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Imaging ICRF3 sources at K band with the European VLBI Network

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We explore the capabilities of the European VLBI Network (EVN) to image radio reference frame sources observed through geodetic-style experiments at K band (22 GHz). The EVN includes long East-West and North-South baselines (from Europe to Asia and from Europe to South Africa) along with baselines of shorter and intermediate lengths within Europe, making it worthwhile to study the potential of the network for imaging in such observing mode. To this end, we use a 22-telescope experiment carried out as part of the EC-funded JUMPING JIVE project in October 2020. The experiment targeted a total of 80 sources from the third realization of the International Celestial Reference Frame (ICRF3), all of which selected from the pool of ICRF3 defining sources. Scheduling of the observations was accomplished by using sub-netting because the primary scope of the experiment was geodesy. Despite this geodetic-style approach, it was possible to image a large majority of the sources, hence demonstrating the capability of the EVN for such work. The resulting images may be used to further assess the source compactness, and hence their astrometric suitability, at a frequency and a resolution higher than probed by the standard S/X observations that formed the basis for selecting those sources as defining sources.

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1. Introduction

The work reported in this paper was carried out as part of the JUMPING JIVE project[1], an EC funded project for the period 2016–2021 whose objective was to enhance the profile of the Joint Institute for VLBI ERIC (JIVE). In this project, Work Package 6 "geodetic capabilities" [1] was aimed to implement a fully operational geodetic path at the European VLBI Network (EVN) software correlator (SFXC) at JIVE and measure the geodetic position of the non-geodetic EVN telescopes. For the latter, two 24-hour experiments have been carried out using the EVN at K band, one in June 2018 (labeled EC065) and one in October 2020 (labeled EC076) [2]. Based on these data, geodetic positions at the cm level have been derived for the relevant EVN telescopes [3].

In the following, we explore the use of the same data, more specifically those from EC076, to image the sources targeted in these observations. Section 2 describes the VLBI observing network, source selection scheme and scheduling strategy, while Sect. 3 presents the imaging results. The latter includes plots of the resulting images for a few sources. Comparisons with independent VLBI images obtained with the Very Long Baseline array (VLBA) at K band and with images at X band and at S band from a global VLBI network including the VLBA are also provided to qualify the quality of the EVN images. Conclusions and future prospects are drawn in Sect. 4.

2. Observations

The observing network used to acquire the data involved in this work includes all EVN radio telescopes that have the capability to observe at K band, namely 17 telescopes in Europe, Asia and South Africa. The network was further augmented with the four e-MERLIN out-stations with K band capability (Cambridge, Darnall, Knockin and Pickmere in the UK) and the 26 m antenna in Hobart (Australia). In all, this forms a large network of 22 telescopes (Fig. 1, left panel). The e-MERLIN out-stations provide short baselines which help with the recovery of extended structure, while the Hobart telescope helps with North-South resolution.

A total of 80 sources belonging to the third realization of the International Celestial Reference Frame [4] were observed during the experiment. Because the primary scope of the project was to determine the geodetic positions of the EVN telescopes, all sources were chosen among the pool of ICRF3 defining sources. This selection should limit potential effects due to source structure since the defining sources are deemed to be compact. We arranged for these 80 sources to be well spread in right ascension and declination, as reflected by the sky distribution plotted in Fig. 1 (right panel). No sources below $-30°$ declination were selected because the network would then be reduced to the single baseline between Hartebeesthoek and Hobart, which would make imaging impossible.

The scheduling of the observations was achieved using NASA's SKED software. While the sky coverage above each telescope was optimized in the usual way to allow for the estimation of tropospheric parameters for geodesy, we also arranged for the observations to be reasonably well spread over all sources and forced each scan to include at least four telescopes. The number of scans per source was between 2 and 10, with a mean value of 5.6, while the number of observations ranged from 30 to 546, with a mean value of 257. Due to the large network, one-third of the scans had more than 10 telescopes and 10% had 16–18 telescopes, a very favorable situation for imaging.

