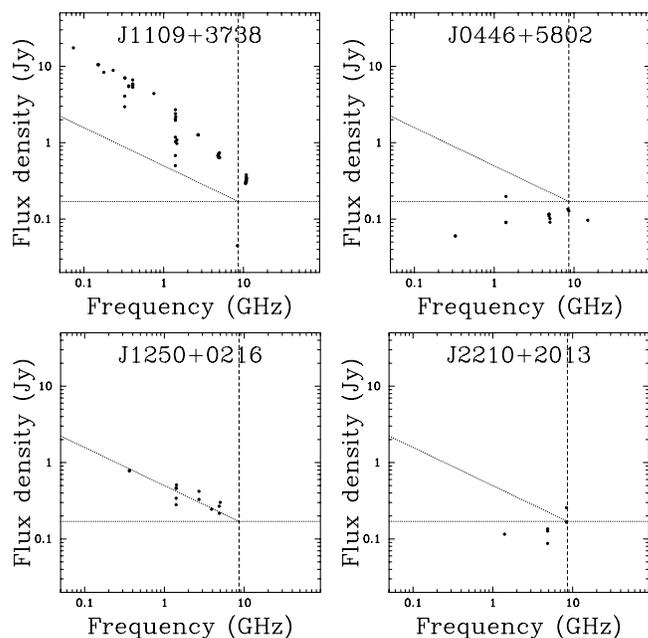


FIG. 1.—Illustration of the candidate selection procedure. The data from all available publications were located through the CATS database. The diagonal dotted lines represent  $\alpha = -0.5$ . Object J1109+3738 was not selected, since its integrated spectral index was less than  $-0.5$ . Object J0446+5802 was not selected, since its flux density extrapolated to 8.6 GHz was less than 170 mJy. Objects J1250+0216 and J2210+2013 satisfied all the selection criteria mentioned in § 3 and were selected. Their  $u-v$  and image data are presented in Fig. 3.

almost all of the sources with a spectral index greater than  $-0.5$  and an estimated total flux density at 8.6 GHz of  $S > 170$  mJy. It is based on the fact that many of the catalogs used, including NVSS (Condon et al. 1998), FIRST (White et al. 1997), 87GB (Gregory & Condon 1991), GB6 (Gregory et al. 1996), CLASS (Myers et al. 2003), JVAS (Patnaik et al. 1992; Browne et al. 1998; Wilkinson et al. 1998), PMN (Wright et al. 1994, 1996; Griffith et al. 1995), and PKSCAT90 (Wright & Otrupcek 1990), are complete down to 150–250 mJy and below. This should provide us with a sample of the same completeness characteristics. However, it is well known that flat-spectrum sources are variable (e.g., Kellermann & Pauliny-Toth 1968); consequently, at some level the variability corrupts our estimations of spectral index and total flux density. The membership of a source in the completeness sample is also changeable and depends on the observation epochs of the various compilation surveys. The quantitative analysis of completeness of the resulting correlated flux-density-limited sample of the sources from the combined ICRF-Ext. 2 and VCS1–VCS5 catalogs has to take into account the frequency-dependent variability properties (e.g., Kovalev et al. 2002), as well as the compactness characteristics of flat-spectrum sources (e.g., Popov & Kovalev 1999; Kovalev et al. 2005). This is beyond the scope of this paper and is deferred to another publication. We expect the present sample to be sufficiently complete, robust, and unbiased for most statistical studies of flat-spectrum radio sources.

## 4. OBSERVATIONS AND DATA PROCESSING

The VCS5 observations were carried out in three 24 hr observing sessions with the VLBA on 2005 July 8, 9, and 20. Each of the 675 target sources was observed in two scans of 120 s each. The target sources were observed in a sequence designed to minimize loss of time from antenna slewing. In addition to these objects, 97 strong sources were taken from the Goddard Space

Flight Center astrometric catalog 2004f\_astro.<sup>3</sup> Observations of three or four strong sources from this list were made every 1–1.5 hr, 70–80 s per scan. These observations were scheduled in such a way that at each VLBA station at least one of these sources was observed at an elevation angle less than 20° and at least one at an elevation angle greater than 50°. The purpose of these observations was to provide calibration for mismodeled atmospheric path delays and to tie the VCS5 source positions to the ICRF catalog (Ma et al. 1998). The list of tropospheric calibrators<sup>4</sup> was selected from the sources that, according to the 2 cm VLBA survey results (Kovalev et al. 2005), showed the greatest compactness index, i.e., the ratio of the correlated flux density measured at long VLBA spacings to the flux density integrated over the VLBA image. In total, 772 targets and calibrators were observed. The antennas were on-source about 65% of the time.

