ASTROMETRIC REPRESENTATION OF THE GAIA EXTRAGALACTIC REFERENCE FRAME FROM GROUND OBSERVATIONS

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ABSTRACT

The Gaia Extragalactic Celestial Reference Frame (GCRF) will be formed by about 500 000 quasars, up to magnitude G = 20, defined to typical precision of 50 μas. The GCRF is pivotal for many of the mission objectives, starting with the astrometry catalogue. Yet the pre-mission representation of the GCRF is complicated because of the comparatively small number of observed quasars. Here, we present a restricted representation of the GCRF, based on the Véron-Cetty & Véron list of 48 921 quasars. This representation brings the original list to a fully coherent placement on the ICRS. The source positions have been collected from the USNO B1.0 catalogue, which is complete to V = 20. Around each of them, fields of size as small as 6′ were detailed, in which were picked up B1.0 stars and their corresponding positions from catalogs extending the HCRS to dimmer magnitudes. The UCAC2 (48 million stars, to RV = 16, precise to 30 mas) and the 2MASS (470 million objects, complete to J = 16, precise to 100 mas) acted as the astrometric reference catalogs. Taking as paradigm the B1.0 positions corrected by the UCAC2, a reference frame is obtained containing 37 513 quasars, globally aligned to 1mas with the ICRF. The optical minus radio standard deviation is at 150 mas, much smaller therefore than the nominal 200 mas B1.0 accuracy (the o–r standard deviation is above 300 mas for the original V&V entries). The extragalactic reference frame obtained in this manner enables us to gather insights on the distribution and luminosity of the GCRF. At the same time it provides a useful frame for all-purpose observations.

Key words: Gaia; Reference frame; Quasar.

1. INTRODUCTION

The clean sample, i.e., harbouring no contaminant stars, of quasars observed by Gaia is currently estimated to contain from 50 000 to 100 000 objects. The GCRF itself will be formed by a much larger contingent of some 500 000 quasars. Presently the Véron-Cetty & Véron (2003) list, hereafter V&V, is the most extended sample of the GCRF population. In its 11th edition, it contains 48 921 quasars, therefore about the same as the minimum of the Gaia quasars clean sample. The V&V list thus provides the best available template for the GCRF. Although not statistically complete, its remarkable survey of the literature accesses informations on magnitude, radio flux, colour and redshift. The precision of the sources' positions, because of the very completeness of the survey, can vary widely and is given to 1″.

On the other hand, such precision is sufficient to locate the sources. As are, in addition, the magnitude and colour information. In this way, the V&V quasars can, in principle, be found in dense, deep, all-sky catalogues, as the USNO B1.0 (Monet et al. 2003). The B1.0 contains 1 045 913 669 entries, to nominal precision of 200 mas, plus proper motions information, and B, R, and I magnitudes. It is believed to be complete to V = 20. The catalogue epoch is 2000.0, and the positions are referred to the HCRS, through the plate reduction by Tycho 2 stars.

Zonal errors are known to be present on the B1.0 positions, but recent analysis suggest that the positions are locally coherent in neighbourhoods up to 20° (da Silva Neto et al. 2004). Local corrections can then be found, by comparing its stellar positions to those from more precise catalogs, preferably at the original date of the plates. To furnish the local corrections to the B1.0 positions, the UCAC2 catalogue (Zacharias et al. 2003) combines precise stellar positions and proper motions, adherence to the HCRS, deepness on magnitude, and high density. It numbers 48 330 571 stellar entries, up to R = 16, and average individual precision of 50mas.

The combination of the V&V list of quasars (represented in Figure 1) with their positions taken from the B1.0, and locally corrected by the UCAC2 frame, is able to deliver an extragalactic reference frame, tied to the HCRS, representing the ICRS. The next Section presents the method used for obtaining the quasar positions. The preliminary results are presented in Section 3. Conclusions and perspectives are summarized in the last Section.

[*]On leave from home institute

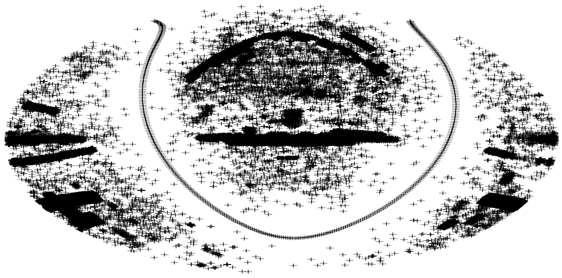

Figure 1. Sky distribution of the V&V quasars. The centre of the plot is at α=12^h, δ=0°. The plane of the Galaxy is represented, showing the difficulty of detecting quasars.