[1]See the web page of the project at https://jumping.jive.eu/

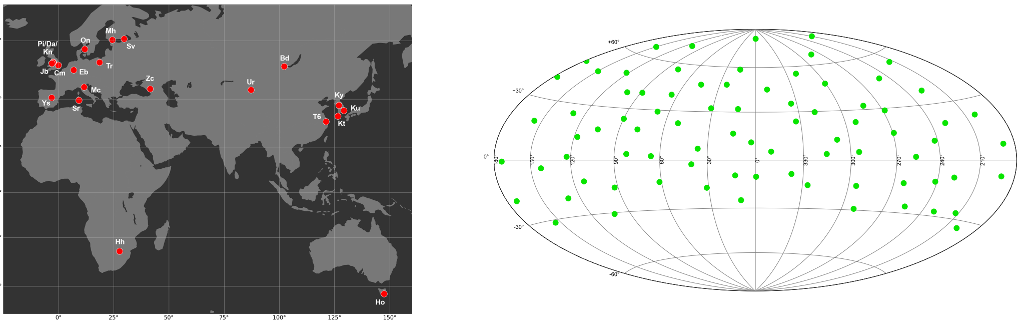

Figure 1: *: Left:* geographical location of the 22 radio telescopes that participated in the EC076 experiment. *Right:* sky distribution of the 80 ICRF3 defining sources observed in the course of that experiment.

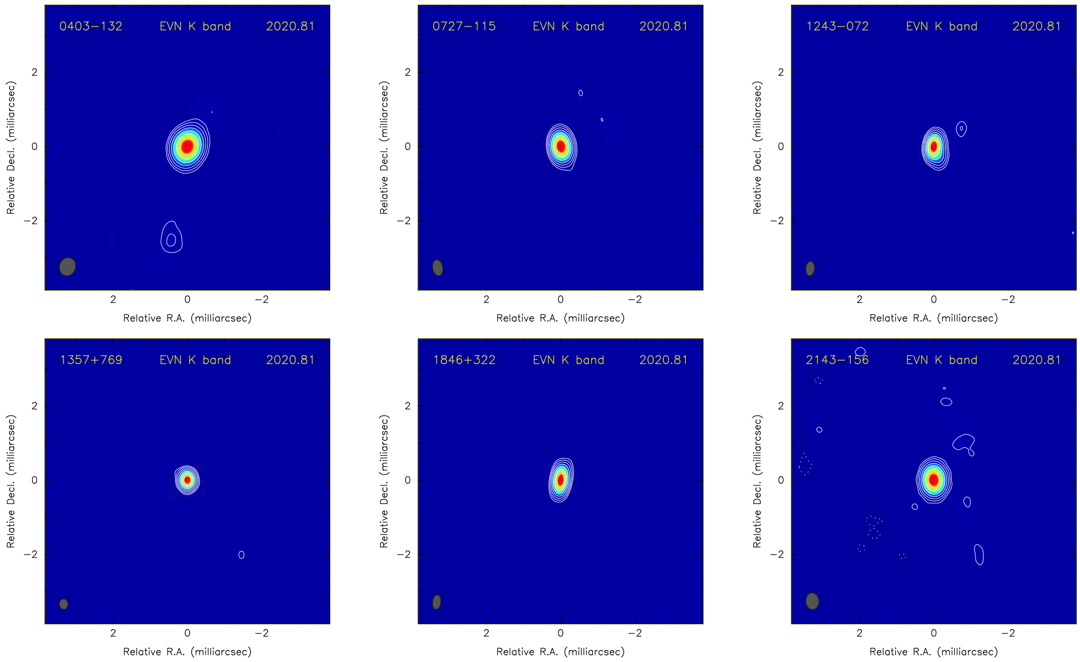

Figure 2: VLBI images at K band for six ICRF3 defining sources (0403−132, 0727−115, 1243−072, 1357+769, 1846+322, 2143−156) observed in the EVN experiment EC076 conducted on 23 October 2020. Contour levels are drawn at ± 1, 2, 4, 8, 16, 32 and 64% of the image peak brightness.

3. Imaging results

The imaging was accomplished based on the distributed EVN pipelined data using an automatic DIFMAP script with no recalibration and no sophisticated editing of the data. Despite this brutal approach, a large majority of the 80 sources have been imaged, proving the potential of the EVN for such work. The images produced for six of the observed sources are shown in Fig. 2 as examples. Apart from a few exceptions (see next section), the sources are found to be mostly very compact at the EVN resolution (0.2 mas), therefore confirming that they qualify well as defining sources for the celestial reference frame. The dynamical range of the images is generally at the 1% level or lower.