Similar to the previous VCS observing campaigns (e.g., Petrov et al. 2006), we used the VLBA dual-frequency geodetic mode, observing simultaneously at the S band and X band. Each band was separated into four 8 MHz channels (IFs) that spanned 140 MHz around 2.3 GHz and 490 MHz around 8.6 GHz to provide precise measurements of group delays for astrometric processing. Since the a priori coordinates of the candidates were expected to have errors of up to 30'', the data were correlated with an accumulation period of 1 s in 64 spectral channels in order to provide an extra-wide window for a fringe search.

Processing of the VLBA correlator output was done in three steps. In the first step the data were calibrated using the Astronomical Image Processing System (AIPS) (Greisen 2003). In the second step the data were imported to the Caltech DIFMAP package (Shepherd 1997), *u-v* data were flagged, and maps were produced using an automated procedure of hybrid imaging developed by G. Taylor (Pearson et al. 1994), which we adapted for our needs. We were able to reach the VLBA image thermal noise level for most of our CLEAN images (Wrobel & Ulvestad 2006). Errors on our estimates of correlated flux density values for sources stronger than ~100 mJy were dominated by the accuracy of amplitude calibration, which for the VLBA, according to Wrobel & Ulvestad (2006), is at the level of 5% at 1–10 GHz. An additional error is introduced by the fact that our frequency channels are widely spread over the receiver bands, while the VLBA S-band and X-band gain-curve parameters are measured around 2275 GHz and 8425 MHz, respectively (Wrobel & Ulvestad 2006), and the noise diode spectrum is not ideally flat. However, this should not add more than a few percent to the total resulting error. Our error estimate was confirmed by comparison of the flux densities integrated over the VLBA images with the single-dish flux densities we measured with RATAN-600 in 2005 June and August for slowly varying sources without extended structure. The methods of the single-dish observations and data processing can be found in Kovalev et al. (1999). In the third step the data were imported to the Calc/Solve program, group-delay ambiguities were resolved, outliers were eliminated, and the coordinates of new sources were adjusted using ionosphere-free combinations of X-band and S-band group-delay observables of the three VCS5 sessions, 19 VCS1–VCS4 experiments, and 3976 24 hr IVS experiments<sup>5</sup> in a single least-squares solution. The positions of 3486 sources were estimated, including all the detected VCS5 sources: 590 targets and 97 tropospheric calibrators. Boundary conditions were imposed requiring zero net

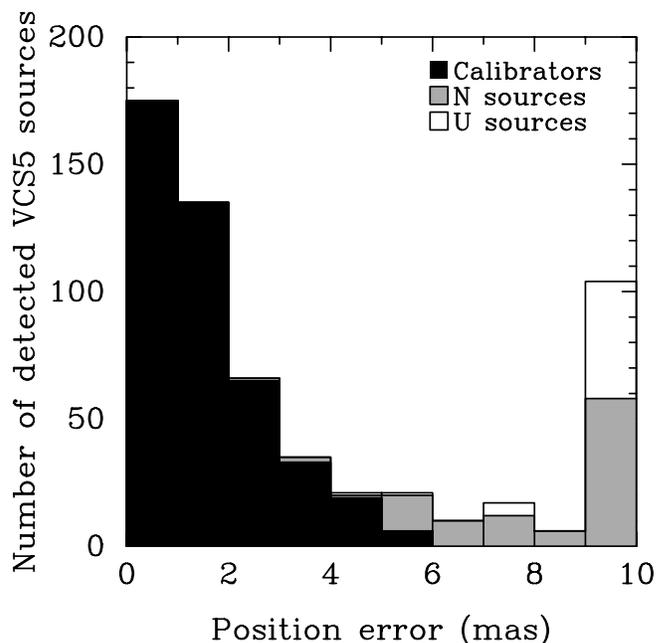


FIG. 2.—Histogram of semimajor error ellipse of position errors. The last bin shows errors exceeding 9 mas. See the explanation of the different assigned source classes in §§ 4 and 5.

rotation of position adjustments of the 212 sources listed as defining sources in the ICRF catalog with respect to their coordinates from that catalog.

