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Optical positions of compact extragalactic radio sources with respect to the Hipparcos Catalogue

E. Costa and P. Loyola

Departamento de Astronomía, Universidad de Chile, Casilla 36-D, Santiago, Chile

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Abstract. Optical positions relative to the Hipparcos Catalogue, and therefore within the International Celestial Reference System (ICRS), have been obtained for the optical counterparts of 25 compact extragalactic radio sources (CERS) south of $\delta \sim +10^\circ$. Most of these sources are being monitored as Benchmark objects for the establishment of a unified extragalactic radio/optical reference frame. Precision levels as good as $0.1''$ in both coordinates were achieved. A comparison with VLBI radio positions available for these sources is presented. A finding chart is given for the optical counterpart of Q 1937−101. To a limiting magnitude of $B \sim 20.5$, no optical counterpart was found for the source 1148-671.

Key words: astrometry — reference systems — radio continuum: galaxies

1. Introduction

In the process of selecting the best Benchmark objects for the establishment of a quasi−inertial unified radio/optical extragalactic reference frame (those with minimum radio-optical position residuals and minimum structure), it must be kept in mind that the measured residuals do not necessarily represent real offsets between the radio and optical emission centroids; in some cases they simply reflect the errors of the optical positions (which are at least an order of magnitude larger than those of the radio positions) and/or deviations between the radio and optical reference frames.

In spite of the above, by means of conventional ground-based observations it has been possible in the past to uncover unsuitable link objects and system deviations; subsequent removal of these sources and system realignment has allowed −in an iterative process− a continuous refinement of the selection criteria. A point has been reached in which the interpretation of more subtle differences requires that the radio and optical positions be displayed in essentially the same reference system. The Hipparcos Catalogue, which has been constructed to coincide with the ICRS, and therefore can be considered an extension to the optical domain of the radio extragalactic reference system, provides the appropriate workframe for this to be realized.

In this paper we present positions with respect to the Hipparcos Catalogue for the optical counterparts of 25 CERS selected from the list of Jauncey et al. (1989, hereafter Jauncey) and the NRL/USNO list (see e.g. Johnston et al. 1995, hereafter Johnston). The observations were made as a part of the monitoring program being carried out with the flat−field 70/100/210 cm Maksutov Astrograph at the Estación Astronómica de Cerro el Roble, in an effort to contribute to the selection of Benchmark CERS (see Costa & Loyola 1997 −hereafter Paper IV− and references therein). Precision levels as good as $0.1''$ in both coordinates were achieved.

2. Observations and reductions

References to the optical identifications, finding charts, and other relevant data for the sources can be found in Jauncey et al. (1996). Notes on individual objects can be found in Sect. 5.

The two−step observational and reduction procedure was the same one described in detail in Costa & Loyola (1992, hereafter Paper I), with the exception that on this occasion the Hipparcos Catalogue was used as primary reference frame. The number of Hipparcos stars that were identified in each $5^\circ \times 5^\circ$ field around the CERS varied between 48 and 129, which gave an average of roughly 60 measurable stars (excluding close pairs, stars near the edges of the plates and bright stars); with lower densities found towards the equatorial zone. In comparison to the IRS system used in our previous work, the Hipparcos Catalogue not only provides a more precise primary reference frame, but also a denser and more homogeneous grid

