VLBA Calibrator Survey 9 (VCS–9)

© L. Petrov

Astrogeo Center, USA

The goals, current status, and preliminary results of the VLBA Calibration Survey VCS–9 are discussed.

Keywords: VLBI, Astrometry.

1 Motivation

Nowadays, more than 2/3 of VLBA observations are made in a phase-referencing mode. Planning such observations is facilitated tremendously owing to the existence of the phase calibrator list that is taken from the Radio Fundamental Catalogue (RFC)*. Despite the fact that the total number of VLBI astrometric sources by 2016.10.01 reached 11.444 objects, it is not uncommon to hear a complaint that "there is no good calibrator just near my target field". For reliable phase-referencing, a calibrator should be close to the target, preferably within 1–2°. Since known calibrators are distributed unevenly over the sky, there are still areas where their density is not sufficient.

Table 1

The probability to find a known compact radio source with positions known at mas level within a disk of the specified radius in any at $\delta > -30^\circ$. Sources from category "astr" have position accuracy better than 5 mas. Sources from category "cal" have position accuracy better 5 mas and correlated flux density brighter 25 mJy at baselines longer 3000 km. The table is valid for 2015.01.01

dist	all, %	astr, %	cal, %
1.0°	51.5	49.4	39.9
1.5°	79.7	77.8	67.8
2.0°	93.8	92.8	86.3

To overcome this problem, a VLBA project of further densification of the calibrator list for the area with $\delta > -40^\circ$ was launched. The first original goal of the project was to extend the spacial coverage of VLBI astrometric catalogue to that level that any field of view of Pan-STARRS (disk of 1.5° radius) and/or LSST (disk of 1.75° radius) will be guaranteed to have at least one VLBI calibrator. This would

*Available at http://astrogeo.org/rfc

allow to improve position accuracy of these catalogues. With a release of Gaia catalogue of 1.14 billion stars with a median position accuracy of 2.3 mas this objective became irrelevant. However, a new goal emerged with the release of Gaia catalogue: extending the list of Gaia/radio counterparts and a search for sources with statistically significant radio/optic offsets.

The second goal of the survey is to study the population of steep spectrum sources. Traditionally, flat-spectrum sources were scheduled for VLBI surveys. The pool of known flat spectrum sources brighter 50 mJy at 4.8 GHz (single dish) at $\delta > -30°$ without prior VLBI observations had only 2284 objects at the beginning of the project and has already been depleted. Remaining sources either have spectrum steeper than -0.5 ($S \sim f^{+\alpha}$) or have unknown spectrum. The population of steep spectrum sources is poorly studied due to a heavy selection bias in the past.

2 Observations

The observing campaign started on 2015.08.07. The target list is combined from three sets:

— all the sources from GB6 [2] and PMN [3] catalogues at $\delta > -40°$ brighter 70 mJy at 4.85 GHz, except those observed in prior surveys, known planetary nebulae and HII regions within $40''$;

— all the sources from the NVSS catalogue [1] at $\delta > -40°$ and $|b| > 5°$ brighter 200 mJy, except those observed in prior surveys and present in the first list;

— ~ 400 peculiar sources: objects with large position offsets between radio and preliminary version of Pan-STARRS catalogues, candidates for association with *Fermi*, known sources with poor position accuracy, etc.

Observations are scheduled in one scan of 60 s long at remote wings of the C-band receiver: at [4.128, 4.608] and [7.392, 7.872] MHz simultaneously, single polarization, 2 bit sampling, aggregate bit rate 2 Gbps. The campaign was scheduled totally automatically: the array operator 1–40 hours in advance selects the start and stop dates of a segment and using Web interface executes a remote program that generates key-file with the schedule. The scheduling software assigns a score for every target source that is visible in accordance with slewing time and its priority. A source with the highest score is scheduled. The priorities are assigned to increase chances of being observed for sources that are in the area of a low VLBI calibrator density, or just bright.

In addition to target objects, every hour 4 sources from a pool of known bright and compact objects are observed. These sources are selected in such a way that every station has two observations at elevations $[15°, 35°]$ and two observations at elevations $[45°, 90°]$. The VCS9 observing campaign ran in the so-called "fill-in" mode: segments from 3.5 to 10 hours long are scheduled when other high priority VLBA programs could not observe due to bad weather or failures of 1 or 2 stations. Unlike to traditional observing campaigns where the principal investigator determines which sources will be observed, only statistical criteria are specified for

