THE CATALOG OF POSITIONS OF OPTICALLY BRIGHT EXTRAGALACTIC RADIO SOURCES OBR S-1

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ABSTRACT

It is expected that the European Space Agency mission Gaia will make it possible to determine coordinates in the optical domain of more than 500,000 quasars. In 2006, a radio astrometry project was launched with the overall goal of making comparisons between coordinate systems derived from future space-born astrometry instruments and the coordinate system constructed from analysis of global very long baseline interferometry (VLBI) more robust. Investigation of the rotation, zonal errors, and non-alignment of the radio and optical positions caused by both radio and optical structures is needed to validate both techniques. In order to support these studies, the densification of the list of compact extragalactic objects that are bright in both radio and optical ranges is desirable. A set of 105 objects from the list of 398 compact extragalactic radio sources with decl. > −10° was observed with the Very Long Baseline Array and European VLBI Network (EVN) with the primary goal of producing images with milliarcsecond resolution. These sources are brighter than 18 mag in the V band, and they were previously detected by the EVN. In this paper, coordinates of observed sources have been derived with milliarcsecond accuracies from analysis of these VLBI observations using an absolute astrometry method. The catalog of positions for 105 target sources is presented. The accuracies of source coordinates are in the range of 0.3–7 mas, with a median of 1.1 mas.

Key words: astrometry – catalogs – surveys

Online-only material: machine-readable and VO tables

1. INTRODUCTION

The method of very long baseline interferometry (VLBI), first proposed by Matveenko et al. (1965), allows us to derive the position of sources with nanoradian precision (1 nrad ≈ 0.2 mas). The first catalog of source coordinates determined with VLBI contained 35° objects (Cohen & Shaffer 1971). Since then, hundreds of sources have been observed under geodesy and astrometry VLBI observing programs at 8.6 and 2.3 GHz (X and S bands) using the Mark3 recording system at the International VLBI Service for Geodesy and Astrometry (IVS) network. Analysis of these observations resulted in the ICRF catalog of 608 sources (ICRF stands for International Celestial Reference Frame; Ma et al. 1998). Later, over 6000 sources were observed in the framework of the Very Long Baseline Array (VLBA) Calibrator Survey (VCS) program (Beasley et al. 2002; Fomalont et al. 2003; Petrov et al. 2005, 2006; Kovalev et al. 2007; Petrov et al. 2008), the VLBA regular geodesy RDV program (Petrov et al. 2009), the VLBA Imaging and Polarimetry Survey (VIPS; Helmboldt et al. 2007; Petrov & Taylor 2011), the VLBA Galactic Plane Survey (VGaPS; Petrov et al. 2011a), the ongoing Australian Long Baseline Array Calibrator Survey (LC; Petrov et al. 2011b), and several other programs. The number of extragalactic sources with positions determined from analysis of observations under absolute astrometry or geodesy programs reached 6455 by 2011 June, and it continues to grow rapidly due to analysis of new observations and an ongoing campaign of in-depth reanalysis of old observations.

The catalog of positions for all compact extragalactic radio sources determined with VLBI with accuracies in a range of 0.05–30 mas forms a dense grid on the sky that can be used for many applications, such as differential astrometry, phase-referencing VLBI observations of weak objects, space navigation, Earth orientation parameter determination, and space geodesy. To date, this position catalog is the most precise astrometric catalog. However, the high accuracy of positions of listed objects can be used directly only by applications that utilize the VLBI technique. Applications that use different observational techniques can benefit from the high accuracy of VLBI positions only indirectly by observing common objects from the VLBI catalog with instruments at other wavelengths. Over the past three decades, significant efforts have been made to connect the VLBI position catalog and existing optical catalogs made with the use of ground instruments. An overview of the current status of radio–optical connection and detailed analysis of the differences between VLBI and optical source positions can be found in Andrei et al. (2009). According to them, the standard deviation of the differences between the VLBI and optical catalogs is ∼130 mas. It was shown by Zacharias & Zacharias (2008) that when modern dedicated ground-based observations are used, the differences are close to 30 mas.