In a separate solution, the coordinates of the 97 well-known tropospheric calibrators were estimated from the VCS5 observing sessions only. Comparison of these estimates with coordinates derived from the 3976 IVS geodetic/astrometric sessions provided us a measure of the accuracy of the coordinates from the VCS5 observing campaign. The differences in coordinate estimates were used for computation of parameters  $a$  and  $b(\delta)$  of an error inflation model in the form  $[(a\sigma)^2 + b(\delta)^2]^{1/2}$ , where  $\delta$  is declination and  $\sigma$  is an uncertainty derived from the fringe amplitude signal-to-noise ratio using the error propagation law. More details about the analysis and imaging procedures can be found in Beasley et al. (2002) and Petrov et al. (2005). The histogram of source position errors is presented in Figure 2.

In total, 590 out of 675 sources were detected and yielded at least two good points for position determination. This 87% detection rate confirms the validity of the applied candidate selection procedure (§ 3). It should be noted that, due to an omission, the list of target sources contained 21 objects previously observed and detected in the VCS4 campaign.

However, not all of these 590 sources are suitable as phase-reference calibrators or as targets for geodetic observations. Following Petrov et al. (2005) we consider a source suitable as a calibrator if (1) the number of good X/S pairs of observations is eight or greater in order to rule out the possibility of a group-delay ambiguity resolution error, and (2) the position error before reweighting is less than 5 mas following the strategy adopted in processing VCS observations. Only 433 sources satisfy this calibrator criteria. Other detected sources were somewhat resolved and/or below the detection limit of these observations of 60 mJy. Some of these may become suitable phase calibrators for future experiments with higher data rates and more sensitivity than the VCSs. Among the 157 noncalibrators, 53 sources had less than eight observations at the X band and less than eight observations at the S band. We consider the positions of these sources to be

<sup>3</sup> Available at <http://vlbi.gsfc.nasa.gov/solutions/astro>.

<sup>4</sup> Available at [http://vlbi.gsfc.nasa.gov/vcs/tropo\\_cal.html](http://vlbi.gsfc.nasa.gov/vcs/tropo_cal.html).

<sup>5</sup> See <http://vlbi.gsfc.nasa.gov/solutions/2005c>.

TABLE 1  
THE VCS5 CATALOG

CLASS (1)	SOURCE NAME		R.A. (J2000.0) (4)	DECL. (J2000.0) (5)	ERRORS (mas)		CORR. (8)	NO. OF OBS. (9)	CORRELATED FLUX DENSITY (Jy)				BAND (14)
	IVS (2)	IAU (3)			$\Delta\alpha$ (6)	$\Delta\delta$ (7)			8.6 GHz		2.3 GHz		
									Total (10)	Unres. (11)	Total (12)	Unres. (13)	
C.....	0008+006	J0011+0057	00 11 30.403309	+00 57 51.87984	1.02	2.00	0.114	25	0.09	0.07	...	...	X
C.....	0009+467	J0012+4704	00 12 29.302900	+47 04 34.73946	0.77	1.08	-0.371	35	0.13	0.12	0.10	<0.06	X/S
N.....	0013-240	J0016-2343	00 16 05.738818	-23 43 52.18956	30.58	16.85	-0.808	17	...	...	0.15	0.08	S
C.....	0015-054	J0017-0512	00 17 35.817204	-05 12 41.76727	0.46	0.92	-0.278	54	0.20	0.12	0.14	0.09	X/S
C.....	0015-280	J0017-2748	00 17 59.006128	-27 48 21.57153	1.75	3.51	0.712	32	0.24	0.16	0.20	0.06	X/S
C.....	0034+078	J0037+0808	00 37 32.197173	+08 08 13.05750	0.38	0.50	-0.225	76	0.25	0.14	0.19	0.10	X/S
C.....	0035-037	J0038-0329	00 38 20.794340	-03 29 58.96178	0.32	0.63	-0.347	77	0.20	0.16	0.31	0.21	X/S
N.....	0036-191	J0039-1854	00 39 16.924431	-18 54 05.61863	4.97	9.83	0.749	8	0.12	...	0.18	0.10	X/S
C.....	0037+011	J0040+0125	00 40 13.525489	+01 25 46.35014	0.99	1.94	-0.124	29	0.11	<0.06	<0.06	...	X
C.....	0041+677	J0044+6803	00 44 50.759589	+68 03 02.68607	0.91	0.58	-0.130	59	0.28	0.22	0.14	<0.06	X/S