Send offprint requests to: E. Costa

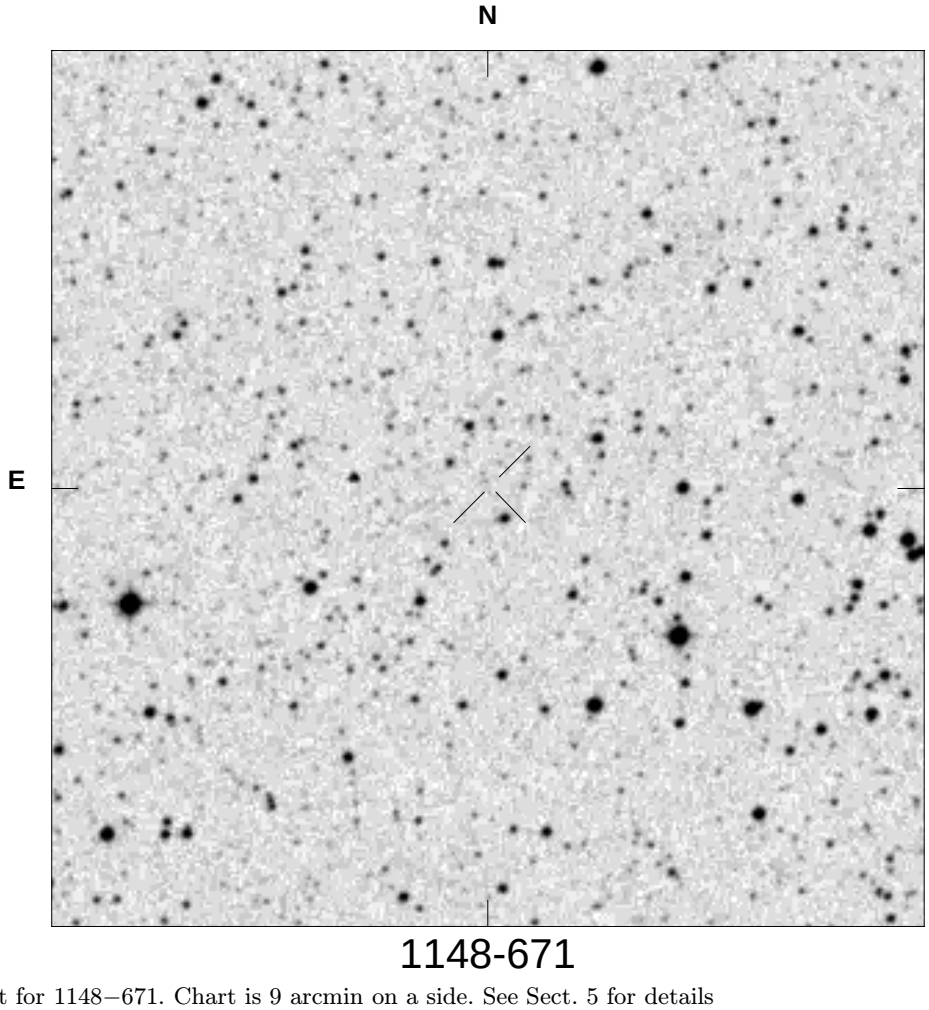

Fig. 1. Finding chart for 1148−671. Chart is 9 arcmin on a side. See Sect. 5 for details

of reference objects in the field of the CERS. This latter characteristic is a major improvement for our application; extensive experience with the IRS and AGK3R/Perth 70 catalogues, which provided an average of less than 20 measurable stars in the fields of the CERS, has shown that the solutions for cases with low density of catalogue stars are critically dependent on their distribution.

3. Results

The resulting optical positions with respect to the Hipparcos frame, and therefore in the system of the ICRS, are given in Table 1. The first column gives the IAU designation of the sources, the second and fourth columns their right ascensions and declinations, the third and fifth columns their corresponding total internal errors and the sixth column the epochs of the observations. Finally, Col. (7) gives the magnitude and nature of the objects. Q, G and EF stand for QSO, Galaxy and empty field, respectively. var.? indicates that the optical counterpart could be grossly variable, as suggested by the inconsistencies detected in the value assigned to its magnitude.

4. Errors

The errors of the measurements were determined as described in Sect. 4.2 of Paper I. The total internal errors of the positions presented in Table 1 were determined using the same relations given in Sect. 4.1 of Paper I.

Although it was predictable that the error of the Hipparcos Catalogue would be negligible compared to the errors of the measurements, we nevertheless did not use mean values for $\epsilon_c(\alpha)$ and $\epsilon_c(\delta)$ and calculated the error contribution of this catalogue on a zonal basis. It was determined that $\epsilon_c(\alpha)$ varied between 1.9 and 9.7 mas and that $\epsilon_c(\delta)$ varied between 2.2 and 7.1 mas.

5. Notes on individual objects

1148−671: The provisional $m \sim 19.3$ optical counterpart proposed by Jauncey for this radio source is incorrect. A comparison of our optical position with the VLBI radio position published by Ma et al. (1997, hereafter Ma) gives (radio-optical): $\Delta\alpha = -0.66''$ and $\Delta\delta = 5.21''$. Figure 1 shows more or less precisely the position of the radio

Table 1. Optical positions in the ICRS system of 25 compact extragalactic radio sources