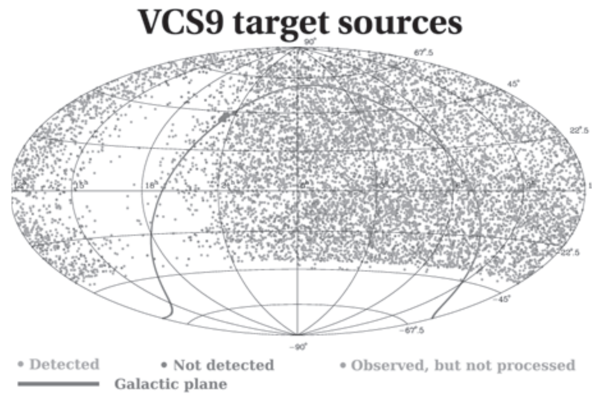

Fig. 1. The distribution of observed target sources

scheduling campaigns in the fill-in mode. These criteria, alongside with availability of time slots at given ranges of local siderial time determine the probability of that a given source will be observed.

3 Preliminary results

The data were correlated with the DiFX correlator with spectral resolution 62.5 KHz and accumulation period length 100 ms. This correlator setup allowed us to search for fringes in a very wide window limited mainly by the primary beam. The detection limit drops a factor of 2 at $3'$ at 7.6 GHz and at $5'$ at 4.4 GHz. This setup generates 100 Gb visibilities per 1 hour observing time, which is a substantial amount but still manageable. The advantages of using a wide fringe search window are 1) usage of low accurate input catalogues (typical errors of GB6 are 20–$40''$) is possible; 2) a compact component in an extended source that can be located up to several arcminutes away of the peak at a low-resolution image can be found; 3) a second source or a second component can be searched for within several arcminutes of the main target.

Fig. 1 shows the distribution of observed, detected, and non-detected sources. The zone within right ascensions 15–20 hours is under-observed because of a high demand for VLBA time by other high priority programs.

Table 2 summarizes the status of the VCS9 campaign on 2016.10.01. The output of the program is the catalogue of source positions and images of detected sources at 4.4 and 7.6 GHz. The preliminary results are accessible from the project web site http://astrogeo.org/vcs9. The median position accuracy of the catalogue is 1.2 mas, 90 % percentile is 7.2 mas. In total, 4973 images at both bands, including calibrators, were made available.

Using preliminary results of VCS9 campaign, the distributions of sources over spectral index between 1.4 (NVSS) and 4.85 GHz (PMN, GB6) catalogue were computed. The main result can be formulated as “a rule of one third”: one third of all detected sources have steep spectra and one third of non-detected sources have flat spectra. No attempt was made to evaluate completeness of the sample. This will

Table 2

Status of the VCS9 project by 2016.10.01

Total time in hours:	536
The number of sources observed:	11012
The number of segments observed:	99
The number of segments processed:	36
The number of target sources processed:	2874
The number of target sources detected at any band:	1583
Detection rate:	55 %

be done later after completion of data analysis. But even incomplete results show clearly that the share of compact objects within steep spectrum sources is much bigger than it was tacitly assumed before.

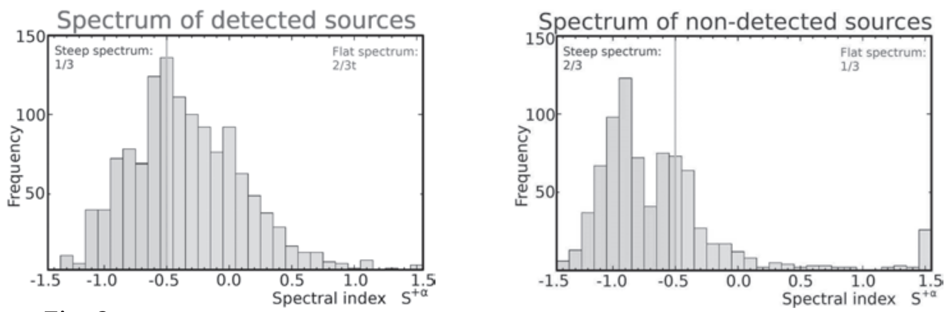

Fig. 2. The distribution of spectral indices for detected (*Left*) and not detected (*Right*) sources

References

1. *Condon J. J., Cotton W. D., Greisen E. W., Yin Q. F., Perley R. A., Taylor G. B., Broderick J. J.* The NRAO VLA Sky Survey // Astron. J., 1998. — VOL. 115. — P. 1693–1716.
2. *Gregory P. C., Scott W. K., Douglas K., Condon J. J.* // Astrophys. J., 1996. — VOL. 115. — P. 427–432.
3. *Wright A. E., Griffith M. R., Hunt A. J., Troup E., Burke B. F., Ekers R. D.* The Parkes-MIT-NRAO (PMN) Surveys. VIII. Source Catalog for the Zenith Survey // Astrophys. J., 1996. — VOL. 103. — P. 145–171.