On the differences between the optical and radio positions of ICRF2 sources

FAPERJ
Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro

ON
OBSERVATÓRIO NACIONAL

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Introduction

Fixed (non-rotating) directions on the celestial sphere can be kinematically defined by the positions of very distant objects. Such a concept has been the basis of the fundamental celestial frames adopted by the IAU since January 1998 (Ma et al., 1998, Arias et al, 1995). The current one, effective as of 1st January 2010, is the second realization of the International Celestial Reference Frame (ICRF2; IERS, 2009). It contains the positions of 3414 extragalactic sources as determined by very long baseline interferometry (VLBI) techniques, but only the very precise (< 0.4 milliarcseconds) positions of 295 sources, selected on the basis of positional stability and the lack of extensive intrinsic source structure, are effectively used to define the frame axes. The others have consistent positions with the defining ones and help to densify the frame. In contrast with the advantage of being a natural choice to the kinematical materialization of fixed directions, due to their large distances, extragalactic sources may present spatially extended structures at radio wavelengths. Their intrinsic radio structure is a limiting factor to the definition of the celestial frame (Charlot et al., 2008) and may also lead to differences between the respective optical and VLBI positions (da Silva Neto et al., 2002). This last feature is most frequent among the non defining sources. In this work we show, from observations carried out with SOAR/SOI of ICRF2 sources, that these differences have correlation with the source's structure index in the X-band (8.4GHz) and that they may be significant. Our main conclusion is that the presence of the extended structure should be taken into consideration when comparing optical and VLBI positions of ICRF2 sources in the future.

• *Observational data, reduction and results*

Our sample consists of 7 ICRF2 sources, presented in Table 1, observed with SOAR/SOI. All images are in the R Bessel filter. Notice the values of the structure indices in the X- (8.4GHz) and S-bands (2.3GHz) given in this table. These indices are determined from VLBI techniques and are used to quantify the astrometric suitability of the sources within the ICRF2. They are integer numbers ranging from 1 (best case – most compact sources) to 4 (worst case – most extended sources). Details on the determination of these numbers can be obtained from Fey & Charlot 1997 and Fey & Charlot 2000. Figure 2 gives an example of an ICRF2 source (0906+015) with structure indices 3 and 2 in the X- and S-bands, respectively.

Table 1. Observational data and results.

IERS ID	Type	# of observed frames	# ref. stars used/total	V	z	Struct. Index X	Struct. Index S	$(O-C)_\alpha\cos\delta$ (mas)	$(O-C)_\delta$ (mas)
0440-003	Quasar	13	10/12	19.2	0.844	4	1	−62 (15)	−94 (24)
0743-673	Quasar	8	8/8	16.4	1.510	n.a	n.a	+11 (21)	−11 (21)
0754+100	BL Lac	8	8/14	15.0	0.660	2	1	−35 (25)	+65 (27)
0808+019	BL Lac	8	12/14	17.2	1.148	2	2	−24 (37)	+36 (33)
0829+046	BL Lac	6	10/10	16.4	0.180	2	2	−24 (33)	+23 (41)
0906+015	Quasar	8	10/12	17.8	1.018	3	2	+57 (26)	−41 (30)
0920-397	Quasar	24	23/36	18.8	0.591	2	1	+5 (30)	+72 (30)

Columns show: IERS identification, object type, number of SOI frames used, number of reference stars: used/total, magnitudes, redshifts, structure indices, and offsets in the sense optical -VLBI. Precisions are given between parentheses. n.a stands for *not available.* Angular units are given in milliarcseconds (mas).

The SOI is a mosaic of two 2kx4k CCDs separated by a gap of 7.8" along the largest dimension. This amounts to a total field of view of 5.3'x5.3'. To cover the gap and to also count on a larger number of reference stars, overlapping images were acquired. Angular measurements on these images were first obtained from the individual CCDs with the software PRAIA (Assafin et al. 2006). Then, these measurements were all combined by means of overlapping techniques (Teixeira et al. 1992, Camargo et al. 2005) to provide the final results shown in the last two columns of Table 1. The reference catalogue was the UCAC2 (Zacharias et al. 2004).