(1) IAU Designation	(2) RA h m s	(3) $\epsilon_\alpha \cos\delta$ $\pm''$	(4) DEC $^\circ\ '\ ''$	(5) ϵ_δ $\pm''$	(6) Plate Epoch	(7) Mag and Nature
0047−579	00 49 59.427	0.20	−57 38 27.12	0.17	27/09/92	Q, 18.5
0202−765	02 02 13.641	0.13	−76 20 02.86	0.10	21/11/92	Q, 16.8
0219−637	02 20 54.196	0.10	−63 30 19.55	0.09	08/11/93	Q, 18.9
0302−623	03 03 50.655	0.10	−62 11 25.87	0.11	19/11/92	Q, 18
0316−444	03 17 57.671	0.17	−44 14 17.44	0.18	22/11/92	G, 16
0355−669	03 55 47.924	0.13	−66 45 34.04	0.09	05/01/94	Q, 17.3
0537−158	05 39 31.996	0.09	−15 50 30.37	0.16	16/01/93	Q, 18
0622−441	06 23 31.783	0.18	−44 13 02.48	0.15	15/01/93	Q, 16.9
0824+110	08 27 06.532	0.16	+10 52 23.16	0.11	02/03/94	Q, 17 var?
0830+115	08 33 14.355	0.14	+11 23 35.27	0.12	03/03/94	Q, 18.5
0907−023	09 09 44.923	0.13	−02 31 30.27	0.13	04/03/94	Q, 18.6
0915−213	09 17 27.037	0.10	−21 31 34.50	0.15	05/03/94	Q, 18.5
0957+003	10 00 17.656	0.12	+00 05 23.67	0.11	03/03/94	Q, 17.6
1030−357	10 33 07.679	0.13	−36 01 56.89	0.12	04/05/94	Q, 18.5
1103−006	11 06 31.775	0.09	−00 52 52.47	0.15	02/05/94	Q, 16.5
1105−680	11 07 12.677	0.15	−68 20 51.01	0.13	05/05/94	Q, 18.4
1106+023	11 08 45.510	0.14	+02 02 40.63	0.10	03/05/94	G, 17.3
1148−671	11 51 13		−67 28 11		04/05/94	EF?
1451−400	14 54 32.931	0.13	−40 12 32.54	0.10	02/05/92	Q, 18.5
1548+056	15 50 35.274	0.10	+05 27 10.60	0.15	03/08/94	Q, 18 var?
1733−565	17 37 35.766	0.21	−56 34 03.05	0.18	17/06/93	G, 17
1937−101	19 39 57.255	0.13	−10 02 41.57	0.15	04/08/94	Q, 19 var?
2052−474	20 56 16.375	0.16	−47 14 47.37	0.11	25/09/92	Q, 19
2232−488	22 35 13.244	0.14	−48 35 58.89	0.12	23/09/92	Q, 17.2
2355−534	23 57 53.266	0.12	−53 11 13.51	0.13	26/09/92	Q, 17.8

source. At the limit of our plates ($B \sim 20.5$), no optical object is seen in that position. The finding chart and the radio source position identification were obtained using standard IRAF procedures from a digitized image extracted from the Digitized Sky Survey (DSS), produced by the Space Telescope Science Institute. Unfortunately, this scan is based on a shallow 4 min exposure "supplemental" visual plate of the UK Schmidt Survey, which prevented us from examining the radio source position down to $B \sim 22.5$, the approximate magnitude limit of the "standard" blue UK Schmidt plates.

1937−101: To the best of our knowledge, no finding chart has been published for this object. Figure 2 shows the optical counterpart we propose, based on the small radio-optical residuals derived (see Table 2). The finding chart and the optical identification were obtained, as explained for Fig. 1, from a DSS scan based on a 55 min exposure UK Schmidt blue plate.

6. Comparison with other data and discussion

Table 2 gives the differences in the system of the ICRS with VLBI radio positions taken from the list of Ma, in the sense radio minus this work (CL). The residuals obtained are consistent with the precision of our optical data, and show that none of these CERS can be ruled out as possible link objects (source 1148−671 was not included in Table 2). Although the number of comparison objects is small, we nonetheless plotted the residuals as a function of the coordinates to search for possible systematic effects; no clear evidence in this sense was found.

The optical data presented in Table 1 were also compared with, mostly unpublished, optical positions with respect to the IRS Catalogue we have obtained for these objects. The same plate material was used for both determinations. This comparison yielded the following statistics: $\overline{\Delta\alpha\cos\delta} = -0.06''$, $\sigma(\overline{\Delta\alpha\cos\delta}) = 0.17''$; $\overline{\Delta\delta} = 0.10''$, $\sigma(\overline{\Delta\delta}) = 0.23''$; $n = 24$. Plots of the (Hipp−IRS) residuals as a function of the coordinates show clear systematic effects similar to those reported in Paper IV. This is not