NOTES.—Assigned source classes in col. (1): C, calibrator; N, noncalibrator with reliable coordinates; U, noncalibrator with unreliable coordinates; see §§ 4 and 5 for details. Units of right ascension are hours, minutes and seconds; units of declination are degrees, minutes and seconds. Table 1 is published in its entirety in the electronic edition of the *Astronomical Journal*. A portion is shown here for guidance regarding its form and content.

unreliable, because we cannot rule out errors in group-delay ambiguity resolution. The other 104 sources had eight or more observations at one of the bands, so we can rule out the possibility of group-delay ambiguity resolution errors, and therefore, we consider our estimates of the positions of these sources to be reliable.

## 5. THE VCS5 CATALOG

The VCS5 catalog of 590 detected target sources is listed in Table 1. Column (1) gives the source class: “C” if the source can be used as a calibrator, “N” if it cannot but its determined positions are reliable, and “U” if the source is a noncalibrator with unreliable positions. Columns (2) and (3) give the IVS source name (B1950.0 notation) and IAU name (J2000.0 notation). Columns (4) and (5) give the measured source coordinates at the J2000.0 epoch. Columns (6) and (7) give the inflated source position uncertainties in right ascension (without the  $\cos \delta$  factor) and declination in milliarcseconds, and column (8) gives the cor-

relation coefficient between the errors in right ascension and declination. The number of group delays used for the position determination is listed in column (9). Columns (10) and (12) give the estimate of the flux density integrated over the entire map in janskys at the X band and S band, respectively. This estimate was computed as a sum of all CLEAN components if a CLEAN image was produced. If we did not have enough detections of the visibility function to produce a reliable image, the integrated flux density was estimated as the median of the correlated flux density measured at projected spacings less than 25 and 7  $M\lambda$  for the X and S bands, respectively. The integrated flux density means the total flux density with spatial frequencies less than 4  $M\lambda$  at the X band and 1  $M\lambda$  at the S band filtered out, or, in other words, the flux density from all the components within a region about or less than 50 mas at the X band and 200 mas at the S band. Columns (11) and (13) give the flux density of the unresolved components estimated as the median of the correlated flux density values measured at projected spacings greater than 170  $M\lambda$  for the X band and greater than 45  $M\lambda$  for the S band. For some sources no estimates of the integrated and/or unresolved flux density are presented, because either no data were collected on the baselines used in the calculations or these data were unreliable. Column (14) gives the data type used for position estimation: X/S stands for ionosphere-free linear combination of X and S wide-band group delays, X stands for X-band-only group delays, and S stands for S-band-only group delays. Some sources for which less than eight pairs of X-band and S-band group-delay observables were available had two or more observations at the X band and/or S band. For these sources either X-band- or S-band-only estimates of the coordinates are listed in the VCS5 catalog.

In addition to Table 1, the HTML version of the catalog is posted on the World Wide Web.<sup>6</sup> For each source there are eight links: to a pair of postscript images of the source at the X band and S band, to a pair of plots of correlated flux density as a function of baseline length projected to the source plane, to a pair of FITS files of CLEAN components of naturally weighted source images, and to a pair of FITS files with calibrated  $u-v$  data. This data set is also accessible from the NRAO archive,<sup>7</sup> which links

TABLE 2

SOURCES NOT DETECTED IN VCS5 VLBA OBSERVATIONS

SOURCE NAME			
IVS	IAU	R.A. (J2000.0)	DECL. (J2000.0)
0032-011	J0034-0054	00 34 43.93	-00 54 13.0
0039+211	J0041+2123	00 41 45.10	+21 23 41.1
0104+650	J0107+6521	01 07 51.35	+65 21 20.5
0137-273	J0139-2705	01 39 55.42	-27 05 29.4
0212-214	J0214-2113	02 14 40.73	-21 13 28.2
0258+356	J0301+3551	03 01 47.96	+35 51 24.5
0426+351	J0430+3516	04 30 14.41	+35 16 23.1
0434-225	J0436-2226	04 36 34.31	-22 26 18.6
0506-196	J0508-1935	05 08 19.03	-19 35 56.4
0512-129	J0515-1255	05 15 17.51	-12 55 27.8

NOTES.—The 85 sources presented in this table include the gravitational lens 1422+231, which was detected but not processed in VCS5. The J2000.0 source positions are taken from the NVSS (Condon et al. 1998); they were used for VCS5 VLBA observing and correlation. Units of right ascension are hours, minutes and seconds; units of declination are degrees, minutes and seconds. Table 2 is published in its entirety in the electronic edition of the *Astronomical Journal*. A portion is shown here for guidance regarding its form and content.