This level of agreement between VLBI and optical positions roughly corresponds to the position accuracy of common objects from ground optical catalogs, typically at a level of 100 mas. The European Space Agency space-born astrometry mission Gaia, scheduled to be launched in 2013, promises according to Lindegren et al. (2008) to reach submilliarcsecond accuracies of determining positions of quasars of 16–20 mag that will rival the accuracy of absolute astrometry VLBI. Since position catalogs produced with Gaia and VLBI will be completely independent, their mutual rotations, zonal differences, and possibly other systematic effects can be interpreted as errors of one of the techniques after resolving the differences due to a misalignment of centers of optic and radio images of quasars and a frequency-dependent core shift (Kovalev et al. 2008; Porcas 2009; Sokolovsky et al. 2011). Investigation of their systematic differences will be needed to assess the overall quality of Gaia results and possible errors in the VLBI position catalog.

This comparison will produce valuable results if (1) it is limited to those common sources whose VLBI positions are known...
with errors smaller than several tenths of a milliarcsecond, (2) the number of sources is large enough to derive meaningful statistics, and (3) the sources are uniformly distributed over the sky. However, the number of quasars that (1) are bright both in optical and radio wavelengths and therefore can be detected with both techniques (e.g., brighter than magnitude 18 as suggested by Mignard 2003) and (2) have a compact core is currently rather limited. Among 3946 radio sources with $\delta < -10^\circ$ observed with VLBI in absolute astrometry mode, 508 objects have an association with a quasar or a BL Lac object brighter than V $0^m 18^m$ from the catalog of Veron-Cetty & Veron (2010) within a 4" search radius.

It was realized in the mid-2000s that a densification of the list of such objects is desirable. A specific program for identifying new VLBI sources in the northern hemisphere, suitable for aligning the VLBI and Gaia coordinate systems, was launched in 2006 (Bourda et al. 2008) with the eventual goal of deriving highly accurate positions of sufficiently radio-bright quasars from VLBI observations in absolute astrometry mode. Since the current VLBI position catalog is complete to the correlated flux density level of 200 mJy, the new candidate sources should necessarily be a factor of two to four weaker than that level. The original observing sample consisted of 447 optically bright, relatively weak extragalactic radio sources with declinations above $-10^\circ$. The detailed observing scheme of this project is presented in Bourda et al. (2008). The first VLBI observations resulted in the detection of 398 targets with the European VLBI Network (EVN; Bourda et al. 2010), although no attempt to derive their positions or produce images was made. VLBI observations of this sample in the absolute astrometry mode promise to increase the number of optically bright radio sources with precisely known positions by 80%.

As a next step of implementing this program, a subset of 105 detected sources was observed with the global VLBI network that comprises the VLBA and EVN observing stations with the goal of revealing their morphology on milliarcsecond scales from VLBI images (Bourda et al. 2011) for consecutive screening of the objects with structure that may potentially cause non-negligible systematic position errors. I present here results of astrometric analysis from this VLBI experiment. Observations and their analysis are described in Sections 2 and 3. The position catalog is presented in Section 4. Concluding remarks are given in Section 7.

2. OBSERVATIONS

The observations used in this paper were carried out during a 48 hr experiment GC030 on 2008 March 7–9 with a global VLBI array comprising 10 VLBA and 6 EVN stations (Eflslberg, Hartrao, Medicina, Noto, Onsala60, and DSS63 for part of the time), simultaneously in the $S$ and $X$ bands. The data were recorded at 512 Mbps. The schedule was prepared by ensuring a minimum of three five-minute scans of each target source, while minimizing the slewing time from source to source. In total, 115 objects, including 105 target sources and 10 strong calibrators, were observed during a 48 hr observing session. Three target objects were observed in two scans, 20 target objects were observed in three scans, 43 target objects were observed in four scans, 26 objects were observed in five scans, 10 objects were observed in six scans, 2 objects were observed in seven scans, and 1 object was observed in eight scans. Antennas spent 78% of the time recording emission from target sources.

