Mem. S.A.It. Vol. 83, 966

Memorie della

Towards an accurate alignment of the VLBI frame and the future Gaia optical frame – VLBI observations of weak extragalactic radio sources: status and future plans

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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 with the highest accuracy. However, the number of quasars that are bright in optical wavelength (for the best position with Gaia), that have a compact core (to be detectable on VLBI scales), and that do not exhibit complex structures (to ensure a good astrometric quality), is currently rather limited. It was hence realized that the densification of the list of such objects was necessary. Accordingly, we initiated a multi-step VLBI observational project, dedicated to finding additional suitable radio sources for aligning the two frames. The sample consists of ~450 optically-bright weak extragalactic radio 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. The second step, dedicated to extract the most point-like sources of the sample, by imaging their VLBI structures, was initiated in 2008. About 25% of the detected targets were observed with the Global VLBI array (EVN+VLBA; Very Long Baseline Array) during a pilot imaging experiment, revealing ~50% of them as point-like sources on VLBI scales. The rest of the sources were observed during 3 imaging experiments in March 2010, November 2010 and March 2011. In this paper, we give an overview of the project.

1. Introduction

During the past decade, the IAU (International Astronomical Union) fundamental celestial

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reference frame was the ICRF (International Celestial Reference Frame; Ma et al. 1998; Fey et al. 2004), composed of the VLBI (Very Long Baseline Interferometry) 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[1], 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 June 2013, will survey all stars and QSOs (Quasi Stellar Objects) brighter than apparent optical magnitude 20 (Perryman et al. 2001). Using Gaia, optical positions 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 (Lindegren et al. 2008). 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 (Mignard 2003), and must not show extended VLBI structures in order to ensure the highest VLBI astrometric accuracy (Fey and Charlot 2000).

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 (Bourda et al. 2008). With the determination of the ICRF2, which is based on the VLBI position of ~4–5 times more sources, ~200 extragalactic radio sources were found suitable for aligning ICRF2 with the future Gaia frame (~6% of the catalog; see P. Charlot paper, this volume). This highlights the need to identify additional suitable radio sources, which is the goal of a VLBI program that we initiated four years ago. This program has been devised to observe 447 optically-bright extragalactic radio sources, on average 20 times weaker than the ICRF sources, extracted from the NRAO VLA Sky Survey, a dense catalog of weak radio sources (Condon et al. 1998). The observing strategy to detect, image, and measure accurate VLBI positions for these sources is described in Bourda et al. (2010). In this paper, we give the status of this program and outline future prospects.

[1] IERS Technical Note 35 (2009): The Second Realization of the International Celestial Reference Frame by Very Long Baseline Interferometry.

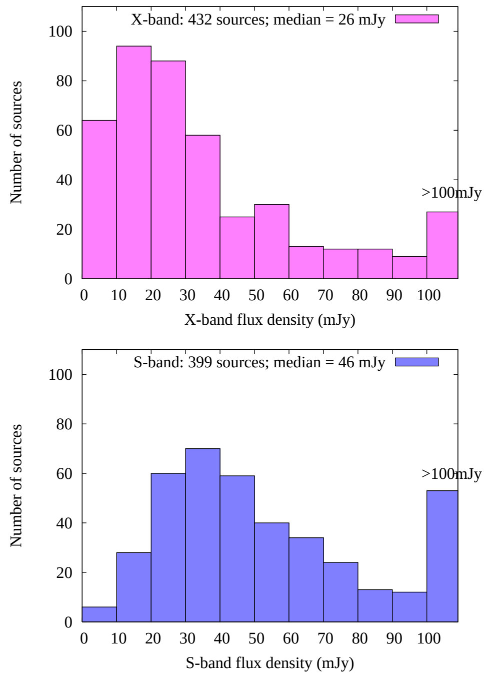

Fig. 1. Mean correlated flux density distribution, at X- and S-bands, for the sources detected in EC025A and EC025B. The corresponding median values are 26 mJy and 46 mJy, respectively.

2. The observing program

2.1. VLBI detection

The initial observations, whose goal was to assess the VLBI detectability of the 447 targets, were conducted with the European VLBI Network[2] (EVN), recording at 1 Gbps in a geodetic-style dual-frequency S/X mode, in June and October 2007 (during two 48–hours experiments, EC025A and EC025B, respectively). These showed excellent detection rates of 97% at X-band and 89% at S-band. Overall, 398 sources were detected at both frequencies, corresponding to an overall detection rate of about 89% (Bourda et al. 2010). The mean correlated flux densities were also determined for each source and band by averaging over all scans and baselines detected (see Fig. 1):

- At X-band, 432 sources were detected and the mean correlated fluxes ranged from 1 mJy to 190 mJy, with a median value of 26 mJy.
- At S-band, 399 sources were detected and the mean correlated fluxes ranged from 8 mJy to 481 mJy, with a median value of 46 mJy.