<sup>6</sup> See <http://vlbi.gsfc.nasa.gov/vcs5>.

<sup>7</sup> Available at <http://archive.nrao.edu>.

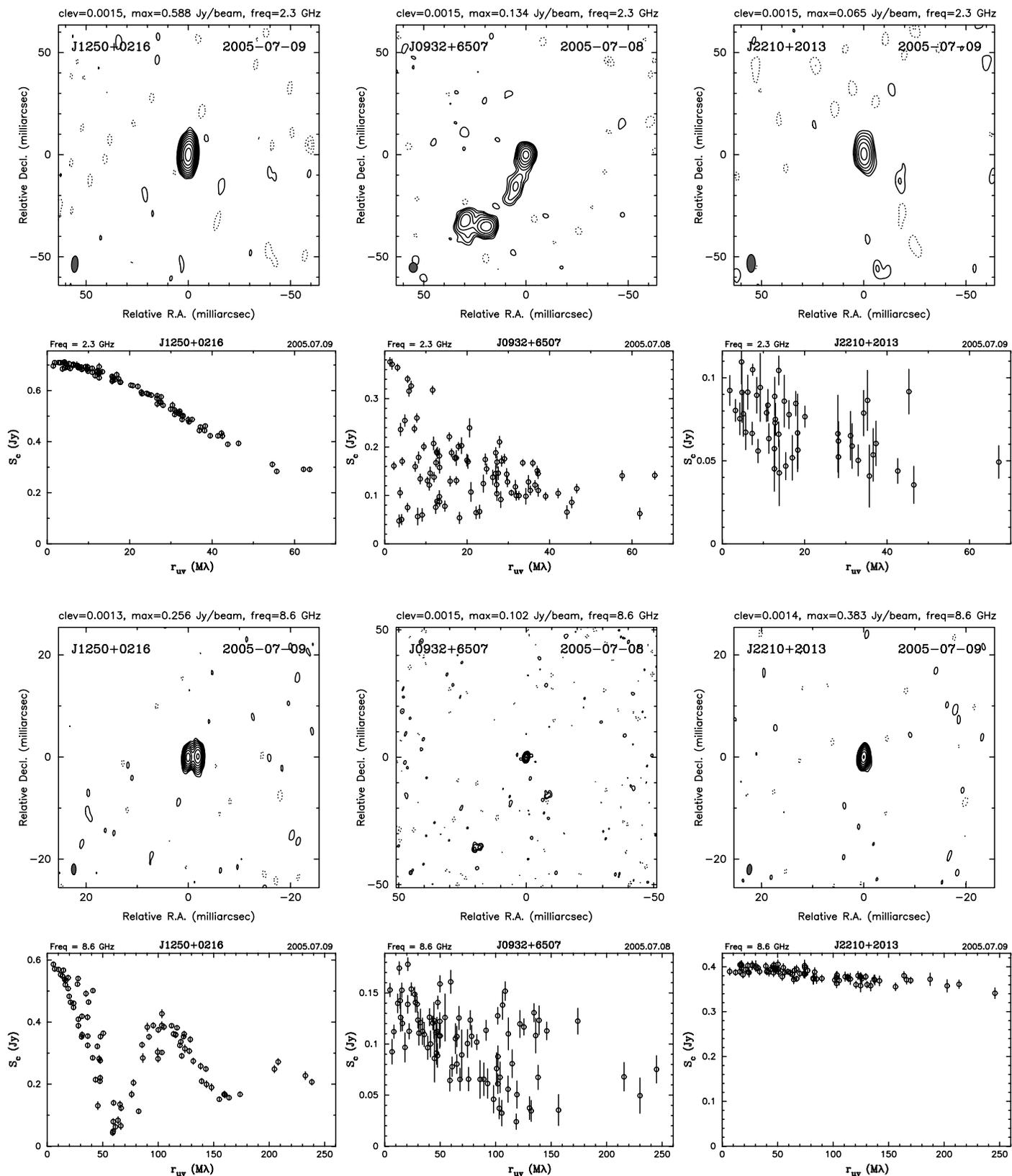


FIG. 3.—*Top row:* Naturally weighted CLEAN images at the S band (2.3 GHz). The lowest contour is plotted at the level given by “clev” in each panel title ( $\text{Jy beam}^{-1}$ ), and the peak brightness is given by “max” ( $\text{Jy beam}^{-1}$ ). The contour levels increase by factors of 2. The dashed contours indicate negative flux. The beam is shown in the bottom left corner of each panel. *Second row:* Dependence of the correlated flux density at the S band on projected spacing. Each symbol represents a coherent average over one 2 minute observation on an individual interferometer baseline. The error bars represent only the statistical