PLANS FOR AN ACCURATE ALIGNMENT OF THE VLBI FRAME AND THE FUTURE GAIA FRAME

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ABSTRACT. The European space astrometry mission Gaia will construct a dense optical QSO-based celestial reference frame. For consistency between optical and radio positions, it will be fundamental to align the Gaia and VLBI frames with the highest accuracy. A proper alignment is also important in the framework of astrophysics, for example to probe properly the AGN jets properties and the physics of these objects. The VLBI-Gaia frame alignment requires quasars that are bright at optical wavelength, that have a compact radio core, and that do not exhibit complex structures. In this paper, we draw prospects for this alignment, based on the ICRF2 catalogue and an ongoing dedicated VLBI project designed to observe additional weaker extragalactic radio sources for this purpose. The list of suitable sources will have to be monitored to check the relevance of the sources for the alignment, especially in terms of position stability and structures. Accordingly, we present the observations we envision in the framework of the IVS and other VLBI networks, before and during the Gaia mission.

1. THE IMPORTANCE AND CHALLENGES OF ALIGNING FRAMES

During the past decade, the IAU (International Astronomical Union) fundamental celestial 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 (IERS Technical Note 35, 2009), 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.

The alignment between the VLBI and Gaia frames will be important not only for guaranteeing a proper transition if the fundamental reference frame is moved from the radio to the optical domain, but also for registering the radio and optical images of any celestial target with the highest accuracy. Such a registration will allow one, for example, to pinpoint the relative location of the optical and radio emission in active galactic nuclei (AGN) to a few tens of μas, placing constraints on the overall AGN geometry. Estimates of this optical-radio core shift indicate that it may amount to $\sim$100 μas on average at X-band (Kovalev et al. 2008), significantly larger than Gaia and VLBI position accuracies. It should thus be directly measurable. Conversely, these shifts will also affect the accuracy of the link between the two frames. For this reason a large number of objects is desirable in order to average out such effects.

2. STATUS AND PLANS TO ALIGN FRAMES

The alignment between the VLBI and Gaia frames, 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 & 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). This highlighted 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, selected 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). From the pilot imaging experiment conducted in March 2008, about half of the sources observed were found to be point-like (Bourda et al. 2011). Assuming similar statistics for the subsequent experiments, this would lead finally to a sample of about 200 sources suitable for the alignment of the frames.

3. ICRF2 SUITABILITY

With the advent of the ICRF2, which comprises 4–5 times more sources than the ICRF, one may wonder how many additional suitable link sources one would get. We hence investigated the optical counterparts of the ICRF2 sources within the LQAC (Large Quasar Astrometric Catalogue; Souchay et al. 2009). By cross-correlating these two catalogues (with a cut-off value of $3''$; see Table 1 for the results), we found 1 128 ICRF2 sources with a proper optical counterpart (i.e. magnitudes V or R or I $\leq$ 18 from LQAC).

In order to estimate the astrometric quality of these sources, we then calculated the X-band continuous structure index from the VLBI images available (see Bourda et al. 2011 for more details; see Figure 1 for the distribution plot). In all, structure indices were derived for 34% of the 1 128 optically-suitable ICRF2 sources. Among these, 201 sources were found to have an appropriate X-band structure index (i.e. < 3.0), corresponding to 6% of the catalogue. Figures 2 and 3, respectively, show the X-band flux density distribution for these 201 sources, and their dissemination on the sky. This latter appears quite homogeneous.

Magnitude	mag > 0	$0 <$ mag ≤ 20	$0 <$ mag ≤ 18
V	1 220	1 184	511
R	2 076	1 938	755
I	1 806	1 800	1 013

Table 1: Number of ICRF2 sources cross-identified within LQAC, depending on the value and the type of the magnitude (cross-identification cut-off value of $3''$).

