THE LARGE QUASAR ASTROMETRIC CATALOGUE (LQAC) AND THE DENSIFICATION OF THE ICRF THROUGH THE LQRF (LARGE QUASAR REFERENCE FRAME)

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ABSTRACT. As quasars are generally considered as ideal objects for astrometry, for they are supposed to materialize quasi-inertial directions in space, it looks interesting to compile all the existing quasars catalogues in a single one, emphasizing the astrometric quality of the objects according to the catalogue they are coming from. This is the purpose of the LQAC (Large Quasar Astrometric Catalogue) achieved by Souchay et al. (2009). In this paper we explain in some details the basic principles of the construction of the LQAC, as well as the prospects of a new version of this catalogue, and the link with the establishment of the Large Quasar Reference Frame (Andrei et al. 2009).

1. THE LQAC: AN EXHAUSTIVE COMPILATION OF THE VARIOUS QUASARS CATALOGUES

The quasars are playing a fundamental role in astrometry, because they are supposed to indicate quasi-inertial directions in space. As a consequence the primary reference frame for all astronomers is the ICRF (International Celestial Reference Frame) (Ma et al. 1998) with its recent up-date the ICRF2 (Boboltz et al. 2010), based on a set of 3414 radio loud extragalactic objects, mainly quasars, observed via the VLBI, presently the most accurate technique for the measurements of celestial coordinates, at the level of a few μas (microarcseconds). If the quality of optical observations, typically of the order of a few mas (milliarcseconds) at best, is by two orders worse than VLBI, no doubt that in the near future, with the improvement of optical techniques and the up-come of space missions as GAIA, the gap between the two kinds of techniques will be shortened. Moreover the number of optically recorded quasars is roughly 30 times larger than the ICRF2 sample ($\approx$ 110,000 objects instead of 3,500 ones). This overwhelming advantage in density of "optical quasars" counterbalances in some way their lack of accuracy with respect to radio-loud quasars. In fact, in order to construct the LQAC, we gathered the 12 largest quasar catalogues, 4 from radio interferometry programs and 8 from optical surveys.

One of the important steps consisted in carrying out the cross-identification between these catalogues. For that purpose we adopted an archiving strategy giving priority to the *a priori* most accurate catalogues (in fact the 4 radio ones), with a letter as a flag for each one. The list of the catalogues concerned is given in table 1. The most accurate catalogue was obviously the ICRF-Ext2 (Fey et al. 2004) (because it was not still superseded by the ICRF2 during the construction of the LQAC) which naturally was labelled with flag "A". It was followed by the three other VLBI catalogues, the VLBA (Fomalont et al. 2003) which contains 3357 sources with a milliarcsecond accuracy (flag "B") , the VLA (flag "C") and the JVAS (flag "D") catalogues which complete the radio quasars sample. At optical wavelengths the largest quasars catalogue was by far the fifth version of the SDSS (Sloan Digital Sky Survey) by Adelman-Mc.Carthy et al. (2007) containing 74 868 objects, followed by the 2-degree Field (2dF) Quasar Redshift Survey quoted as 2QZ (Croom et al. 2004) and including 22 971 objects. The FIRST radio survey (Gregg et al. 1996) and the Hewitt and Burbridge (1993) catalogue complete the list. Notice that for the LQAC we also took into account other optical catalogues as 2MASS (Cutri et al. 2003), the USNO B1.0 catalogue (Monet et al. 2003) and the GSC2.3 catalogue (Lasker et al. 2008). In fact the purpose of including these last three catalogues was not to include other quasars, but to complete significantly the photometric data after cross-identification with the quasars of the catalogues already mentioned before.

Table 1: Characteristics of the catalogues participating in the LQAC (Large Quasar Astrometric Catalogue) compilation.

Catalogue	Flag	Wavelength	No. quasars	Accuracy arcsec	Search radius arcsec
ICRF-Ext2	A	radio	717	0.001	1
VLBA	B	radio	3 357	0.001	1
VLA-015	C	radio	1 701	0.015	1
JVAS	D	radio	2 118	0.2	1
SDSS	E	optical	74 868	0.2	1
2QZ	F	optical	22 971	0.2	1
FIRST	G	radio	969	0.5	2
VLA+015	H	radio	157	0.2	2
HB	I	optical+radio	7 245	1.5	2-5-30*
2MASS	J	infrared	-	0.2	1
GSC2.3	K	optical	-	0.2	1
B1.0	L	optical	-	0.2	1
VV06	M	optical+radio	85 189	1.0	2-5-10*

*Three different search radii have been considered for the cross-identification.

For all the catalogues, except the Hewitt and Burbridge (1993), quoted in the following as HB, the positions of the objects are accurate at the level of $1''$ (arcsecond). Therefore the cross-identifications of quasars between these catalogues do not present any difficulty when adopting a $1''$ search radius. This is due to the fact that the probability to find two different quasars in one arcsecond circle is quasi-null. Things are becoming more complicated when one of the catalogues, which is the case of the sole HB one, contains objects with large positioning uncertainty. In the particular case of the HB catalogue, the search radius must be extended up to $30''$, for the uncertainty in position of the sources can reach this amount. Thus the probability of mismatch is rather big, but fortunately the redshift is a helpful criteria to discriminate the case of a simple or double object. In the case the redshift is roughly the same ($\Delta z < 0.1$, the object is considered as the same in the two catalogues. In the opposite case the two objects are considered to be different. This is illustrated in Fig. 1, where we can observe that the differentiation between the two cases is rather easy.