Although the overall goal of the observing program was absolute astrometry, the design of the GC030 experiment suffered from several limitations and was not favorable for determining source coordinates with high accuracy. First, the intermediate frequencies (IFs) were selected to cover a continuous range in both the $S$ and $X$ bands: 2.22699–2.29099 GHz and 8.37699–8.44099 GHz, respectively. There were two considerations behind the selection of this frequency setup (P. Charlot 2011, private communication). First, at the beginning of 2008, the 512 Mbps mode was new. At that time, that setup was tested only for the case of contiguously allocated IFs. It was not clear whether every non-VLBA station would be able to support the wide-band mode. Since it happened in the past that a change in the frequency setup ruined experiments, the decision was made to stay safe and make the schedule using IFs spread contiguously over the band. Second, it was known (for example, D. Gordon 2010, private communication) that the AIPS implementation of fringe fitting, task FRING, does not produce correct group delays when the IFs are spread over the wide band. As a workaround, all absolute astrometry/geodesy experiments prior to 2010 were processed using a two-step approach: first the fringe fit was made using data from each IF individually, and then group delays over the entire band were computed using fringe phases from each individual IF derived in the previous step. The drawback of that approach is that a source should be detected at each IF individually, which raises the detection limit by $\sqrt{N}$, where $N$ is the number of IFs at each band (4 in our case). Since the target sources were expected to be weak, it was important to avoid a degradation of the detection limit by a factor of two. Work for developing an alternative fringe fitting procedure (Petrov et al. 2011a), free from this drawback, was underway in 2008, when the experiment was scheduled, but was not finished at that time. Unfortunately, group delays determined with the contiguous frequency setup are one order of magnitude less precise with respect to the frequency allocation traditionally used for absolute astrometry work with the VLBA.

The second limitation of the GC030 schedule for astrometry use was a relatively rare observation of sources at low and high elevations for better estimation of troposphere path delay in the zenith direction. It was found in the past that if calibrator sources were observed at low and high elevations at each station every 1–2 hr, the reliability of estimates of the path delay in the neutral atmosphere was significantly improved, and as a result, systematic errors caused by mismodeling propagation effects were reduced (Petrov et al. 2005).

The third limitation of the GC030 schedule was a small number of sources observed in prior astrometry/geodesy programs in dual $S/X$ bands: only 19 objects. Observations of a large number of sources, typically 30–60 objects in a 24 hr experiment, overlapping with previous observations, help to establish firmly the orientation of the array and to link positions of new sources with positions of other objects.

Despite all these limitations, it was worth the effort to derive source positions from such data since the a priori positions of these objects determined from Very Large Array (VLA) observations (Becker et al. 1995; Condon et al. 1998) were in the range of 0$\dprime$03–1$\dprime$.

3. DATA ANALYSIS

The data were correlated at the Socorro hardware VLBA correlator. The correlator computed the spectrum of cross-correlation and autocorrelation functions with a frequency setup of 0.25 MHz at accumulation intervals of 1.048576 s. The method used for further analysis is described in full detail in Petrov et al. (2011a). Here only a brief outline is given. For
the first step, the fringe amplitudes were corrected for signal distortion in the sampler and then calibrated according to measurements of system temperature and elevation-dependent gain.

Since the log files from VLBA sites for the second half of the experiment were lost, no phase calibration was applied. Then the group delay, phase delay rate, group delay rate, and fringe phase were determined for all observations for each baseline for the X and S bands separately using the wide-band fringe fitting procedure. These estimates maximize the amplitude of the sum of the cross-correlation spectrum coherently averaged over all accumulation periods of a scan and over all frequency channels in all IFs. After the first run of fringe fitting, 12 observations at each baseline with the strongest signal-to-noise ratios (S/N) were used to adjust the station-based complex bandpass corrections, and the group delays were computed again. This part of the analysis was conducted with PIMA software. Then the results of fringe fitting were exported to the VTD/post-Solve VLBI analysis software for interactive processing group delays with an S/N high enough to ensure that the probability of false detection was less than 0.001. This S/N threshold was 5.8 for the GC030 experiment. A detailed description of the method for evaluation of the detection threshold can be found in Petrov et al. (2011a).

Then, theoretical path delays were computed according to the state-of-the-art parametric model as well as their partial derivatives, and small differences between group delays and theoretical path delay were used to estimate corrections for a parametric model that describes the observations with least squares (LSQs). Coordinates of the target source, positions of a parametric model that describes the observations with least squares (LSQs). Coordinates of the target source, positions of a parametric model that describes the observations with least squares (LSQs). Coordinates of the target source, positions of a parametric model that describes the observations with least squares (LSQs).