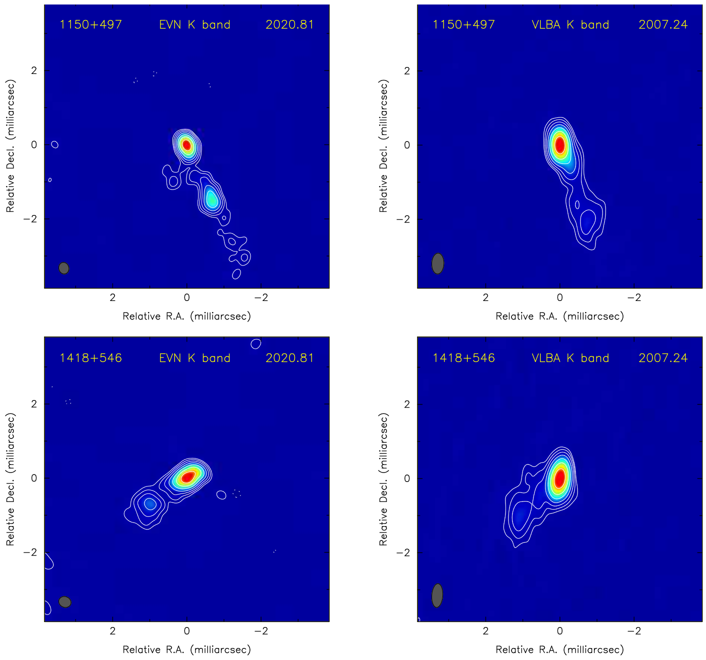

Figure 3: Comparison of EVN (left) and VLBA (right) images at K band for the sources 1150+497 and 1418+546. Contour levels are drawn at ± 1, 2, 4, 8, 16, 32 and 64% of the image peak brightness.

Figure 3 compares our EVN images for two sources that are not point-like (1150+497 and 1418+546) with previously published VLBA images of the same two sources, also at K band [5]. Though not at the same epoch, the EVN and VLBA images compare well, indicating similar jet-like structure elongated in the same direction for the two sources. The comparison also shows that the EVN provides somewhat higher resolution compared to the VLBA, which should help to probe source structure even closer to the core, for the benefit of the celestial reference frame.

Figure 4 shows images of the source 1418+546 at X band and S band for an epoch close to that the EVN data. These images were produced from the "Research & Development with the VLBA" (RDV) experiment 142 carried out on 19 August 2020, just two months before EC076. They are available from the Bordeaux VLBI Image Database (BVID)[2]. For convenience, our K band image of 1418+546 from EC076 is reproduced in the same figure. Comparison of that image with the RDV images at X band and S band, as plotted in Fig. 4, shows consistent structure over the three frequency bands, which is another indication of the validity of the derived EVN images.

4. Conclusion and future prospects

Preliminary imaging of a sample of ICRF3 defining sources observed during a geodetic-style EVN experiment carried out at K band demonstrates the capabilities of the EVN for such imaging work. Beyond their use for astrophysics, the high-resolution K band images produced will be useful to assess the continued astrometric suitability of these sources. Our immediate goal in the future will be to refine the calibration and data editing and from there to finalize the imaging. We also plan

[2]See https://bvid.astrophy.u-bordeaux.fr/

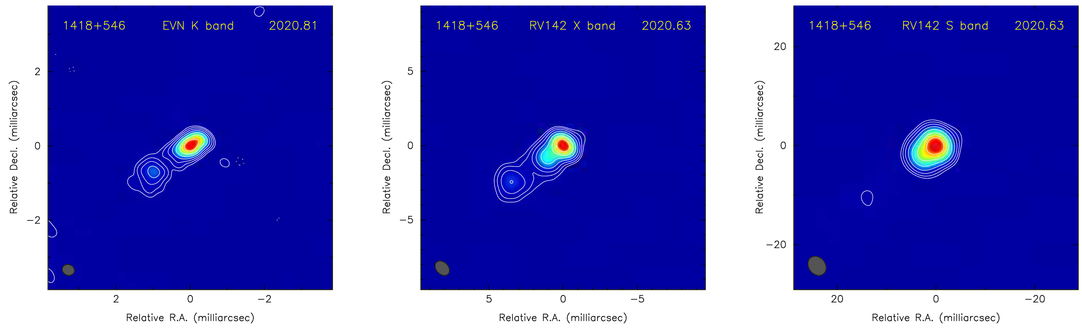

Figure 4: VLBI images of the source 1418+546 at K band (left panel), X band (middle panel) and S band (right panel). The K band image is from EC076 while the X band and S band images are from the RDV experiment 142. Contour levels are drawn at ± 1, 2, 4, 8, 16, 32 and 64% of the image peak brightness.

to conduct detailed comparisons with recent VLBA images of the same sources (de Witt et al., this conference). Having demonstrated the potential of the EVN for this work, we are also considering engaging further observations, focusing at first on the rest of the ICRF3 defining sources visible by the EVN, and then going to weaker sources, taking advantage of the large sensitivity of the network.

Acknowledgments

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