2. ADVANTAGES OF THE LQAC

The work consisting in compiling all the recorded quasars with a periodical up-date has been done for the last two decades in a very systematic, regular and complete manner by Véron-Cetty and Véron as in their recent version (Véron-Cetty and Véron 2006). Nevertheless the LQAC, whose the acronym implies that it is directed towards astrometric quality, brings some further improvements with respect to the compilation above : (i) it aims at being larger by including new quasars; (ii) it gives the most accurate determination of the celestial positions of the objects; (iii) it contains more information concerning their photometric properties; (iv) for the sake of homogeneity it systematically privileges large surveys to small catalogues; (v) by using a system of flag it gives directly a clear information about the cross-identification between the twelve catalogues in the compilation; (vi) it is based on a compilation strategy which ranges the catalogues by decreasing order of accuracy; (vii) it proposes a determination of the absolute magnitudes of the quasars in bands r and i by using up-to-date models of galactic extinction mapping (Schlegel et al. 1998) and new values of cosmological parameters (Spergel et al. 2007).

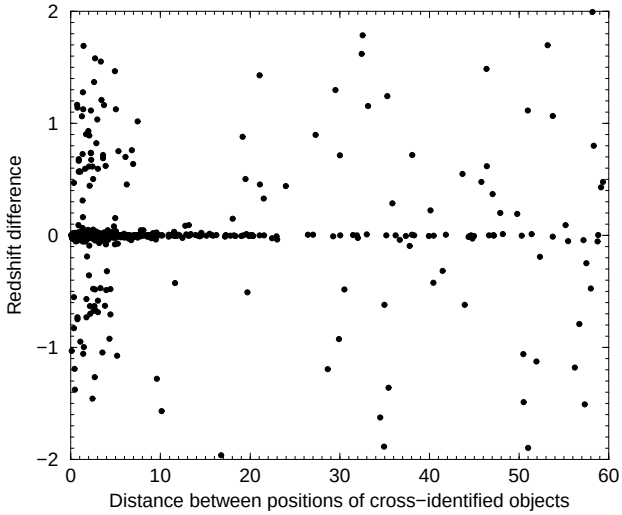

Figure 1: Comparisons of redshifts between common objects of the Hewitt and Burbridge catalogue and of the pre-compiled A-H catalogue, with respect to the angular distance of the objects. The quasars ranged horizontally corresponds *a priori* to a single object whereas those clearly out of the horizontal line correspond to a double object.

3. THE LQRF AND THE FUTURE UPDATE OF THE LQAC

Following the construction of the LQAC, the Large Quasar Reference Frame (LQRF) was built by Andrei et al. (2009) in order to give the positions of the LQAC quasars with an optimized accuracy with respect to the original catalogues, the care of avoiding incorrect matches of its constituents quasars, the homogenization of the astrometry from different catalogues and the aim of obtaining a milli-arcsecond global alignment with the ICRF, as well as typical individual source position accuracies higher than 100 mas (milliarcseconds).

The methodology for building the LQARF is the following one: starting from the updated and presumably complete Large Quasar Astrometric Catalog (LQAC) list of QSOs, the initial optical positions of the quasars were taken from the USNO B1.0 catalogue (Monet et al. 2003), the GSC2.3 catalogue (Lasker et al. 2008), and from the SDSS Data Release 5 (Adelman-McCarthy et al. 2007). Then, the initial positions were placed onto UCAC2-based reference frames (Zacharias,2006), followed by an alignment with the ICRF, to which were added the most precise sources from the VLBA calibrator list and the VLA calibrator list (when reliable optical counterparts exist). Finally, the LQRF axes were inspected through spherical harmonics, to define right ascension, declination and magnitude terms. In its first version (Andrei et al. 2009) the LQRF contains 100.165 quasars, represented with a rather homogeneous spatial density across the sky, from -83° to +88.5° in declination. For these reasons it can be considered as a good densification of the ICRF, the average angular distance between adjacent elements being roughly 10 arcmins.

Following all these efforts towards densification and accuracy, an up-dated version of the LQAC, called LQAC-2, is presently in preparation. The improvements with respect to the first version (Souchay et al. 2009) will be both quantitative and qualitative. On the quantitative side the quasars recently discovered will be included, in particular those coming from the last up-date of the SDSS quasars catalogue. Thus the expected total number of objects will be increased from roughly 110 000 to at least 140,000. On the qualitative side, in addition to the column giving the celestial coordinates as taken directly from the original catalogues participating at the compilation, another column with the coordinates (*a priori* more accurate) computed for the LQRF (Andrei et al. 2009) will be given. Moreover each object will

have an identification number directly associated with its celestial coordinates (α, δ).A significant new information will concern the compacity of the objects, a fundamental point to determine their ability to serve as a point-like source. A compacity index will be given, numbered from 1 to 10, according to its profile. At last the ambiguity concerning the HB quasars positions mentioned in Section 1 will be eliminated after clear recognition of the HB objects and positioning at the level of $1''$.

4. REFERENCES

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