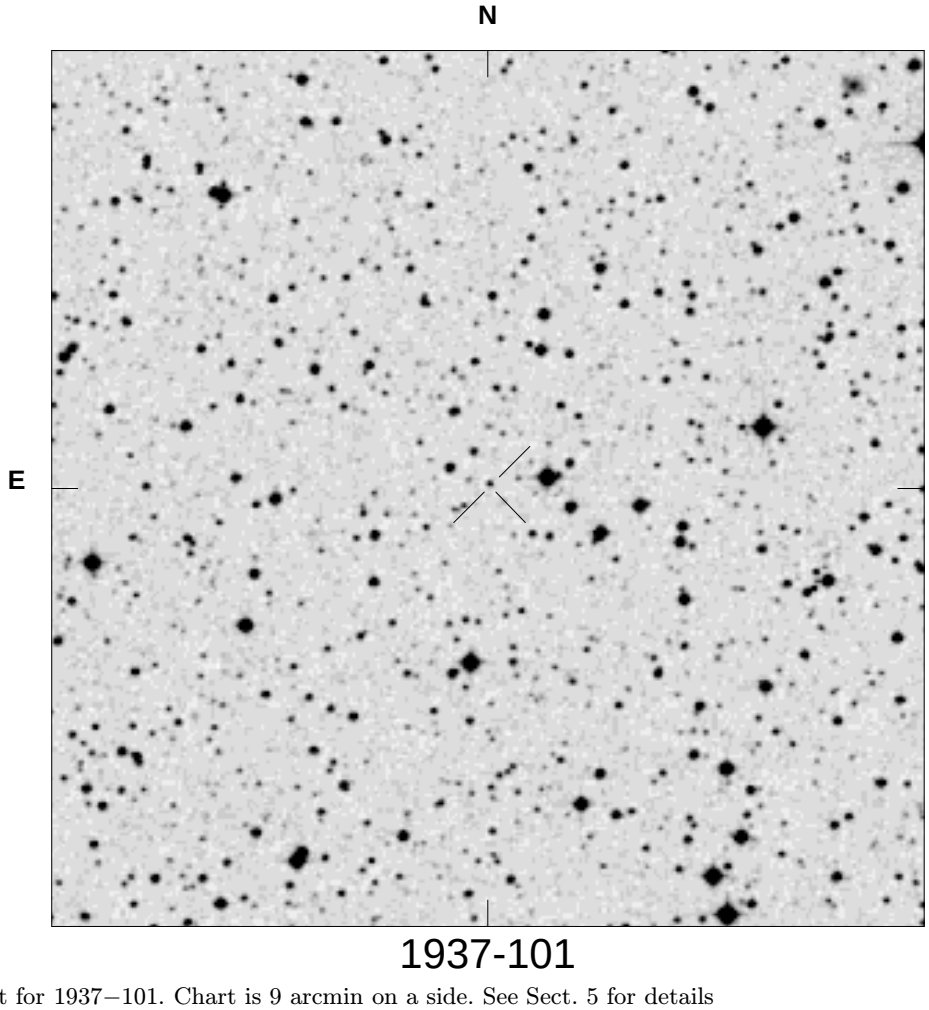

Fig. 2. Finding chart for 1937−101. Chart is 9 arcmin on a side. See Sect. 5 for details

Table 2. Comparison in the ICRS with the VLBI radio positions given by Ma

IAU Designation	(Radio − CL) $\Delta\alpha\cos\delta$ ″	$\Delta\delta$ ″
0047−579	+0.37	−0.22
0202−765	+0.19	−0.20
0302−623	−0.17	+0.32
0537−158	+0.20	+0.05
0622−441	+0.03	−0.06
1105−680	+0.10	+0.28
1451−400	−0.21	+0.03
1548+056	−0.07	−0.15
1733−565	+0.04	−0.11
1937−101	+0.02	+0.05
2052−474	−0.15	−0.26
2232−488	−0.07	+0.09
2355−534	+0.00	−0.18
Mean residual	+0.02	−0.03
Sigma	0.17	0.18
Standard error	0.05	0.05
N° of common objects	13	

surprising considering that our Hipparcos referred optical positions are linked to the ICRS, therefore a comparison of these positions with IRS referred positions brings out the deviations of the IRS(FK5) system from the ICRS.

7. Conclusions

The level of accuracy and homogeneity attained by the Hipparcos Catalogue provides the necessary workframe to "fine-tune" the selection of Benchmark objects to link the radio/optical extragalactic reference frames, and subsequent testing of their equivalence. However, for this to be fully realized, it is necessary to improve the accuracy of the optical positions, in particular the precision of the measurement of the optical counterparts. As shown by the relations given in Sect. 4.1 of Paper I, in the case of optically faint CERS, ϵ_r completely dominates the total internal error. One way to achieve this is by means of CCD observations in combination with conventional photographic astrometry. First results from a pilot program being carried out by us (Costa & Loyola, in preparation) show that it is possible to obtain positions for the optical counterparts of very faint ($V \sim 20-22$) CERS, relative to

stars in the field of the CCD, with an average precision of 30 mas, yielding total internal errors of the order of 70 mas.

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