2.2. VLBI imaging

Proceeding further with our program, the second step was targeted at imaging the sources previously detected, using the global VLBI network (EVN+VLBA; Very Long Baseline Array), recording at 512 Mbps in a geodetic-style dual-frequency S/X mode, in order to identify the most point-like sources and therefore the most suitable ones for the alignment.

A pilot imaging experiment[3] was carried out in March 2008 (during 48–hours; experiment designated GC030) to image 105 of the 398 previously detected sources. As a result, all sources were successfully imaged at both bands (Bourda et al. 2011; see http://www.obs.u-bordeaux1.fr/BVID/GC030). The total flux densities of these sources were determined at both S- and X-bands (see Fig. 2), as well as their continuous structure indices (see Fig. 3; for a definition of the *continuous* structure index see e.g. Bourda et al. 2011). We showed that about 50% of these targets were point-like sources (i.e. 47 sources out of 105 observed had an X-band structure index < 3.0).

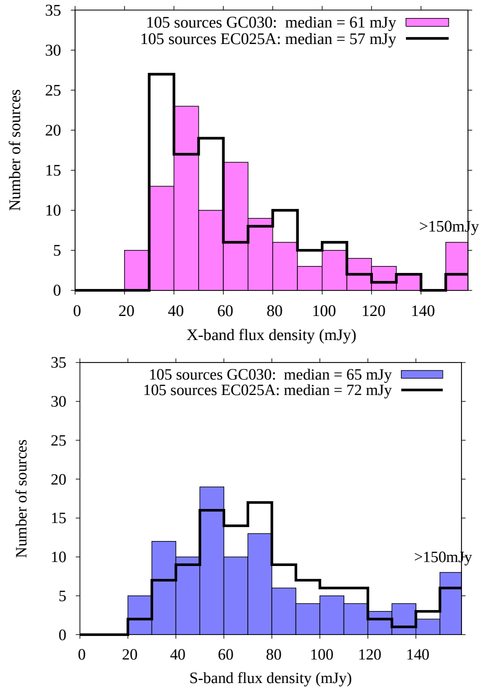

Fig. 2. Distribution of the total flux densities at X- and S-bands for the 105 sources observed during the pilot imaging experiment GC030. The corresponding mean correlated flux density distribution determined during EC025A for the same sources is plotted in black.

[2] The network comprised the antennas of Effelsberg, Medicina, Noto, Onsala-25m, as well as the 70-m Robledo telescope for part of the time (in October 2007).

[3] The network comprised 5 telescopes of the EVN (Effelsberg, Medicina, Noto, Onsala-25m and the South-African antenna at Hartebeesthoek), the DSN 70-m Robledo telescope for part of the time, and 9 antennas of the VLBA; the VLBA Fort Davis antenna could not observe during this experiment.

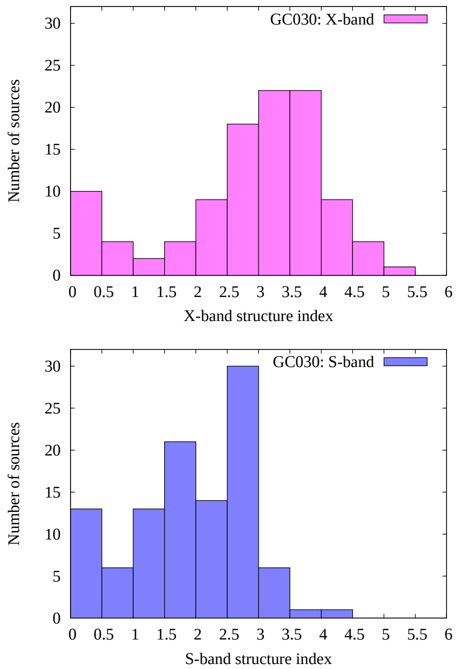

Fig. 3. Distribution of the continuous structure index at X-band (upper panel) and S-band (lower panel) for the 105 sources observed during GC030.

Additional imaging experiments[4] were then carried out with the global VLBI array to observe the remaining 290 sources, during 144 hours:

- In March 2010 (97 sources), during 48 hours;
- In November 2010 (118 sources), during 58 hours;
- In March 2011 (75 sources), during 38 hours.

We are now analyzing these three global observations in order to determine the VLBI structures of the targets and to extract the most point-like sources.

[4] The network comprised the 10 antennas of the VLBA, and five telescopes of the EVN (Effelsberg, Medicina, Onsala-25m, Yebes-40m and either Noto or the South-African antenna at Hartebeesthoek).

2.3. VLBI astrometry

The final stage of this program, dedicated to determining very accurate VLBI positions (i.e. position accuracy wanted to better than 100 μas) for the most point-like sources of the sample will begin in 2012.

3. Summary and future prospects

Within the next few years, the alignment between optical and radio frames will benefit from this multi-step VLBI project. Obtaining such an alignment with the highest accuracy is essential, not only to ensure consistency between measured radio and optical positions, but also to measure directly core shifts within AGNs. This will be of great interest in the future for probing AGN jets properties. Furthermore, while making the Gaia link possible, these new VLBI positions will also serve in the future to densify the VLBI frame at the same time.

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