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Imaging Capabilities of the Next Generation VLBI System

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Abstract. We study the capabilities of the VLBI2010 system to produce images of reference sources, which are the basis of the International Celestial Reference Frame (ICRF). To this end, we have developed a procedure to simulate VLBI data, based on VLBI2010 technical recommendations, and to automatically image the sources from such simulated data. Our results confirm that the VLBI2010 system will be able to produce high-quality VLBI images. By comparing results of simulations, we also investigate the effect of network configuration, depending on the source declination, the impact of the number of observations and observing strategy.

1. Introduction

In Sep. 2005, the IVS Working Group 3 VLBI2010 gave recommendations for the next generation VLBI2010 system [1]. This system is based on 12m-class fast-moving antennas associated with broadband recording system, and is being designed to improve the IVS products: the Earth Orientation Parameters, the International Terrestrial Reference Frame, and the International Celestial Reference Frame (ICRF).

An important issue concerning ICRF is the correction of the effect of source structure since most of ICRF sources are not point-like on VLBI scales [2]. In practice, source structure modeling requires imaging the sources on a regular basis, which is currently conducted through dedicated bimonthly RDV (Research and Development VLBA) sessions. In the future, it is anticipated that this may be done on a daily basis with VLBI2010 system, providing a significant contribution to astrophysics, in addition to its primary geodetic and astrometric goals.

In this study, we evaluate VLBI2010 system capabilities for producing high-quality images, based on VLBI2010 technical recommendations in terms of networks and schedules. To this end, we have designed a two-step procedure presented in Sec. 2 to simulate VLBI images, considering a realistic source model. The results of the simulations are then used to explore the imaging capabilities of 16- and 32-station VLBI2010 networks and for different types of schedules as discussed in Sec. 3.

2. Simulation of VLBI2010 Images

The procedure we have designed to produce simulated VLBI images comprises two successive steps: the simulation of VLBI2010 data using a specific pipeline, and the automatic source imaging from these simulated data.

2.1. Generating VLBI2010 Data

A dedicated pipeline was built for generating VLBI2010 data. This pipeline includes home-made Perl and python scripts, which integrate several programs from the Caltech VLBI Package (fake, merge,...)[1]. The major selection criteria for such simulations are as follows.

1. A VLBI2010 schedule. The simulations presented in this paper are based on 16- and 32-station networks [3]. Actual VLBI2010 schedules[2] depend on antenna slew rates and observing strategies. Details about these are provided in Sec. 3 together with the results of our simulations.

2. A structure model of the source. A structure model of the source is required to simulate VLBI amplitude and phase data. In our calculations, we used a simple model comprising one point-like core component plus five Gaussian components, with separations from the core up to 7 mas. Components were approximately aligned along a straight line to reproduce a typical core-jet structure as shown in Fig. 1.

3. A frequency setup. A 4-frequency setup (8406, 8476, 8791 and 8896 MHz), corresponding to the setup used at X band in the RDV sessions, was used in all simulations.

4. Realistic noise. An additive noise of 30 mJy (corresponding roughly to the first contour level in the images) along with a multiplicative noise of 5% of the expected visibility amplitudes was added to simulated amplitude data. In a similar way, a random noise of 10° was added to the phase data. Finally, random station-dependent calibration errors of up to 6% were incorporated to account for the imperfect knowledge of the gain of the antennas.

2.2. Producing Images

The simulated data generated in the previous step are stored in uvfits file. These data are then processed to image the source by using the DIFMAP soft-

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[1] For help on Caltech VLBI programs, see http://www.astro.caltech.edu/~tjp/citvlb/

[2] VLBI2010 schedules are available at http://mars.hg.tuwien.ac.at/~vlbi2010/

Flux, Jy	Separation, mas	P.A., °	Major axis, mas	Axis ratio	Phase, °
3.0	0.0	-	-	-	-
3.0	3.0	135	1.0	0.5	20
2.0	4.0	135	2.0	0.5	−45
2.0	4.5	135	1.0	0.3	−45
1.0	6.0	130	1.5	0.8	110
1.0	7.0	135	1.5	0.8	110

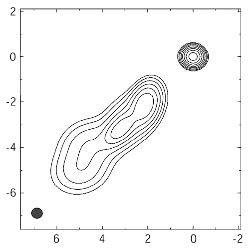

Figure 1. (Left) Components of the source structure model. (Right) Image derived by convolving the model components with a typical VLBI2010 beam (0.5×0.5 mas^2), plotted in the lower left-hand corner of the image. The first contour level is 15 mJy/beam (0.5% of the peak brightness), with successive contours increasing by a factor of two. Units: mas

ware in automatic mode [4]. The procedure is based on the hybrid-mapping technique [5] with a point-source model at start. Visibilities are self-calibrated, Fourier inverted, and CLEANed. Uniform weighting and, after several iterations, natural weighting, are successively applied to derive the final image.

3. Results of Simulations

In this section, we present the results of our simulations with emphasis on specific parameters: the network configuration (16- or 32-station network), the number of observations, and the selected observing strategy.

3.1. Effect of Network Configuration

Simulations were carried out for sources at three different declinations (−40°, 0°, +40°), based on schedules derived from 16- and 32-station networks. Such schedules were produced by maximizing the number of sources observed with slew rates of 6°/sec in azimuth and 2.1°/sec in elevation.