errors. *Third row:* Naturally weighted CLEAN images at the X band (8.6 GHz). *Bottom row:* Dependence of the correlated flux density at the X band on projected spacing.

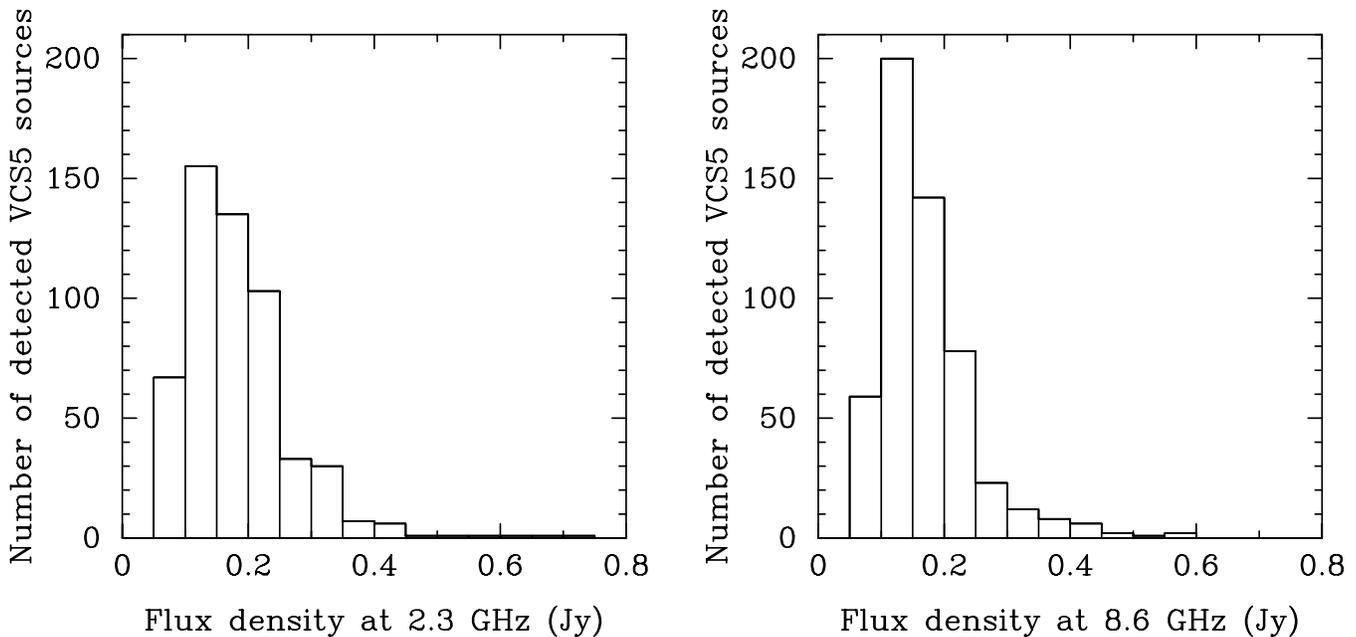


Fig. 4.—Distributions of flux density integrated over VLBA images for all detected VCS5 sources (cols. [10] and [12] of Table 1).

the files to the Virtual Observatory. The positions and the plots are also accessible from the updated NRAO VLBA Calibrator Search Web site.<sup>8</sup>

Table 2 presents 85 sources not detected in VCS5 VLBA observations. Source positions used for observations and correlation are presented. They are taken from Condon et al. (1998). The correlated flux density for the nondetected sources is estimated to be less than 60 mJy at 2.3 and 8.6 GHz.

