Global VLBI Observations of Weak Extragalactic Radio Sources: Imaging Candidates to Align the VLBI and Gaia Frames

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Abstract

The space astrometry mission Gaia will construct a dense optical QSO-based celestial reference frame. For consistency between optical and radio positions, it will be important to align the Gaia and VLBI frames (International Celestial Reference Frame) with the highest accuracy. In this respect, it is found that only 10% of the ICRF sources are suitable to establish this link (70 sources), either because most of the ICRF sources are not bright enough at optical wavelengths or because they show extended radio emission which precludes reaching the highest astrometric accuracy. In order to improve the situation, we initiated a multi-step VLBI observational project, dedicated to finding additional suitable radio sources for aligning the two frames. The sample consists of about 450 optically-bright radio sources, typically 20 times weaker than the ICRF sources, which have been selected by cross-correlating optical and radio catalogs. The initial observations, aimed at checking whether these sources are detectable with VLBI, and conducted with the European VLBI Network (EVN) in 2007, showed an excellent 90% detection rate. This paper reports on global VLBI observations carried out in March 2008 to image 105 from the 398 previously detected sources. All sources were successfully imaged, revealing compact VLBI structure for about half of them, which is very promising for the future.

1. Context

During the past decade, the IAU (International Astronomical Union) fundamental celestial reference frame was the ICRF (International Celestial Reference Frame; [1, 2]), composed of the VLBI positions of 717 extragalactic radio sources, measured from dual-frequency S/X observations (2.3 and 8.4 GHz). Since 1 January 2010, the IAU fundamental celestial reference frame has been the ICRF2 [3], successor of the ICRF. It includes VLBI coordinates for 3 414 extragalactic radio sources, with a floor in position accuracy of 60 μas and an axis stability of 10 μas.

The European space astrometry mission Gaia, to be launched in 2012, will survey all stars and QSOs (Quasi Stellar Objects) brighter than apparent optical magnitude 20 [4]. Optical positions with Gaia will be determined with an unprecedented accuracy, ranging from a few tens of μas at magnitude 15–18 to about 200 μas at magnitude 20 [5]. Unlike Hipparcos, Gaia will permit the realization of the extragalactic celestial reference frame directly at optical bands, based on the QSOs that have the most accurate positions. A preliminary Gaia catalog is expected to be available by 2015 with the final version released by 2020.

In this context, aligning VLBI and Gaia frames will be crucial for ensuring consistency between the measured radio and optical positions. This alignment, to be determined with the highest

accuracy, requires several hundreds of common sources, with a uniform sky coverage and very accurate radio and optical positions. Obtaining such accurate positions implies that the link sources must be brighter than optical magnitude 18 [6], and must not show extended VLBI structures.

In a previous study, we investigated the potential of the ICRF for this alignment and found that only 70 sources (10% of the catalog) are appropriate for this purpose [7]. This highlights the need to identify additional suitable radio sources, which is the goal of a VLBI program that we initiated three years ago [8]. This program has been devised to observe 447 optically-bright extragalactic radio sources extracted from the NRAO VLA Sky Survey, a dense catalog of weak radio sources [9]. The observing strategy to detect, image, and measure accurate VLBI positions for these sources is described in [8].

The initial observations, whose goal was to assess the VLBI detectability of the targets, were conducted with the European VLBI Network (EVN) in 2007. These showed an excellent 90% detection rate [8]. Proceeding further with our program, we now report on global VLBI imaging observations carried out in March 2008 to image 105 of the 398 previously detected sources.

2. Observations and Data Reduction

The observations were performed during a 48-hour experiment (hereafter designated as GC030), on 7–9 March 2008, with a global VLBI array recording at 512 Mb/s in a dual-frequency S/X mode. This network was composed of five telescopes from the EVN (Effelsberg, Medicina, Noto, Onsala-20m, and Hartebeesthoek), the DSN 70-m Robledo telescope for part of the time, and nine antennas of the VLBA (Very Long Baseline Array). Sixteen 8-MHz-wide sub-bands were recorded, with eight contiguous bands at each of S- and X-band. On average, a total of three to four 5-minute long scans were scheduled on each of the 105 target sources. In addition, we observed a sample of ten well-distributed ICRF sources, for use as calibrators. In all, about 80% of the allocated time was spent on source, while the rest was used for slewing.

The correlation of GC030 was done with the VLBA correlator at the Array Operations Center in Socorro (New Mexico, USA). The correlated data were then calibrated using the Astronomical Image Processing System (AIPS[1]). An initial amplitude calibration for each sub-band was accomplished using system temperature measurements taken during the observations combined with gain curves supplied for each telescope. Prior to fringing the targets, phase offsets between the sub-bands were determined by fringing a short calibrator scan, and then applied to all data. This allowed us to combine all sub-bands together when fringing, thereby increasing the signal-to-noise-ratio and maximizing chances of detection for these weak targets. Calibrators were used in a second stage to estimate amplitude correction factors for each station, each band (S and X), and each sub-band. These corrections, at the level of less than 10% on average, were applied to the calibrated data, which were then exported as FITS files.