4. VLBI OBSERVATIONAL PLANS

Based on the current list of VLBI sources suitable for the alignment with the Gaia frame, plans are being devised for VLBI observations prior the launch of the satellite and during the mission. First, we need highly accurate VLBI positions for these sources (i.e. $\sigma < 100$ μas). Accordingly, we need to measure source positions before Gaia launch, for those sources which VLBI position accuracy is not yet sufficient. For this purpose, specific VLBI astrometric observations will be planned from 2012. Then, we need to monitor sources during the Gaia mission, in order to control source position stability and accuracy, as well as potential variations in VLBI structures. To this end, the Gaia scanning law should allow us to carry out quasi-simultaneous VLBI and Gaia observations. This might be also of high interest for astrophysical purposes (e.g. optical-radio comparisons for constraining AGN jets properties).

In order to achieve these plans, we will use several VLBI networks, because they are complementary. The IVS (International VLBI Service for Geodesy and Astrometry) network would be used for the stronger sources, while the EVN, VLBA and DSN networks could be of high interest for weaker sources (European VLBI Network; Very Long Baseline Array; Deep Space Network). Finally, one might think also about higher frequency observations in order to reduce core-shift effects, as the higher you observe in radio frequency the closer you get from the base of the radio jet and hence from the optical emission region.

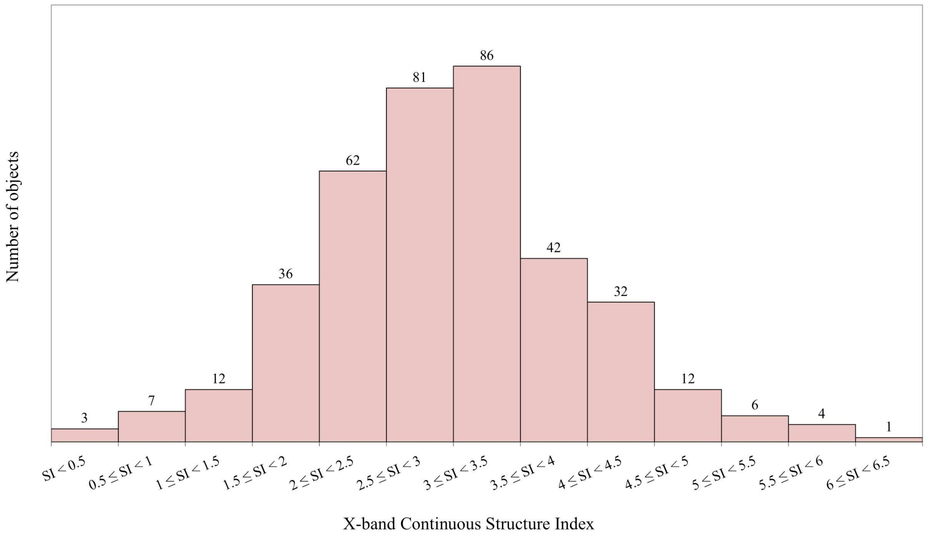

Figure 1: Distribution of the X-band continuous structure index determined for the 1 128 ICRF2 sources with a proper optical counterpart within LQAC.

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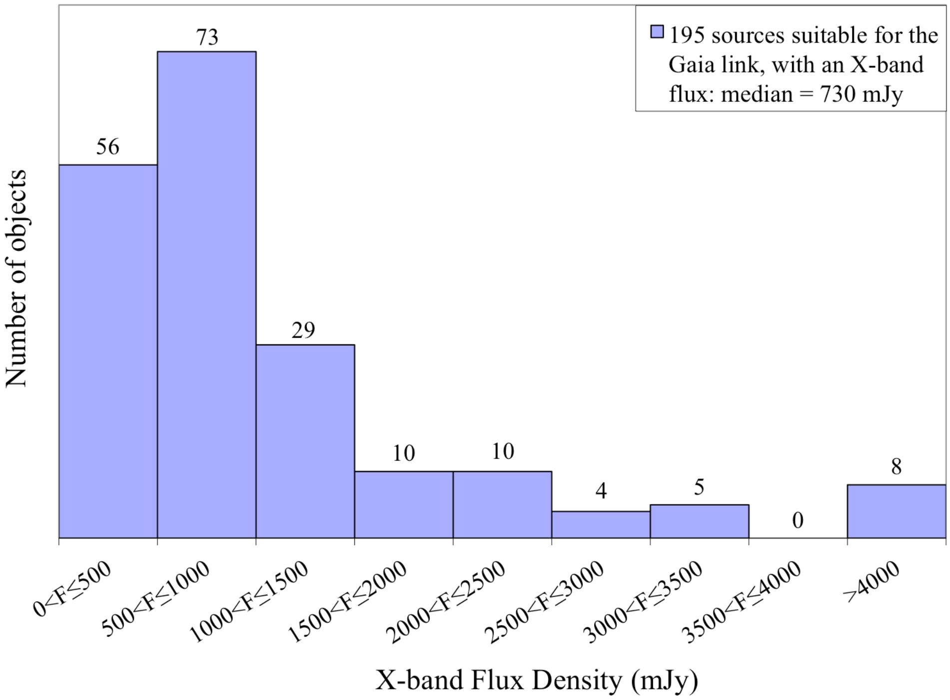

