Optical Positions for Identifications from the MC2 and MC3 Catalogues

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Abstract

Optical positions measured from the Palomar Sky Survey prints are given for objects identified with MC2 and MC3 radio sources. A comparison with other published optical positions for sources in common suggests an r.m.s. error of 0·35−0.35′ arc in each coordinate. Comparison of previously published optical positions from the Sydney measuring machine with subsequent more accurate radio positions indicates an r.m.s. error of 0·28′ arc in each coordinate for the optical positions of stellar objects.

1. Introduction

We present here optical positions accurate to 1′ arc or better for the objects identified by Hazard and Murdoch (1977) with radio sources from the MC2 and MC3 catalogues (Sutton et al. 1974) in the R.A. range 11h28m−17h00m. The original identifications were made on the basis of optical positions with an r.m.s. error of 3′ arc, which was adequate in relation to the radio errors which ranged from 4′ to 15′ arc. More-accurate optical positions are, however, necessary for comparison with accurate radio positions as these become available. This will assist in clarifying doubtful identifications, particularly for stellar objects that are neutral or red in colour.

In general, the positions given here for stellar objects (including BSOs and many of the faint galaxies) have an r.m.s. error of ±0·4′ arc. The remaining galaxies ≥17m have an error ~1′ arc although, for brighter galaxies, the errors increase due to the size of the galaxy image. The measurements were made at Sydney, R.R.E. Malvern and Cambridge by methods which are essentially similar but differ in detail. There is a considerable degree of overlap in the measurements in order to ensure adequate uniformity of the results.

2. Optical Measurements

(a) General Remarks

Since Hunstead (1971) demonstrated that accurate optical positions could be obtained from the Palomar Sky Survey prints, these have been widely used for this purpose. Hunstead (1974) showed that an r.m.s. error of 0·3′ arc is readily achieved. This has been confirmed by subsequent accurate radio positions (see Section 2b).

A transparent overlay showing the positions of the nearby reference stars together with the radio source is produced by a computer program which also predicts the x and y coordinates of these objects. Using well-established techniques, comparison
between the observed and predicted positions of the reference stars gives six param-
eters which account for origin shift, linear stretch of scale and rotation of the
print relative to the axes of the measuring machine. These are then used in computing
the optical position of the candidate object(s) from the measured $x$ and $y$ coordinates.
The curvature of the original plates is taken into account in all calculations, but not
the Schmidt bending corrections which are unimportant at this level of accuracy.

At least four reference stars are required to give some redundancy and to allow
the rejection of cases where the error in either the measurement or the catalogue
position is abnormally large. A unique solution is obtained for three stars but with
no indication of the accuracy of the fitted parameters. An earlier method due to
F. Schlesinger, which uses a fourth star merely as a check, is still used by some
observers (e.g. Veron and Veron 1975). Bridle and Goodson (1977) have recently
adapted Schlesinger’s method to make use of the measurements of all four stars in
a reduction program using a desk-top computer.

The chief sources of error in the measurements arise from: (i) the error $\sigma_r$ in
the positions of the reference stars; (ii) the print and plate distortions $\sigma_p$; (iii) the
setting error $\sigma_s$ on the reference stars; (iv) the setting error $\sigma_o$ on the unknown
object. The overall standard deviation $\sigma$ is then given by

$$\sigma^2 = (\sigma_r^2 + \sigma_p^2 + \sigma_s^2)/(N-3) + \sigma_o^2,$$

where $N$ is the number of reference stars and $N-3$ is the number of degrees of
freedom. Errors (iii) and (iv) can be reduced if desired by repeated measurements.
Other possible sources of error include small irregularities in the drive of the microscope
assembly and any small movements of the print during measurement. Most of the
errors listed above may include a small systematic component, especially the setting
errors; although most systematic errors can be eliminated by rotating the print
through 180° and repeating the measurement. Any small systematic error in the
reference star positions will of course remain.