The resulting images (Fig. 2) indicate that the overall source structure is generally well reconstructed, down to the level of 0.5% of the peak brightness. However, it is found that the weak extended feature at 6–7 mas from the core is not correctly reconstructed with the 16-station network, especially at low declination (Fig. 2, upper panels). This is most probably due to a lack of short baselines, which is clearly visible when comparing the u-v planes for the two networks. On the other hand, the 32-station network reconstructs extended structures more reliably, whatever the source declination (Fig. 2, lower panels).

3.2. Impact of the Number of Observations

VLBI2010 schedules include several thousands of 5 to 22-second long scans (i.e. the number of times each source is observed) per 24 hours, observed by at least 8 stations simultaneously. The average number of scans per source is typically 60 for a 16-station network and 50 for a 32-station network, with 90% of the sources within a ±10-scan range. However, some sources happen sometimes to have a number of scans quite distinct from the average.

In order to study the impact of the number of scans on the image quality, we have compared the simulated images for two sources at similar declination (+20°) but with 22 and 66 scans, respectively. From this comparison, it is found that the extended structure of our source is reasonably well reconstructed when the source is observed 66 times, whereas that is not the case when it is observed only 22 times. This means that the number of scans is a major parameter on image quality. Based on our tests, we suggest a minimum of 40–50 scans per day on each source with a uniform number of scans on every source for a proper image reconstruction.

3.3. Influence of Observing Strategies

In the framework of VLBI2010 project, two main observing strategies are being studied:

- *Observing as many sources as possible per day*, to maximize the number of observations. In this case, the number of scans per day is roughly 6000 for a 16-station schedule and 5000 for a 32-station schedule. Schedules previously used in Sec. 3.1 and 3.2 above were obtained with this strategy.

- *Observing sources distributed all over the sky (uniform sky schedule)*, with the goal of accurately estimating the troposphere above the VLBI stations on short times scales. Such schedules require more slewing time, which implies less observing time spent on the sources. Consequently, the number of scans per day drops by 20–30% to about 4000. As the number of sources observed is still the same (about 100 sources), there are less scans scheduled on each of them compared to the previous strategy.

In order to compare the two strategies, we repeated the 16-station analysis described in Sec. 3.1 with a uniform sky schedule; in this strategy, the sky is covered in 9 minutes with 45-second switching time between sources. As previously, we faced the same problem in reconstructing extended structures for low-declination sources, while replacing the 16-station network with a 32-station network, considering a schedule with similar characteristics, does improve significantly the recovery of extended structures. From this test and other additional ones, we conclude that the selected observing strategy (obtaining a uniform sky coverage or maximizing the number of observations) appears to have no significant impact on the image quality.

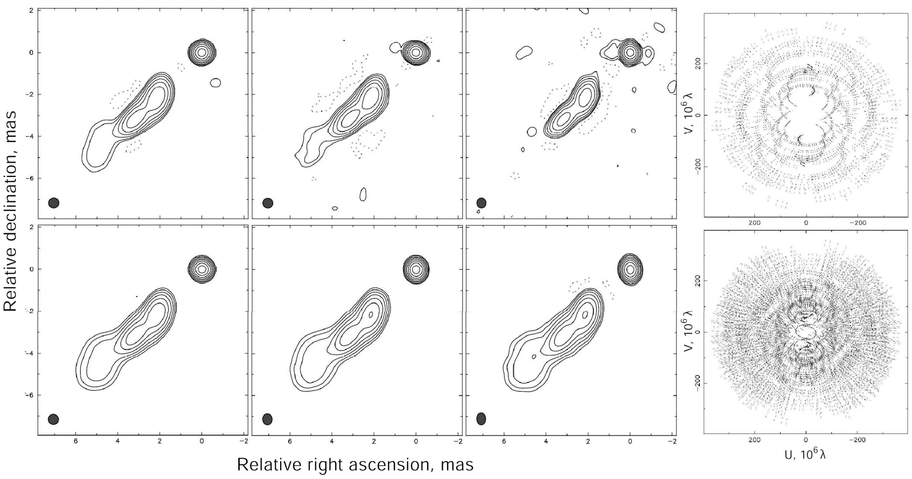

Figure 2. Reconstructed VLBI images at three declinations (−40°, 0°, 40°) and u-v coverage (decl. −40°) for typical VLBI2010 schedules with 16 stations (upper panels) and 32 stations (lower panels). Contour levels are the same as in Fig. 1.

4. Conclusion

In this study, we evaluated VLBI2010 system capabilities for producing high-quality images, based on VLBI2010 technical recommendations in terms of networks and schedules. To this end, we developed a two-step procedure to simulate VLBI2010 data and automatically image the sources.

Overall, the results of our simulations showed that VLBI2010 system is well adapted to produce high-quality images, with roughly the same dynamic range as that currently obtained from RDV sessions. In addition, they highlight that 32-station networks should be preferred over 16-station networks since the latter fails to reconstruct extended structures for sources at low declination. We also found that the number of observations scheduled on each source has a significantly impact on the image quality; based on our tests, we suggest a minimum of 40–50 scans per day on every source to properly reconstruct images. On the other hand, the choice of the observing strategy (optimizing the sky coverage or maximizing the number of sources observed) appears to have no significant impact on the reconstructed images.

In the future, further simulations will be targeted to study the impact of the noise added to the data, and to repeat the analysis presented here for weaker sources.

References

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