Figure 2: Distribution of the X-band flux density for the 201 ICRF2 sources suitable for the alignment with the Gaia frame (units in mJy).

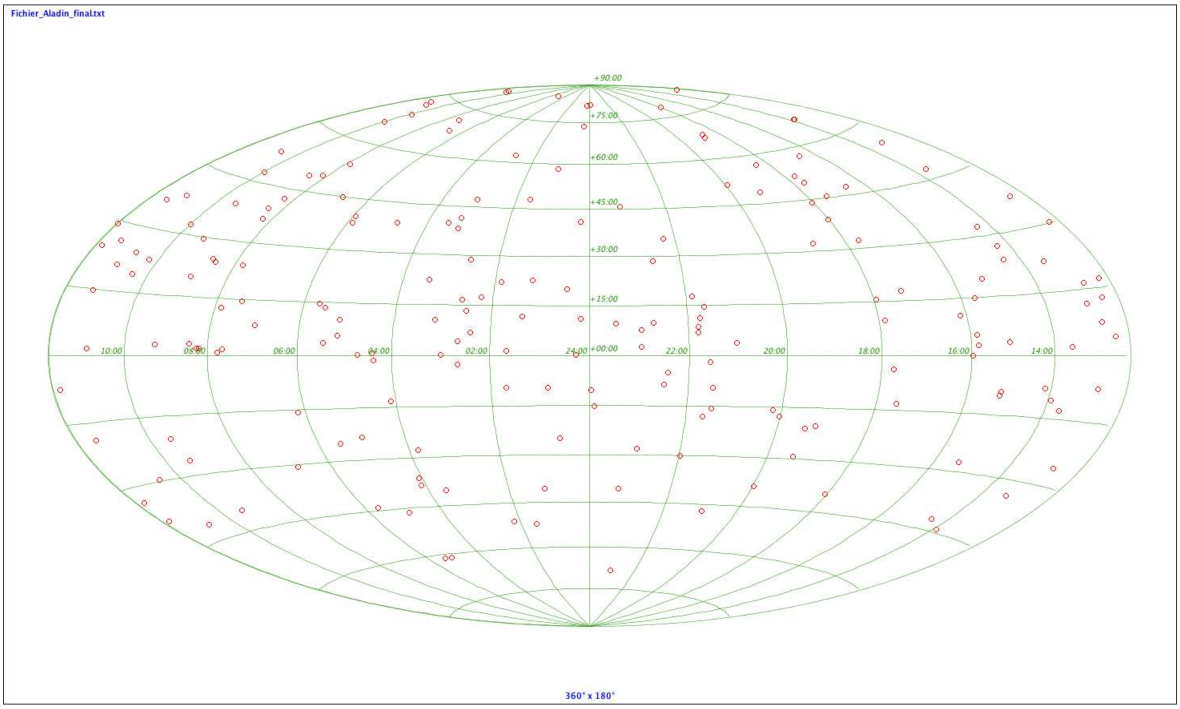

Figure 3: Sky distribution of the 201 ICRF2 sources suitable for the alignment with the Gaia frame.