(b) Sydney Measurements

The measurements made in Sydney are based on SAO (Smithsonian Astrophysical
Observatory) reference stars and were made by a technical assistant. Where possible,
eight stars were chosen, two in each quadrant. The reduction program eliminated
any stars whose fitted position in either coordinate differed from the predicted position
by a predetermined amount, normally set between 0·8° and 1·0° arc. For each
radio source, the procedure was repeated with the print rotated through 180°. Taking
the mean of the two sets of measurements minimized the effects of personal bias in
setting the crosshairs on faint objects and also guarded against gross errors.

As a check on the reliability of the Sydney measurements made by the technical
assistant, the sources from Hoskins et al. (1974) were remeasured using the same
reference stars. The r.m.s. differences between the new measurements and those
made by D. G. Hoskins (Hoskins et al. 1974) was 0·32" arc in right ascension and
0·39" arc in declination. This suggests an ‘observer error’ for the whole procedure
of about 0·25" arc, which should cover all sources of error except $\sigma_r$. Such a value is
consistent with the corresponding r.m.s. error of 0·27" arc obtained by Hunstead
(1974) from repeated measurements.
An independent estimate of the overall accuracy of the Sydney measurements may be obtained by comparing published optical positions with recent more accurate radio positions by Clark et al. (1976) who used VLBI measurements, by Ellsmore and Ryle (1976) who used the Cambridge interferometer and by Wade and Johnston (1977) who used the N.R.A.O. radio link 35 km interferometer. The present comparison is restricted to radio positions accurate to 0.15" arc or better, and to radio compact QSOs or BL Lac objects. There are 10 sources which meet these criteria, 8 from Hunstead’s (1971) original work and 2 from Hoskins et al. (1974). (Results from Hoskins et al. (1972) are not included because, as pointed out in that paper, these measurements were only intended to be accurate to ~1" arc.) For these 10 common sources, the r.m.s. deviation between the optical and accurate radio positions is 0.28" ± 0.04" arc in each coordinate (actually 0.25" in R.A. and 0.31" in Dec., but the values do not differ significantly). Comparing this with the suggested ‘observer error’ quoted above of 0.25" ± 0.04" arc indicates that the contribution of errors in the reference star positions is minimal.

For the present measurements an estimated total r.m.s. error of 0.35" arc seems to be realistic, after making allowance for a small number of cases in which the star distribution is poor or where the forward and reverse measurements differ by more than expected. For galaxies ~18" the errors can be expected to be only slightly greater than for stellar objects, and it seems reasonable to suggest an r.m.s. error of 0.4" arc for them. For brighter galaxies there will be an increasing error due to the difficulty of defining the optical centre. In some cases the error will also be slightly greater for galaxies at the plate limit.

(c) R.R.E. Malvern and Cambridge Measurements

Measurements were also made by one of us (N.S.), partly with the Coradagraph measuring machine at R.R.E. Malvern, Worcestershire, and subsequently with a similar machine at the Institute of Astronomy, Cambridge. The R.R.E. Malvern positions were referred to typically five AGK3 (Astronomische Gesellschaft) stars, with at least one in each quadrant. The use of a smaller number of stars here made it more difficult to be sure of eliminating any star with a larger error than normal. Although no measurements were made with the prints rotated through 180°, each reference star was measured with the microscope drive travelling in alternate directions and the average reading was taken. This should have eliminated the largest component of any personal bias. The emphasis in the measurements by N.S. was on achieving an adequate accuracy for the purpose within a minimum time on any one object in order to increase the rate of production. The later Cambridge measurements are all of galaxy identifications and are referred to AGK2 stars. An HP 9820 desk computer was used to carry out the reductions as the measurements were made. These have an estimated accuracy of ~1" arc.

Comparison between the Sydney and R.R.E. Malvern measurements for 31 stellar objects gives an r.m.s. difference of 0.6" arc in each coordinate. This suggests an r.m.s. error of 0.5" arc in the Malvern measurements (which is quite adequate) but indicates that the combined average values should be weighted 2 : 1 in favour of the Sydney measurements. Further support for the above-quoted r.m.s. error in the Sydney measurements (and hence for the necessary weighting factor) comes from a comparison for 17 sources between the Sydney measurements and measurements
by A. N. Argue (personal communication), who also used the Coradagraph machine at R.R.E. Malvern, but with a greater number of reference stars.