The remaining data reduction was conducted with the Caltech DIFMAP[2] software-package which was used for imaging. Visibility data for each frequency band were self-calibrated, Fourier inverted, and CLEANed following the hybrid-mapping technique [10], using DIFMAP in an automatic mode. A point-source model was used as a starting model for the iterative procedure in all cases. Uniform weighting and, after several iterations, natural weighting, were applied to derive the final images.

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[1]http://www.aips.nrao.edu
[2]http://www.astro.caltech.edu/~tjp/citvlb/index.html

3. VLBI Imaging Results

Based on the analysis described above, VLBI maps at X- and S-bands were successfully produced for each of the 105 target sources observed during GC030. These images have the following characteristics:

- The typical beam has a size of about 1.2×0.5 mas at X-band and 4.2×2.0 mas at S-band.
- The dynamic range (defined as the ratio of the first plotted contour level to the peak brightness) is generally $\sim$1:100.
- The typical image noise rms is 0.080 mJy/beam at X-band and 0.117 mJy/ beam at S-band. This compares well with the theoretical image thermal noise at X- and S-bands, which are 0.050 and 0.082 mJy/beam, respectively.

Figures 1 and 2 show the VLBI maps that we produced for the first six sources of the list (when ordered by increasing right ascension): 0003+123, 0049+003, 0107−025, 0109+200, 0130−083, and 0145+210. The total flux densities for these sources, as integrated from the GC030 images, are respectively: 128 mJy, 49 mJy, 46 mJy, 120 mJy, 78 mJy, 126 mJy at X-band, and 115 mJy, 28 mJy, 56 mJy, 78 mJy, 140 mJy, 268 mJy at S-band. When considering all 105 targets, the total flux density ranges from 23 mJy to 222 mJy at X-band, with a median value of 61 mJy, and from 22 mJy to 397 mJy at S-band with a median value of 65 mJy. Based on the X-band and S-band flux densities, the spectral index α (defined as $S \propto \nu^{\alpha}$, where S is the source flux density and ν is the frequency) has also been determined. In this definition, the sources with a dominating compact core are expected to have $\alpha > -0.5$. The median value of α for the sources observed during GC030 is -0.05, with $\alpha > -0.5$ for more than 90% of the targets (97 sources out of 105 sources imaged).

4. Astrometric Quality

The images derived from GC030 show a variety of morphologies, ranging from point-like sources to extended or even double sources. In order to identify the most point-like ones, suitable for the Gaia link, we used the so-called "structure index" (SI) as an indicator of astrometric quality [11, 12]. Accordingly, only sources with SI < 3 should be used, since one wants to determine the link with the highest accuracy.

Analysis of the structure index values at X- and S-bands for all 105 sources observed during GC030 indicates that about half of them (47 sources) show point-like or compact structures at X-band (SI < 3), whereas the other half show extended structures. The resulting list of suitable sources is given in [13]. We note that these 47 sources increase the number of potential link sources by 70% when added to the 70 suitable sources already identified in [7], which is very promising considering that only one fourth of our targets has been imaged thus far.