Figure 1 summarizes our main results. It plots the structure index in the X-band of the sources shown in Table 1 as a function of the angular distance between their respective optical and VLBI positions. In spite of the small number of points, this figure is representative of the following: the greater the structure index in the X-band the more likely to obtain a larger (and significant) offset between the optical and VLBI positions of the ICRF2 sources. This conclusion was also obtained from a larger set of sources observed with the wide field imager at the ESO/MPG 2.2m telescope (brazilian time at the instrument).

It is interesting to point out that the intrinsic structure is an evolving feature of the extragalactic sources and thus constant monitoring is needed. As a consequence, their structure index numbers may change with time. This was the case, as indicated in Fig. 1, to the source 0808+019. Its structure index in the X-band was recently updated from 1 to 2, based on VLBI experiments made in 2008.

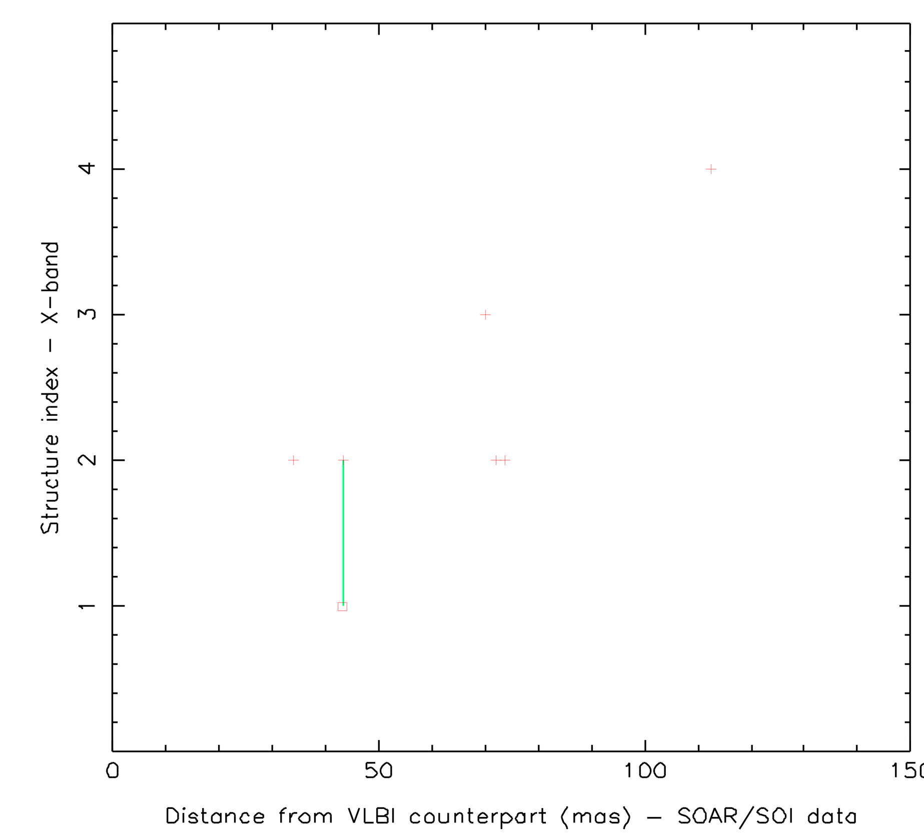

Figure 1. Structure index in the X-band of the sources in Table 1 as a function of the angular distance between their respective optical and VLBI positions. The small square indicates the index number of source 0808+019 from VLBI experiments up to 2005. The green line links it to the updated value from experiments made in 2008. This plot indicates that the higher the structure index in the X-band is, the more frequent a significant discrepancy between the optical and VLBI positions of ICRF2 sources will be found.

• *Comments on individual sources*

- 0743-673 – this source was also observed with the wide field imager at the ESO/MPG and with the SOFI camera at the NTT (see Camargo et al. 2005). Measurements with the first instrument gave offsets of +55 (30) mas and +17 (35) mas in right ascension and declination, respectively. With the latter instrument, offsets of +112 (13) mas and 23 (14) mas were obtained. These values should be compared to those in Table 1 to this source. The agreement seen to the offsets in declination is not shared by those in right ascension. In addition to statistical fluctuations, this result seems to also include the presence of an extended structure along the right ascension of 0743-673, as shown by the high angular resolution map in Ojha et al. 2005.
- 0920-397 – this is a definition source. It illustrates that even the most suitable reference frame sources within the ICRF2 may present significant offsets (Table 1). On average, it is expected that smaller dispersions and smaller mean values of the distances between the optical and VLBI positions be associated to smaller values of the structure index in the X-band.

