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Interpretation of VLBI Results in Geodesy, Astrometry and Geophysics

The Large Quasar Astrometric Catalog and the Radio-Optical Link

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Abstract. Face to the huge and always increasing number of quasars recorded in various surveys and catalogues, we made a general compilation of all these objects, by including their best astrometric estimates and a large quantity of informations concerning their photometry, radio fluxes, and redshift. Moreover we evaluated the absolute magnitude of all the objects with up-to-date cosmological parameters and galactic extinction maps. A flag was adopted for the main catalogues of our compilation which enables a direct information of the cross- identifications. Our catalog is quoted as LQAC (Large Quasar Astrometric Catalog) and contains 113653 quasars at all.

1. Strategy for the LQAC Compilation of Quasars

The first guiding principle of our compilation is to insist on the astrometric quality. For this purpose we retain for each quasar the a priori most accurate value of its celestial coordiantes with respect to the ICRF (International Celestial Reference Frame). This leads to a hierarchy in the catalogues taken into account with a flag represented by a letter corresponding to its place in the hierarchy. For instance the ICRF-Ext.2 will be considered as the most accurate one and consequently will be attributed the flag "A", followed by the VCS catalogue with flag "B" etc... When an object is found in common to two or more catalogues, through an appropriate procedure of cross-identifications, then it will be characterized by its best equatorial coordinates according to

our hierarchy. Notice that roughly 90% of our quasars sample are included in only 11 catalogues, whereas the remaining ones are found in more than 200 small ones. Consequently we use the flags "A" to "L" to symbolize each of the 11 leading catalogues (concerning the VLA catalogue two flags will be used as will be explained in the following), and flag "M" to characterize the remaining ones. In this last case a number designates the catalogue of origin in which the object has been detected for the first time. In the following we recall the characteristics of the catalogues participating in our compilation.

• The ICRF-Ext.2 catalogue (Flag "A")

The up-coming of the ICRF-Ext.1 and of the ICRF-Ext.2 [7] brought 109 new sources in the catalogue, thus leading to a total number of 717 radio-sources. Notice that among the ICRF-Ext.2 catalogue, a very small sample of objects are not quasars : 10 of them are ranged in the category of AGN (Active Galactic Nuclei) and 10 of them in the category of BL LAC (BL Lacertae). Although we are a priori exclusively considering quasars in our compilation, we keep these particular objects thanks to their remarkable astrometric accuracy.

• The VLBA Calibrator Survey (VCS) catalogue (flag "B")

In the original VCS1 campaign [3] 1811 sources were observed but the final VCS1 catalogue contained 1289 sources from dual frequency solutions, with 43 sources from the 8.4 GHz only solution. Our catalogue used in our compilation contains finally 3357 objects. As given the very high acccuracy in the equatorial coordinates of the quasars, we put this catalogue in second position, with flag "B", just after the ICRF-Ext.2. The only additional information that we pick up from the original catalogue are the radio fluxes in the two bandwidths above.

• The VLA catalogue (flags "C" and "H")

The VLA catalogue of quasars contains information concerning the accuracy of source positions. Therefore we decided to separate the original catalogue in two parts, one with accuracy better (less) than $0.15''$ and another containing all the sources with accuracy worse than this value. The first sub catalogue, with flag "C", contains 1701 quasars with an astrometric precision around 10 mas whereas the second one, with flag "H" is much smaller with only 157 quasars with an accuracy around $0.2''$. For all objects, fluxes are given at 6 frequencies: 0.3 GHz, 4 GHz, 5 GHz, 8.4 GHz, 15 GHz, and 23 GHz. Nevertheless, only a few of these flux determinations are given for the objects.

• The radio JVAS catalogue (flag "D")

Our JVAS (Jodrell Bank-VLA Astrometric Survey) catalogue contains 2118 sources with 8.4 GHz flux information [11, 4, 17]. The associated technological device is MERLIN (Multi-Element Radio Linked Interferometer Network) which represents the UK's national radio imaging facility. It is operated by the University of Manchester and consists in an array of radio telescopes distributed around Great Britain, with separations up to 217 km. It operates at frequencies ranging from 151 MHz to 24 GHz, with a resolution better than 50 mas at 5 GHz.

• The optical SDSS catalogue (flag "E")

The SDSS (Sloan Digital Sky Survey) is covering about one quarter of the

sky, observed from a dedicated 2.5-m telescope located at Apache Point, New Mexico. Images are obtained in five broad optical bands (designated by u, g, r, i, z) covering the wavelength range of the CCD response from atmospheric ultraviolet cutoff to the near infrared [8]. The astrometric calibration [13] yields an accuracy per coordinate of 45 mas when reduced against the USNO CCD Astrograph catalogue (UCAC) and 75 mas when reduced against Tycho-2.

Our SDSS quasars input catalogue is by far the largest one, thanks to the DR5 release. It contains 74 868 objects [14]. and gives extensive photometric information for the quasars with magnitudes estimations in the u, b, v, g, r, i, z colors and a presise redshift evaluation.

• The 2QZ catalogue (flag "F")

The 2-degree Field (2dF) QSO Redshift Survey, quoted as 2QZ [5] is based on a pre-selection of quasars candidates from well defined criteria from a broad-band u, b_j, r colors obtained starting from automated plate measurements (APM) of UKST photographic plates. Then a spectroscopic follow-up of the QSO's candidates already selectioned was completed by a χ^2 minimization technique. The survey area comprises 30 fields arranged in two $75^\circ \times 5^\circ$ declination strips, one passing across the South Galactic Cap, centered on $\delta = -30^\circ$ and the other passing across the North Galactic Cap, centered on $\delta = 0^\circ$.