5. Future Prospects

It is anticipated that the remaining 293 detected sources from our initial sample will be observed within the coming year and imaged in the same way. Assuming similar statistics , we expect another 150 suitable link sources to be identified. The final stage of this project, dedicated to measuring accurately the VLBI position of those sources, will be engaged in the near future. While making the Gaia link possible, these new VLBI positions will also serve to densify the ICRF at the same time.
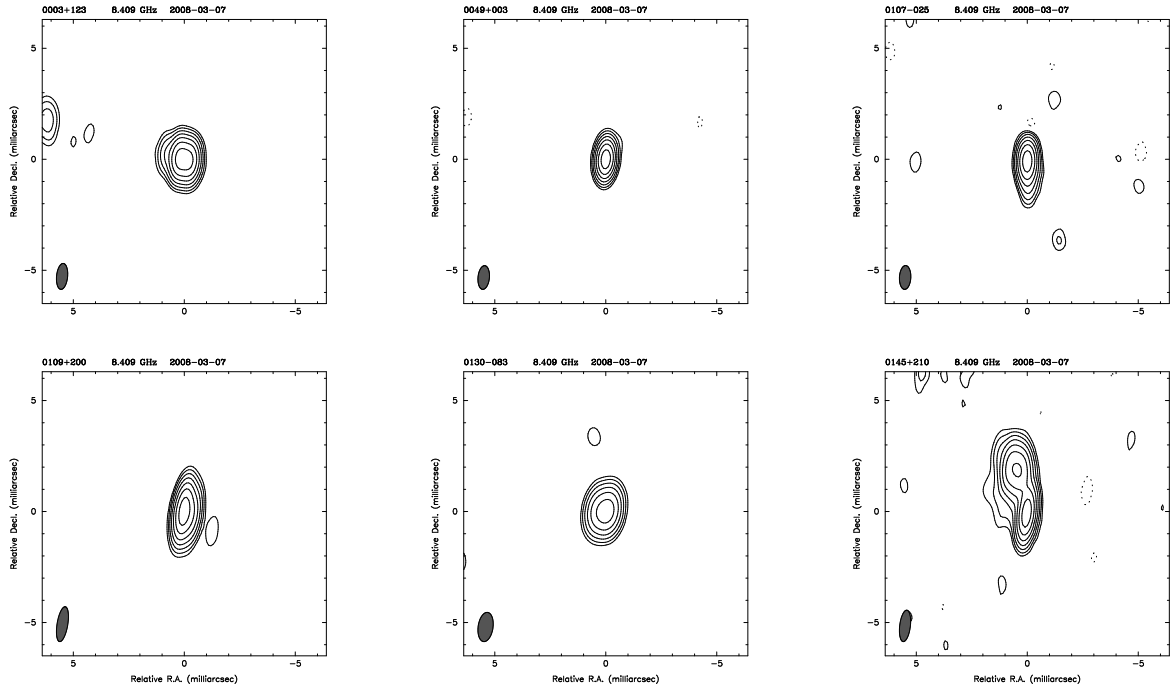
Figure 1. VLBI images at X-band for the first six sources from GC030 (when ordered by increasing right ascension). Contour levels start at 1% or 2% of the peak brightness and increase by a factor of 2 each time.
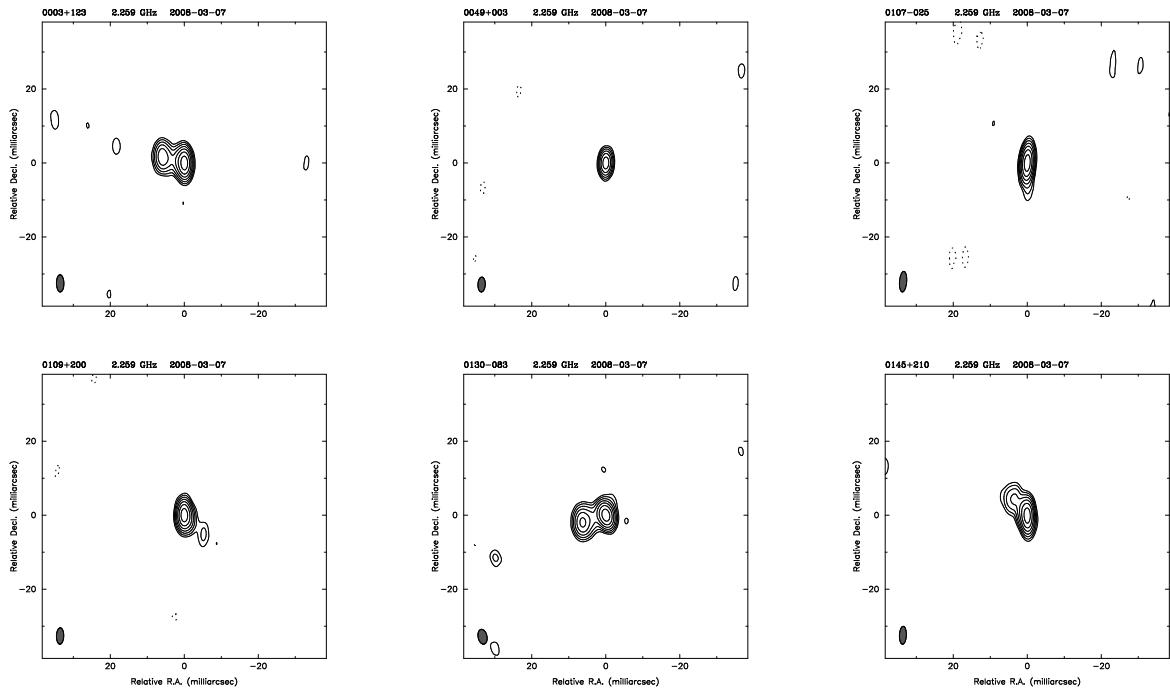

Figure 2. VLBI images at S-band for the first six sources from GC030 (when ordered by increasing right ascension). Contour levels start at 1% or 2% of the peak brightness and increase by a factor of 2 each time.

6. Acknowledgements

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