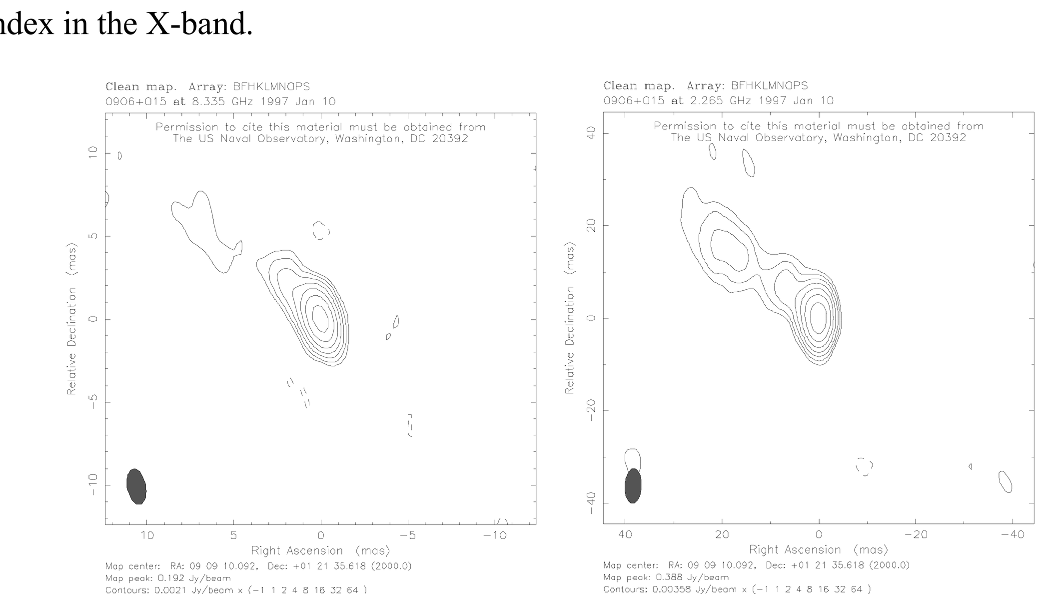

Figure 2. High angular resolution maps of 0906+015 in the X- and S-bands.

• *Conclusions & Comments:*

The positional accuracies listed in the ICRF2 are of the order of the milliarcsecond to most of the sources, being them defining or not. This is, at least, 1 order of magnitude better than the accuracy that studies like this one can reach from direct imaging at optical wavelengths. Frequently, the difficulty resides in translating the angular measurements from the instrument, where precisions as good as a few milliarcseconds can be achieved, into right ascension and declination consistent with an adopted system. As a consequence, offsets like those shown in Table 1 tend to be attributed to either systematic errors in the reference catalogue or to statistical fluctuations. The results presented here and by da Silva Neto et al., however, tell us that there is something else affecting the offsets.

An independent work by Zacharias. M & Zacharias N. (2009, XXVII GA-IAU) reports offsets between optical and VLBI positions of sources listed in the ICRF2 that may reach 100 milliarcseconds. The authors' conclusions to this fact are either a real physical offset between the centres of emission at radio and optical wavelengths or a problem in the optical reference frame. Although the latter can not be discarded, this work gives basis to a real physical offset as the origin of the large offsets. It is just as well to mention that the largest offsets found in that work, resulting in angular distances between the optical and VLBI positions greater than 100 milliarcseconds, came from sources with a structure index of 3 in the X-band.

Our main conclusion is that the presence of the extended structure should be taken into consideration when comparing optical and VLBI positions of ICRF2 sources in the future.

References & Acknowledgements

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- *This work has made use of material from he Bordeaux VLBI Image Database (BVID).*
- *This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France.*
- *This research has made use of the United States Naval Observatory (USNO) Radio Reference Frame Image Database (RRFID).*