Observations that deviated by more than 3.5σ in the preliminary solution were identified and temporarily eliminated, and additive corrections to a priori weights were determined. The most common reason for an observation to be marked as an outlier was a misidentification of the main maximum of the two-dimensional Fourier transform of the cross-spectrum. Then the fringe fitting procedure was repeated for observations marked as outliers. This time, however, the group delay and phase delay rates were evaluated for these observations in a narrow window of 4 ns wide centered around the predicted value of group delay computed using parameters of the VLBI model adjusted in the preliminary LSQ solution. New estimates of group delays for points with probabilities of false detection less than 0.1, which corresponds to an S/N > 4.6 for the narrow fringe search window, were used in the next step of the interactive analysis procedure. The observations marked as outliers in the preliminary solution and detected in the narrow window at the second round of the fringe fitting were tried again. If the new estimate of the residual was within 3.5 formal uncertainties, the observation was restored and used in further analysis. Parameter estimation, elimination of remaining outliers, and adjustments of additive weight corrections were then repeated. In total, 16,629 matching pairs of X and S band group delays out of 22,750 scheduled were used in the solution. Each source was detected at both bands and had a number of dual-band pairs in the range of 19–321.

The result of the interactive solution provided a clean data set of ionosphere-free linear combinations of X- and S-band group delays with updated weights. The data set that was used for the final parameter estimation utilized all dual-band S/X data acquired under absolute astrometry and space geodesy programs from 1980 April through 2010 December, including the data from the GC030 experiment—a total of 8 million observations. Thus, the GC030 experiment was analyzed exactly the same way as over 5000 other VLBI experiments, using the same analysis strategy that was used for processing prior observations for the ICRF, VCS, VGaPS, LCS, and K/Q survey (Lanyi et al. 2010) catalogs. The estimated parameters are right ascensions and declinations of all sources, coordinates and velocities of all stations, coefficients of B-spline expansion of nonlinear motion for 17 stations, coefficients of harmonic site position variations of 48 stations at four frequencies: annual, semiannual, diurnal, semi-diurnal, and axis offsets for 67 stations. Estimated variables also included Earth orientation parameters for each observing session, parameters of clock function and residual atmosphere path delays in the zenith direction modeled with the linear B-spline with intervals of 60 and 20 minutes, respectively. All parameters were adjusted in a single LSQ run.

The system of LSQ equations has an incomplete rank and defines a family of solutions. In order to pick a specific element from this family, I applied the no-net rotation constraints on the positions of 212 sources marked as “defining” in the ICRF catalog (Ma et al. 1998) that required the positions of these sources in the new catalog to have no rotation with respect to their positions in the ICRF catalog. No-net rotation and no-net-translation constraints on site positions and linear velocities were also applied. The specific choice of identifying constraints was made to preserve the continuity of the new catalog with other VLBI solutions made during last 15 years.

The global solution sets the orientation of the array with respect to an ensemble of ∼5000 extragalactic remote radio sources. The orientation is defined by the continuous series of Earth orientation parameters and parameters of the empirical model of site position variations over 30 years evaluated together with source coordinates. Common sources observed in the GC030 experiment as amplitude calibrators provided a connection between the new catalog and the old catalog of compact sources.

As a valuable by-product of GC030 observations, positions of the rxs63 station were determined (see Table 1). To my knowledge, this is the only S/X experiment with participation of this station that can be found in publicly accessible databases. The velocity of rxs63 was constrained to be the same as the velocity of the rxs65 station that is located 1440 m from rxs63.

Radio images of observed sources in both the S and X bands were presented in graphical form in Bourda et al. (2011). In order to provide a measure of source strengths at long and

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2 Available at http://astrogeo.org/pima.
3 Available at http://astrogeo.org/vtd.
short baselines for predicting the S/N in future observations, I made my own simplified amplitude analysis and derived the median correlated flux densities at baseline projection lengths shorter than 900 km and longer than 5000 km. This procedure is described in detail in Petrov et al. (2011b). It is outlined briefly here. First, I computed the a priori system equivalent flux density (SEFD) using system temperatures and gain curves converted to flux densities by multiplying them by the square root of the product of the a priori SEFDs of both stations of a baseline. Then I adjusted multiplicative gain corrections from fringe amplitudes for every observation used in astrometric analysis, except those marked as outliers, were applied these corrections to estimates of correlated flux densities derived by this method with its form and content.)