At total the sample contains 22 971 quasars in the 2QZ for our compilation. Notice that a little more than 2000 quasars are found in common in the 2QZ and SDSS catalogues. Recently, [15] analyzed the global rotations between the two catalogues thanks to these common objects.

• The FIRST catalogue (flag "G")

The FIRST radio survey [9] has provided a new resource for constructing a large quasar sample, with positions accurate to better than $1''$, and with high radio sensitivity. One of the main tasks consisted in matching the radio catalogue from the NRAO VLA survey [1] with an optical catalogue provided by the Automated Plate Machine (APM) digitization of Palomar Sky Survey Plates. Optical selection was accompanied by several spectroscopic campaigns in order to refine the selection criteria. The first release concerned $300 deg^2$ and contained about 200 objects. It was completed by a second release (White et al.,2000) containing 636 quasars distributed over $2682 deg^2$ and a third one [2] in the South Galactic Cap, containing 321 quasars for $589 deg^2$. For our compilation we use 972 quasars of the most recent catalogue. In addition to their position supposed to be accurate at the level of $1''$, we kept the r and b magnitudes together with the radio flux at 1.4 GHz (20 cm) and the redshift.

• The Hewitt and Burbridge catalogue (flag "I")

About fifteen years ago [10] have published a catalogue containing all known quasars with measured emission redshifts, that is to say 7245 objects, nearly all QSO's. From this catalogue we extract for each object, when available and when they have not been already recorded by the "A" to "H" catalogue compilation, the informations which are useful for our compilation, i.e. the u, b, v, g, r, i magnitudes together with the redshift. An important problem presented by this catalogue is the poor accuracy of the equatorial coordinates

for a significant proportion of the quasars in the list.

• Additioning informations with the 2MASS (flag "J"), GSC2.3 (flag "K") and B1.0 (flag "L") catalogues

The USNO-B1.0 catalogue [12] presents magnitude photometric accuracy in up to three colors (Johnston B, R and I), for 1 042 618 261 objects on all-sky basis . The photometry results from scans of 7 435 Schmidt plates taken for the various sky surveys and calibrated using Tycho-2 stars. The resulting photometric accuracy is 0.3 mag., reaching up to $V = 20$.

The GSC2.3 catalogue established from the Space Telescope Science Institute (Stsci) and the Osservatorio Astronomico di Torino, 2006 is an all-sky catalogue of 945 592 683 objects, resulting from photographic Sky Survey plates, at two epochs and three bandpasses, from the Palomar and UK Schmidt telescopes (DSS). The magnitudes are consistent with B, R, and I Johnston, and an estimation of the V magnitude is also given. The GSC2.3 has no formal magnitude limit. The parameters of the bright objects, overexposed on the Schmidt plates, are taken from the Tycho-2 catalogue.

The 2MASS (Two Micron All-Sky Survey) catalogue [6] results from a uniform scanning of the entire sky in three near-infrared bands to detect and characterize point sources brighter than about 1 mJy in each band, with signal-to-noise ratio (SNR) greater than 10. The detectors worked at J (1.25 μm), H (1.65 μm), and Ks (2.17 μm) bands s, to a 3σ limiting sensitivity of 17.1, 16.4 and 15.3 mag. respectively. The 2MASS Point Source Catalogue has a total of 470 992 970 sources.

These three catalogues do not bring a new set of quasars, but enable to complete the data lacking up to this point, especially concerning the photometry. For instance cross-identifications with the 2MASS catalogue adds the infrared magnitudes in J and K bands for 13 647 quasars of our total sample, whereas the GSC2.3 catalogue brings b magnitudes for 69 355 quasars and v magnitude for 41 517 quasars.

2. The LQAC and Future Prospects

Our LQAC catalogue contains a large majority of the recorded quasars at the present time, with 113 666 entries, that is to say 25% more than the 85 182 quasars in the last release of the Véron-Cetty and Véron catalogue [18], which constituted the largest compiled catalogue available until now. Moreover we have included in the LQAC additional informations, when available : they are ranged in 20 columns corresponding to 9 photometric bands (u, b, v, g, r, i, z, J, K), one redshift determination, five radio-fluxes at 1.4 GHz (20 cm), 2.3 GHz (13 cm), 5.0 GHz (6 cm), 8.4 GHz (3.6 cm) and 24 GHz (1.2 cm) and 6 columns related on the estimation of the absolute magnitudes at two bands, i and b. Notice that a large fraction of quasars of the LQAC, i.e. 104 944 objects that is to say 92.33% of the total sample, are coming from only 11 catalogues, the largest one being the last release DR5 of the Sloan Digital Sky Survey. One of the characteristics of the LQAC is to give a flag for each of

these leading catalogues above, which enables to know immediately for which of these catalogues a given quasar has been identified.

In the LQAC related paper [16] we have also studied the homogenity of the data, both in the astrometric and photometric fields, by comparing the parameters as equatorial coordinates , magnitudes and redshifts, as given by two or more different catalogues. We have also presented some statistics concerning the spatial distribution of the objects. At last we think that we have carried out a precise and very careful method to determine with the best accuracy the absolute magnitudes of the quasars at two bandwidths M_i and M_b, by taking into account the most recent models of galactic extinction, of K correction and of luminosity distance.

At last we schedule to up date the LQAC in an annual basis, by adding new discovered quasars, by completing the data and improving its quality, and carrying out statistical studies. We think that this work should be very useful for the VLBI community as well as in the frame of the preparation of future astrometric surveys and space missions as GAIA.

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