2. METHOD

To find the B1.0 position for the V&V quasars three conditions have been enforced. That the positions would match below 1″, which guarantees to be within the combined 2.5 σ level. That the corresponding B1.0 entry had proper motions smaller than the proper motions error. And that the B1.0 and V&V magnitudes would not differ by more than 3. The process is fully automated and, in case of more than one candidate fulfiling the criteria, the one closest to the V&V position was chosen. Next, B1.0 positions were picked for UCAC2 stars around the quasar. For that the UCAC2 positions were placed at the date of the B1.0 original plate containing the quasar. Then the same recognizing criteria of position and magnitude matching were used.

In order to test the method of correction of the B1.0 positions by the UCAC2 stars, 29 quasars were taken randomly across the sky. Around each of them, a field of UCAC2 stars was selected in boxes of side 10′, containing at least 35 stars. For these 29 fields of quasars, were tested complete polynomial solutions with degrees varying from 0 to 3$^{\rm rd}$, and a straight averages solution. Table 1 shows that the different solutions perform alike, both for the correction to the central source position and the associated error, and for the standard deviation of the solution.

Table 1. Comparison between the B1.0 polynomial corrections by UCAC2 stars. Offset refers to the straight mean of the differences B1.0–UCAC2. Right ascension and declination averages and standard deviations for 29 fields are presented. All values in mas.

Solution	$\overline{\Delta\alpha cos\delta}$	$\sigma_{\Delta\alpha cos\delta}$	$\overline{\Delta\delta}$	$\sigma_{\Delta\delta}$
3$^{\rm rd}$ deg.	+42	126	−25	140
2$^{\rm nd}$ deg.	+43	127	−23	136
1$^{\rm st}$ deg.	+61	110	−34	120
0 degree	+42	126	−34	119
offset	+56	118	−45	130

From the results shown in the table, the 1$^{\rm st}$ degree complete solution has been adopted. It allows to use less UCAC2 stars, and hence smaller fields around the quasar. Besides, on the 1st degree solution the error on the central, pseudo-tangential point, which is always the B1.0 position of the quasar, is the smallest. Expressly, the enforced solution is:

$$\xi_{UCAC2} - X_{B1.0} = a\,X_{B1.0} + b\,Y_{B1.0} + c \quad (1)$$

$$\eta_{UCAC2} - Y_{B1.0} = d\,Y_{B1.0} + e\,X_{B1.0} + f \quad (2)$$

3. RESULTS

By using the above defined matching criteria, 42 279 V&V quasars have their position found in the B1.0 catalogue. However, due to the current limitations of the UCAC2 catalogue for the far northern declinations, the full corrections have been determined so far for 37 513 of the V&V quasars. Figure 2 shows the sky distribution of the resulting extragalactic frame.

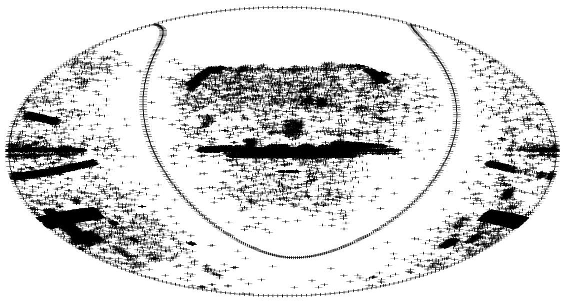

Figure 2. Sky distribution of the 37 513 V&V quasars, which positions have been determined from the B1.0 entries as locally corrected by UCAC2 stars frames. The center of the plot is at α=12^h, δ=0°.

The UCAC2 local corrections have been obtained in square fields of side 6′, and at least 5 references stars (otherwise the field was increased at 1′ steps). The average number of UCAC2 stars was 16. The first degree independent polynomials (Equations 1 and 2) are solved by least squares. Figures 3 to 6 illustrate the obtained corrections.