4. THE CATALOG

I have determined positions of 105 sources observed in the GC030 experiment. They are listed in Table 2. Although positions of all 5336 astrometric sources were adjusted in the LSQ solution that included the OBRS-1 sources, only coordinates of the 105 target sources observed during the GC030 experiment are presented in the table. The first and second columns give the IVS source name (B1950 notation) and IAU name (J2000 notation). The third and fourth columns give source coordinates at the equinox on the J2000.0 epoch. Columns 5 and 6 give formal source position uncertainties in right ascension and declination in mas (without the cos δ factor), and column 7 gives the correlation coefficient between the errors in right ascension and declination. The number of group delays used for position determination is listed in Column 8. Columns 9 and 10 provide the median value of the correlated flux density in Janskys in the S band at baseline projection lengths shorter than 900 km and at baseline projection lengths longer than 5000 km. The latter estimate serves as a measure of the correlated flux density of the unresolved component of a source. Columns 11 and 12 provide the median of the correlated flux density in the S band at baseline projection lengths shorter than 900 km and longer than 5000 km. The last column contains a cross-reference flag: V if a source was observed in the VIPS campaign, X if it was observed in the X/S bands in another absolute astrometry campaign, and VX if it was observed in both.

Uncertainties in source position that were observed only in the GC030 experiment range from 0.3 mas (1345+735) to 7.2 mas (0502+0415) with a median of 1.1 mas. The distribution of the semimajor axes of position error ellipses among 105 target sources in the OBRS-1 catalog is shown in Figure 1.

5. ERROR ANALYSIS

Among 105 target sources, 26 objects were observed in the VIPS C-band (5 GHz) program and 9 objects were observed in dual-frequency S/X VLBA experiments under absolute astrometry programs. For comparison purposes, I made a trial solution that used exactly the same setup as the main solution, but excluded nine common objects from the GC030 experiment. The

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Table 2

| IAU Name | Source Coordinates | Position Errors |
|----------|--------------------|-----------------|
|          | α (hr minutes s)   | δ (° / ′ / ′′)  |
|          |                    | σα (mas) | σδ (mas) | Corr |
|          |                    |          |          |     |
|          |                    | Fcorr S band | Fcorr X-band |
|          |                    |          |          |     |
|          |                    |          |          |     | Flag |

(This table is available in its entirety in machine-readable and Virtual Observatory (VO) forms in the online journal. A portion is shown here for guidance regarding its form and content.)

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4 Available at http://astrogeo.org/vlbi_images.
results of the comparison presented in Table 3 show that, except for a declination of 2043+749, the differences are within formal uncertainties of the OBR-1 catalog. The formal uncertainties of source positions are computed from standard deviations of group delay estimates using the law of error propagation. Since the selection of IFs was unfavorable for a precise determination of group delays and the sources were relatively weak, the thermal noise dominates the error budget.

Realistic uncertainties of parameter adjustments can be evaluated only by exploiting some redundancy in the data or by using additional information. We do not have enough redundancy to evaluate rigorously the level of systematic errors in the GC030 campaign. Comparison of positions of nine common sources indicates that systematic errors, if they exist, do not exceed 1 mas. Although only 10 atmosphere calibrators were included in the schedule, three to five times less than in dedicated absolute astrometry observing experiments, they were observed rather intensively. We can indirectly estimate the level of systematic errors caused by the sparseness of the distribution of calibrator sources by comparing the source distribution in experiment GC030 with that in the prior observing program VCS1 (Beasley et al. 2002). The azimuthal-elevation distribution of sources observed in that campaign for a central VLBA antenna (Figure 3(b) in Beasley et al. 2002) was concentrated in a narrow band at the sky for 95% of the sources, and very few atmospheric calibrators outside that band were used. The reliability of the estimation of atmosphere path delays in the zenith direction was significantly compromised, and as a result, the formal uncertainties from the LSQ solution had to be inflated by adding in quadrature the error floor of 0.4 mas.

The VCS1 campaign can be considered an extreme case of the effect of the non-uniform distribution of observed sources. Both calibrator sources and targets in GC030 were distributed more uniformly than in the VCS1 campaign. Analysis of estimates of residual atmosphere path delays does not show abnormalities. I surmise tentatively that systematic errors of the OBR-1 catalog probably do not exceed 0.4 mas, which is insignificant with respect to its random errors. I presented formal uncertainties from the LSQ solution “as is,” leaving in-depth investigation of systematic errors to the future when more observations in this mode will be collected.

6. DISCUSSION

In the course of the development of radio astrometry over the past 40 years, we have learned that in order to derive precise source positions using absolute astrometry, a VLBI experiment should (1) have IFs spread as wide as possible over the band(s), (2) observe 1–2 hr blocks of three to five sources with at least one source at an elevation 20° above the horizon and one source at an elevation 55° above the horizon, and (3) collect enough bits for detection target sources at long baselines.