Figure 3 presents examples of naturally weighted contour CLEAN images, as well as correlated flux density versus projected spacing dependence for three sources: the strongest VCS5 source at the X band, J1250+0216, with two bright components resolved at the X band and not resolved at the S band; a steep spectrum source with extended structure, J0932+6507; and the source with the most inverted spectrum and very compact structure at the milliarcsecond scale, J2210+2013.

<sup>8</sup> See <http://www.vlba.nrao.edu/astro/calib>.

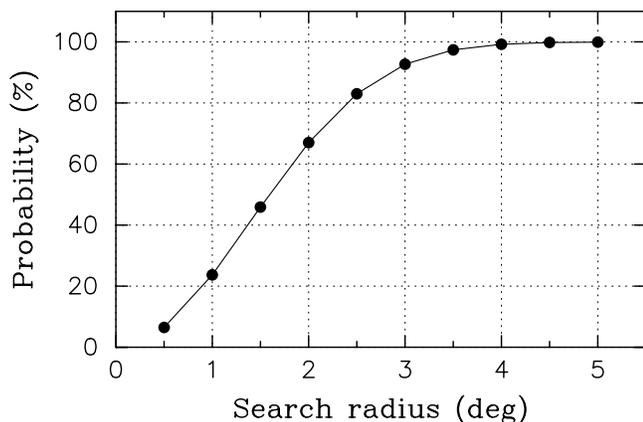


Fig. 5.—Probability (circles) of finding a calibrator in any given direction within a circle of a given radius north of declination  $-30^\circ$ . All sources from 3976 IVS geodetic/astrometric sessions and 22 VCS1–VCS5 VLBA sessions that are classified as calibrators are taken into account.

Figure 4 presents histograms of the 2.3 and 8.6 GHz integrated flux density for 590 detected VCS5 sources, 132 of which have integrated flux density  $S \geq 200$  mJy at 8.6 GHz. Their addition to the previously observed sources forms the statistically complete sample north of declination  $-30^\circ$ . It is interesting to note that many of the discovered VCS5 sources have inverted radio spectra. The 50 mJy cutoff for the original selection of sources from the NVSS catalog allowed us to add inverted-spectrum objects to the list of candidates. A few tens of new compact VCS5 objects with high flux density on VLBA baselines will be useful for geodetic applications.

The sky calibrator density for different radii of a search circle for declination  $\delta > -30^\circ$  is presented in Figure 5. As discussed in Petrov et al. (2006), the addition of these sources to the VCS list does not significantly affect the density for the search radius of  $4^\circ$  but increases it for smaller search circles; e.g., the probability of finding a calibrator within  $2.5^\circ$  is now 83%. This is beneficial for many applications requiring a bright compact calibrator within  $2^\circ$ – $3^\circ$  of a target.

## 6. SUMMARY

The VCS5 has made a significant step toward constructing a homogeneous, statistically complete sample of flat-spectrum compact extragalactic radio sources north of declination  $-30^\circ$  with integrated VLBA flux density greater than about 200 mJy at 8 GHz. The VCS5 has added 569 new sources not previously observed with VLBI under geodesy and absolute astrometry programs. Among them, 433 sources are suitable as phase-referencing calibrators and as target sources for geodetic applications. After processing the VCS5 experiments, the total number of sources with positions known at the nanoradian level is 3486, and the number of VLBI calibrators has grown from 2472 to 2905. This pool of calibrators was formed from the analysis of 22 VCS and 3976 24 hr IVS astrometry and geodesy observing sessions.

In this paper we do not yet provide quantitative estimates of the completeness of our list of compact flat-spectrum sources. In order to get these estimates we will (1) complete the homogeneous imaging of all 3486 sources and get estimates of their integrated flux densities at milliarcsecond scales in the X band and S band;

(2) complete processing of instantaneous single-dish multifrequency, multiepoch flux density measurements with RATAN-600 for this sample; and (3) observe with the VLBA a total-flux-density-limited sample of all sources regardless of their spectral index over a relatively large portion of the sky, complemented with simultaneous multifrequency single-dish measurements. The latter will allow us to assess whether conclusions drawn from the VLBI flat-spectrum source samples can be extended to the whole population of extragalactic objects regardless of their continuum spectrum characteristics.

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