The usefulness of the UCAC2 local corrections is clearly appreciated when comparing the direct B1.0 positions against the VLBI positions for the V&V quasars. In this case, as shown on the left side of Figure 7, an important equatorial offset and large scale zonal variations appear (Fienga & Andrei 2004; da Silva Neto et al. 2004). On the right side of Figure 7, on the other hand, for the same V&V quasars, the differences between the B1.0 positions corrected by UCAC2 stars minus the corresponding VLBI positions are plotted. It is seen that the large systematics both in right ascension and declination effectively disappear.

The present northern limitation brought by the absence of UCAC2 stars in that region, can be overcome either

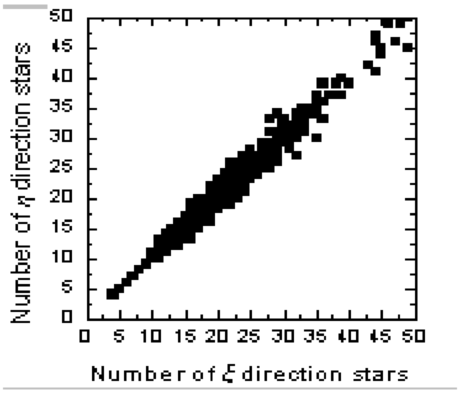

Figure 3. Number of UCAC2 stars used to solve for the independent (X,ξ and Y,η) solutions.

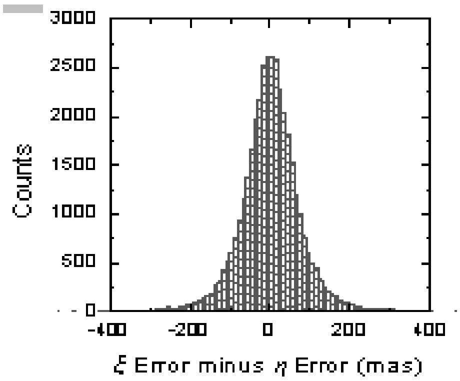

Figure 4. Distribution of the (X,ξ) minus (Y,η) errors from the least squares adjustments of the same sources.

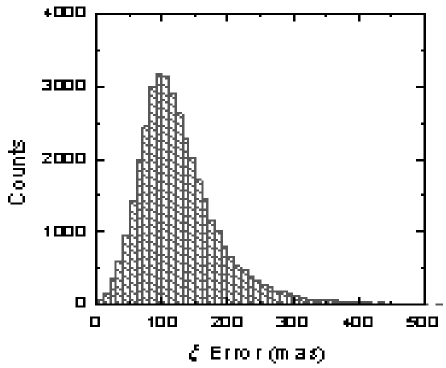

Figure 5. Distribution of standard errors from the least squares adjustments for the (X,ξ) solutions.

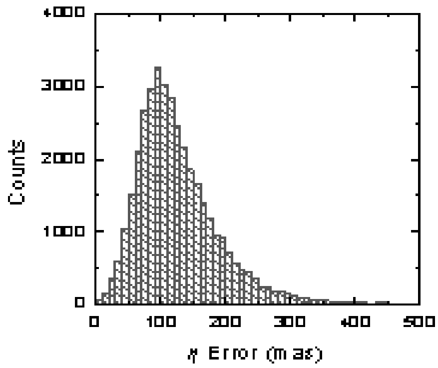

Figure 6. Distribution of standard errors from the least squares adjustments for the (Y,η) solutions.

using the newer UCAC2 version to shortly appear, or by using 2MASS (Cutri et al. 2003) stars. The 2MASS catalogue is tied to the UCAC2, and a pilot reduction was made in selected fields. The reduction was made for all V&V quasars appearing in the 2MASS. The average offset between the 2MASS and UCAC2 stellar positions was $\overline{\Delta\alpha cos\delta}$ = 3 mas (σ 99 mas) and $\overline{\Delta\delta}$ = 11mas (σ 95 mas).

To quantify the improvement obtained and the adherence to the ICRF, Table 2 brings the differences, in the sense optical minus radio, for the subsample of ICRF Ext1 sources. As seen, the standard deviations drop steadily from the V&V tabular representation to the B1.0 corrected by UCAC2 representation. It is interesting to notice that the standard deviations corresponding to the direct B1.0 entries are smaller than the B1.0 catalogue formal errors. This result had already been obtained by da Silva Neto et al. (2004), and might reflect the absence of important magnitude error dependencies, as well as deriving from the absence of proper motions for the quasars.