(d) Possible Systematic Effects

Comparisons of radio and/or optical measurements based on SAO and AGK3 stars have frequently suggested a possible systematic bias in right ascension between AGK3 and SAO positions. These results were summarized by Argue and Taylor (1974). Adgie (1974) found no such effects in a comparison of AGK3 and SAO star positions in the vicinity of 19 radio sources. It is therefore of interest to quote the mean differences and standard errors obtained in the above comparisons between 17 Sydney measurements $(\bar{\alpha}_S, \bar{\delta}_S)$ and those of Argue $(\bar{\alpha}_A, \bar{\delta}_A)$ and between 31 Sydney measurements and the present R.R.E. Malvern measurements $(\bar{\alpha}_R, \bar{\delta}_R)$:

$$\bar{\alpha}_S - \bar{\alpha}_A = 0.18^\prime \pm 0.13^\prime,$$
$$\bar{\delta}_S - \bar{\delta}_A = 0.32^\prime \pm 0.13^\prime;$$

$$\bar{\alpha}_S - \bar{\alpha}_R = -0.16^\prime \pm 0.08^\prime,$$
$$\bar{\delta}_S - \bar{\delta}_R = 0.09^\prime \pm 0.12^\prime.$$

These comparisons could include a small component of personal bias, but there is no evidence of any significant bias in the zero points of either right ascension or declination.

In view of the previous suggestions of a difference between the zero point of right ascension between SAO and AGK3 positions, a comparison (similar to Adgie's (1974) comparison) was made between the SAO and AGK3 stars for 15 of the fields in common with those of Argue. The average number of stars per field was 11, and the average difference SAO–AGK3 for the field means was $0.08^\prime \pm 0.04^\prime$ arc. However, for 3 of these 15 fields, the mean difference was at least twice the standard deviation, which suggests that the distribution of field means is non-Gaussian or at least that there are some fields with an unusually large SAO–AGK3 difference.* The greatest difference was $0.37^\prime$ arc for the mean of 12 stars in the field of 1221 + 114. It seems likely that the occasional occurrence of somewhat large discrepancies over fields a few square degrees in area would contribute to the apparently significant differences for some samples of sources. For 68 stars in 26 fields of the R.R.E. Malvern measurements the mean SAO–AGK3 difference was $-0.02^\prime \pm 0.08^\prime$ arc in R.A. and $0.14^\prime \pm 0.08^\prime$ in Decl., and again there was evidence that the distribution was non-Gaussian. A more systematic comparison of SAO and AGK3 stars would seem to be worth while. Nevertheless, it is of no consequence for the present measurements that some are based on SAO and others on AGK3 positions.†

The mean difference ‘Sydney optical’—‘accurate radio’ for the 10 sources described in Section 2b was $+0.06^\prime \pm 0.08^\prime$ arc in R.A. and $+0.05^\prime \pm 0.10^\prime$ arc in Decl. This is further confirmation that there is no systematic zero point error in either coordinate.

*A similar impression is obtained from examining the detailed results of R. L. Adgie (personal communication).

† Wills (1978) has recently reported a significant difference in SAO—AGK3 right ascensions, but this appeared to be due to a group of sources for which the mean SAO—AGK3 difference was $0.65^\prime$ arc, whilst the remainder clustered about zero difference.
3. Results

Comparison of the Hazard and Murdoch (1977) positions \((\alpha_{HM}, \delta_{HM})\) with the accurate positions \((\alpha, \delta)\) gives the following mean differences \(\mu\) and standard deviations \(\sigma\):

- \(\alpha_{HM} - \alpha\) : 1.2" \(\pm\) 3.0"
- \(\delta_{HM} - \delta\) : 0.3" \(\pm\) 3.1"

thus confirming the suggested r.m.s. error of 3" arc. A small number of cases where the former position has been found to be significantly in error have not been used in the above comparison; these are noted in Table 1.