Unfortunately, the selection of IFs in the GC030 experiment did not satisfy the first condition. The choice of intermediary frequencies is not very important for producing source images and observers often record a continuous bandwidth, but this choice is critical for absolute astrometry applications since precision of group delay is reciprocal to the variance of the frequencies in the band. The choice is especially important for the astrometry of weak sources, since unlike observations of bright sources when systematic errors dominate the error budget, the position accuracy of weak sources is determined by the uncertainties of group delays caused by thermal noise. The frequency setup spread over 494 MHz used in the VLBA geodesy/astrometry RDV program (Petrov et al. 2009) had uncertainties of group delay a factor of 11.1 smaller than in the GC030 experiment at a given S/N. The VLBA hardware allows us to spread the IFs over 1000 MHz that brings uncertainties of group delay down even further by a factor of two (Petrov & Walker 2011).

It should be stressed that there is no necessity to limit the spread of IFs for image experiments. One of the most extensive dedicated imaging programs, the VIPS (Helmiboldt et al. 2007), used four IFs spread over 494 MHz in order to improve the uv coverage and to allow for rotation measure determinations (Taylor et al. 2005). Analysis of both VIPS and RDV observations provided excellent source maps (Helmiboldt et al. 2007; Piner et al. 2007; Pushkarev & Kovalev 2008). Maps from absolute astrometry observations typically have a dynamic range of 1:100–1:1000 (see Petrov et al. 2008 and references therein). These maps allowed Charlton (2008) to determine source structure indexes and from conclusions about the suitability of sources for precise astrometry.

The approach proposed by Bourda et al. (2008) to run three observing campaigns for an absolute astrometry program, the first for detection, the second to produce source maps, and the third to derive source positions, deviates sharply from the strategy used for the past 40 years for determining positions of 6000 sources, which has used one campaign per program.

Our analysis of the GC030 experiment shows that running two separate observing campaigns for imaging and astrometry, which doubles the requested observing time, is not the best
choice. Spreading the IFs over 500 MHz would reduce random errors of position estimates by a factor of 11, i.e., the median position error would be 0.1 mas, without compromising imaging results. With such precise group delays, position accuracy would be limited by systematic errors. More intensive observations of troposphere calibrators to mitigate systematic errors would require approximately 5%–8% additional observing time according to Petrov et al. (2011a). That means that the goal of the project could be reached by using two runs instead of three, which requires one half of the requested resources.

Including EFLSBRG in the array is beneficial because this station improves the baseline sensitivity in the X band by a factor of four, which is important for detecting weak sources. The benefit of using other European stations and especially a station in South Africa, which has almost no mutual visibility with both American and European stations, is less obvious. In order to assess the impact of other stations on the source position estimates, I made a trial solution that excluded MEDICINA, HARTROA, NOTO, ONSALAO60, and TSS63 from GC030. A comparison of position differences showed that they are within formal uncertainties. An average increase of uncertainties of the trial solution using the data from the restricted array was 20% for right ascensions and 30% for declinations. The median increase was 28% and 42%, respectively. Removing EVN stations from the array would, of course, degrade the quality of images, but as analysis of other VLBA experiments, for instance, the K/Q survey (Lanyi et al. 2010), showed the degradation would not be at a level that would undermine their usability for the goals of this specific project.

These are important lessons that we learned from analysis of these observations.

7. SUMMARY

Analysis of the first dual-band S/X VLBA experiment of the campaign for observing optically bright extragalactic radio sources allowed us to determine positions of 105 target sources. Despite using a frequency setup unfavorable for absolute astrometry, the position uncertainties ranged from 0.3 to 7 mas with a median value of 1.1 mas. The sources were relatively weak: the median correlated flux density at baselines longer than 5000 km ranged from 25 to 190 mJy with a median value of around 60 mJy in both bands, which is a factor of two weaker than in the VCS observing campaign. However, recording at 512 Mbps with an integration length of 300 s was sufficient to detect 73% of the observations, including those at long baselines.

A position accuracy of 1 mas is sufficient to use these sources as phase calibrators, but not sufficient to draw meaningful conclusions from comparisons of Gaia and VLBI positions. All the sources will have to be reobserved with the wide-band frequency setup in order to reach the 0.1 mas level of accuracy.

In 2010–2011, the remaining 293 sources were observed with VLBA and EVN. These observations will help us to further extend the position catalog of optically bright radio sources.

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**Facility: VLBA**

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