4. CONCLUSION AND PERSPECTIVES

The list of quasars compiled by Véron & Véron (2003) is an invaluable tool to build a simulation of the Gaia extragalactic celestial reference frame,whose constituent sources should be contained in the USNO B1.0 catalogue, albeit to a much lower precision.

The combination of the V&V list with the positions from the B1.0 catalogue enable to obtain an optical extragalactic reference frame, with one hundred times the number of the ICRF sources. Additionally, the B1.0 systematic errors can be removed by local corrections using UCAC2 stars. As both the B1.0 and the UCAC2 catalogues are tied to the HCRS, so too is the resulting extragalactic reference frame. The UCAC2 local correction mimics a plate reduction, and, due to the smallness of the required fields, it can be performed by independent (X,Y) first degree polynomials.

Presently, the formed extragalactic reference frame contains 37 513 sources. The adherence to the ICRF is -32

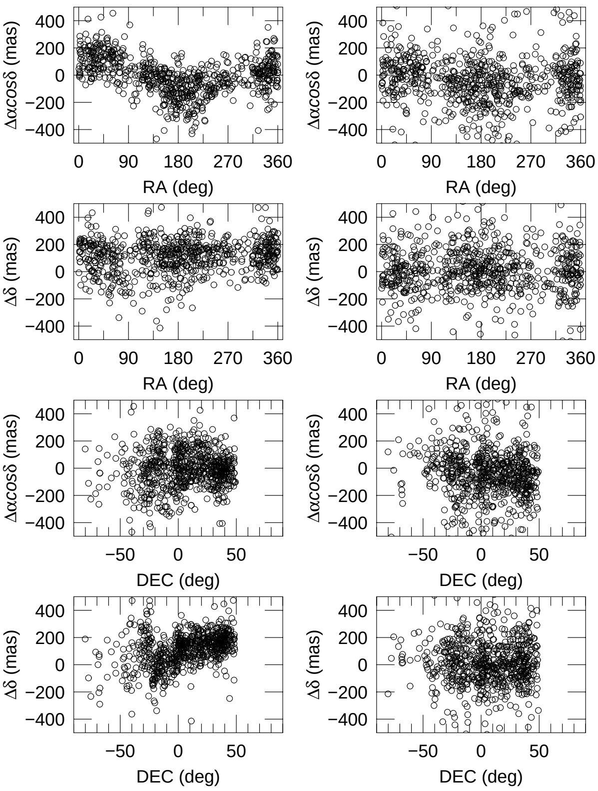

Figure 7. Optical minus radio position differences, for the V&V quasars. $\Delta\alpha cos\delta$ and $\Delta\delta$ dependencies on right ascension and declination. On the left side of the figure, the plots refer to the optical positions taken directly from B1.0 entries. On the right side of the figure, the positions are from the B1.0 values as locally corrected by UCAC2 stars. All differences are in mas, and equatorial coordinates in degrees.

$\pm$ 10mas on right ascension and $+8 \pm$ 9mas on declination. The standard deviations of the offsets to the ICRF positions are at the level of 150 mas. No systematic differences to the ICRF are apparent at this level. To compare, the corresponding standard deviation from the direct V&V entries to the ICRF positions is at the level of 320 mas.

The next steps, already being tackled, are to complete the top northern part of the V&V list, for which UCAC2 stars are not yet available. A way to do it is by using preliminary UCAC2 positions, provided that a study of their proper motion is made. Alternatively, 2MASS stars can be used. At any rate, a thorough reduction using 2MASS stars is planned, for the sake of comparison and study of the 2MASS astrometry. The analysis of residuals is also planned relative to the sources characteristics, as colour, magnitude, and redshift. For the final version of the optical extragalactic reference frame, the adherence to VLBI positions is to be used to furnish harmonic corrections, in such a way as to tie the optical reference frame directly to the ICRF.

Table 2. Comparison between the optical frames to the ICRF positions. The rows correspond to the direct V&V entries, the corresponding B1.0 entries, and the B1.0 entries as locally corrected by the UCAC2. All values in mas.

Difference to ICRF	$\overline{\Delta\alpha cos\delta}$	$\sigma_{\Delta\alpha}$	$\overline{\Delta\delta}$	$\sigma_{\Delta\delta}$
V&V	$+19 \pm 27$	309	-13 ± 29	328
V&V(B1.0)	-23 ± 11	186	$+107 \pm 10$	159
V&V(B1.0+UCAC2)	-32 ± 10	158	$+8 \pm 9$	147

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