(a) Table of Accurate Positions

Optical positions are listed in Table 1 for all suggested identifications except two \(<13^m\) galaxies \((1138+117\) and \(1414+110\), for which positions have been given by Dressel and Condon (1976). Positions are also given for a number of other objects. The measurement code used in column 2 is: M (Molonglo), Sydney measurement; R, R.R.E. Malvern measurement; B (both), weighted mean of M and R (using a weight of 2:1 in favour of the Sydney measurements); C, Cambridge measurement. The magnitude \(m\) and object description given in columns 5 and 6 are taken from Hazard and Murdoch (1977). The symbols used to classify objects are: E, elliptical galaxy; S, spiral galaxy; cg, compact galaxy; g, galaxy of unspecified type; QSO, confirmed quasi-stellar object; BSO, blue stellar image which is brighter on the o than the E print; St, stellar image other than a BSO. A question mark indicates doubt as to the nature of the object. The relative positions (optical relative to radio) given in column 7 have been revised in accordance with the new optical positions. The symbols used in the Notes column (column 8) are: N (nonidentification), the source has not been suggested as an identification; R (reject), the source was previously suggested as an identification but does not now qualify on the basis of the new optical position; W (weak), the radio flux density is <0.45 Jy, and hence the source is not part of the complete sample; B, confirmed BL Lac object; PB, probable BL Lac object; P, probable identification based on the more accurate radio position; S, significant change in position from that given by Hazard and Murdoch (1977); T, further notes on this source are given in the text (see following subsection). A more thorough reassessment of the identifications will be possible when current work on more accurate radio positions is complete (C. Hazard and J. J. Condon, personal communication).

(b) Notes on Individual Sources

1210+121. This object was reported by Hazard and Murdoch (1977) as a star, but more recently as having a featureless spectrum with good signal to noise (J. A. Baldwin, personal communication).

1236+109. Other objects listed by Hazard and Murdoch (1977) are not visible on the Sydney copy of the Palomar prints.

1416+159. This object is well outside the 2\(\sigma\) limit and may not be associated with the radio source.
### Table 1. Optical positions for MC2 and MC3 identifications

See Section 3a of the text for a description of the symbols and Section 3b for additional notes to sources

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1452+165. This object is a double radio source, so that the radio position does not necessarily give an accurate centroid.

1518+156. This object was noted as possibly being slightly blue. The improved position makes it a possible identification (see Section 4b).

1522+113. This source is called 1522+112 in the MC2 catalogue.

1523+161. This source ought not to have been claimed as an identification by Hazard and Murdoch (1977).

1549+107. The 20° galaxy of unspecified type listed by Hazard and Murdoch (1977) is not visible on the Sydney copy of the Palomar prints.

1559+157. See the following note for 1600+158; if the interpretation given there is correct, this identification would not apply.

1600+158. The optical positions given are for a pair of apparently interacting galaxies close to the centroid of this source and 1559+157. These two sources may therefore be associated with the pair of galaxies.

1600+121. The radio declination is wrongly listed by Hazard and Murdoch (1977); it should be 12°06'48".

1618+168. The object listed is the galaxy marked in the finding chart by Hazard and Murdoch (1977). There is possibly a plate limit object to the north-east closer to the radio position.

4. Discussion

(a) Recalibration of Molonglo Catalogues

An attempt has been made to improve the calibration of the MC2 and MC3 surveys on the basis of the confirmed identifications. The present comparison is
restricted to confirmed QSOs, BL Lac objects, and galaxy identifications which have been confirmed by an accurate Texas radio position (Ghigo and Owen 1973; Douglas et al. 1973; Sharp and Bash 1975; Ghigo 1977), and is also restricted to radio sources with $S_{408} > 0.7$ Jy. There are 13 sources from MC2 and 16 from MC3 which meet these criteria. The corrections $\Delta \alpha$ and $\Delta \delta$ implied by the comparison, together with the standard deviations $\sigma_{\Delta \alpha}$ and $\sigma_{\Delta \delta}$, are:

For MC2

$$\Delta \alpha = 1.0^\circ \pm 0.9^\circ, \quad \sigma_{\Delta \alpha} = 3.5^\circ; \quad \Delta \delta = 1.0^\circ \pm 1.1^\circ, \quad \sigma_{\Delta \delta} = 4^\circ;$$

For MC3

$$\Delta \alpha = 1.4^\circ \pm 1.8^\circ, \quad \sigma_{\Delta \alpha} = 7^\circ; \quad \Delta \delta = -1.2^\circ \pm 1.5^\circ, \quad \sigma_{\Delta \delta} = 6^\circ.$$

The values of $\Delta \alpha$ and $\Delta \delta$ are given in the sense of the correction to be applied to the catalogue radio positions to align them with the unweighted mean of the optical positions. There is no clear evidence of any need to change the catalogue calibration at this stage.

(b) Revision of Suggested Identifications

Five sources formerly claimed as BSO identifications are now beyond the $2\sigma$ limit on taking into account the accurate positions. Of these, 1523 + 161 should not have been claimed as an identification, while for 1645 + 174 it was noted that the galaxy was the correct identification based on a more accurate position (Argue et al. 1973). The remaining three objects (1410 + 154, 1517 + 166 and 1623 + 173) are outside the $2\sigma$ limit by $<3^\circ$ arc and still merit further investigation, although they should be discarded from the statistics. A further suggested identification, 1301 + 117, occurs at the $2\sigma$ limit. One BSO, 1505 + 112, previously beyond $2\sigma$, is now also at the $2\sigma$ limit. On the revised position, 1518 + 156 should be included in the list of possible neutral stellar identifications. Ghigo (1977) listed it as a probable QSO, although the agreement with the Texas radio position is not particularly good. Previously suggested galaxy identifications which are now beyond the prescribed $20^\circ$ arc limit in either right ascension or declination are 1529 + 104 and 1336 + 106.

Three BSO identifications (1207 + 118, 1307 + 121 and 1639 + 155) are confirmed by Texas radio positions (generally available only for the stronger sources) and the only BSOs rejected on this basis are 1410 + 154 and 1523 + 161 already noted above. One BSO, 1210 + 121, noted by Hazard and Murdoch (1977) as a star is now found to have a featureless continuum in an observation with good signal to noise (J. A. Baldwin, personal communication). Suggested galaxy identifications rendered unlikely by Texas positions are 1359 + 103, 1509 + 102, 1537 + 162 and 1558 + 116.

(c) Comparison with Other Published Positions

A comparison of the present optical positions with the published measurements of Veron and Veron (1973, 1975, 1977); Wills et al. (1973) and Wills and Wills (1976); and Ghigo (1977) is given in Table 2. In the comparison with the Wills data, one source has not been included where the difference in position is $>2^\circ$ arc in each coordinate, but Ghigo's (1977) measurement of this source agrees with ours. In the comparison with Ghigo (1977), one declination has been rejected where the
Table 2. Comparison between optical positions

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<th>Observer</th>
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<th>$\sigma_x$ (')</th>
<th>$\mu_y$ ('')</th>
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<td>31</td>
<td>$0.02 \pm 0.08$</td>
<td>0.43</td>
<td>$0.02 \pm 0.10$</td>
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* Measurements are by Veron and Veron (1973, 1975, 1977), Wills et al. (1973) and Wills and Wills (1976), and Ghigo (1977).

The difference is $>2^{\prime}$ arc. If one further case where the difference is $1.5^{\prime}$ arc were rejected, the r.m.s. error would be $0.45^{\prime}$ arc. Ghigo (1977) suggested that, due to an undiagnosed fault in the Texas measuring machine, his r.m.s. errors should be regarded as being in the range $0.5^{\prime}$–$0.7^{\prime}$ arc. The present comparisons would suggest that, apart from two declinations, the r.m.s. error is no more than $0.35^{\prime}$ arc in either coordinate. In fact the results (apart from the two discrepant declinations) are consistent with an r.m.s. error of $0.32^{\prime}$ arc in both our measurements and those of Ghigo. The comparisons with Veron and Veron are consistent with their claimed r.m.s. error of $0.5^{\prime}$ arc.

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References


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