THE RECONCILIATION OF OPTICAL AND RADIO POSITIONS

A.N. Argue
University of Cambridge, Institute of Astronomy,
The Observatories,
Madingley Road, Cambridge CB3 OHA, U.K.

SUMMARY

The optical and radio positional reference systems are reviewed. A preliminary comparison indicates that the two do not at present agree to better than 0".2 or 0".3.

1. REFERENCE SYSTEMS

Reconciliation of optical and radio postions is basically a matter of reconciling positional reference systems. For example, the question of whether, for a given source, there is a real physical off-set between the optical and radio centroid at a given frequency cannot be properly investigated until the reference systems have been securely established. In the more sophisticated case of the correlation of optical with VLBI superluminance, the reference systems must be comparable at the millisecond of arc level; it will be seen in Section 3 that this is far from the case at present.

The optical and the radio interferometric systems have each been set up by fundamental and independent methods: their only point of contact has been in the zero-point in Right Ascension (the radio Right Ascensions being relative, not fundamental) where currently the convention is to align to the FK4-based value for 3C 273B determined by Hazard et al. (1971). The two systems are thus regarded as independent, although the very considerable amount of work now being done, or planned, particularly in connection with Space Telescope and Hipparcos, must ultimately result in one unified system.

1.1. The optical system

The FK4 system is defined by 1535 bright stars (V<7.5) distributed over the whole sky. By measuring a subset of these stars and using the astrometric data tabulated in the FK4 Catalogue, the observer can estimate the values of the parameters for his model reduction to the FK4 frame. The

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catalogued positions and proper motions have been derived from fundamental data obtained over about a century at a large number of observatories. The accuracy has been examined by Lederle (1978), with more recent investigations described at this symposium by Schwan and by Brosche: the mean epoch of the FK4 observations was about 1930, and by 1990 the errors in proper motion will have led to cumulative positional errors of 0".1 per star in each coordinate. But a more accurate system FK5, extended to V=9, will be available in 1984.

1.2. International Reference System (IRS)

The star density provided by FK4, namely four per 100 sq°, is altogether too small to provide calibrations for conventional techniques such as photography and CCDs. In addition, the extreme brightness may cause problems with such techniques. IRS is a transit circle extension down to V=9 with a density of one star per sq°. This now permits calibration with high accuracy of photographic astrometry using wide-field astrograghs (eg de Vegt & Gehlich, 1982) or Schmidt surveys (Walter & West, 1980 and this symposium).

1.3. The radio interferometric system

Techniques and reduction procedures have been described by several speakers. The closest approach to a system-defining catalogue analogous to FK4 is the 'Catalogue of Selected Compact Radio Sources for the Construction of an Extragalactic Radio/Optical Reference Frame' compiled by a working group of IAU Commission 24 (Argue et al., 1983, reviewed at this symposium by de Vegt). It contains 233 extragalactic sources. The objective was primarily to provide a list of objects that had been selected as suitable for establishing a quasi-inertial reference frame, not a catalogue of astrometric positions; nevertheless it does make a useful astrometric catalogue since the formal astrometric accuracy of the eight contributing catalogues, varying from 0".030 to better than 0".010 in the case of JPL, was such that the resulting weighted mean catalogue is probably homogeneous to better than 0".050. This could be improved to 0".005 in five years given that the observing time can be made available. In addition to lack of significant radio structure, most of the objects selected have favorable optical properties: more than 70% are QSOs brighter than V=20 and certainly these ought to be very suitable for astrometry. There is however a large amount of work still to be done in searching for real radio-optical off-sets and in examining the possible effects of host galaxies on measured optical positions.

The IAU working group drafted the following two resolutions to Commission 24 for transmission to Commission 8 at the 1982 Patras General Assembly. Due to an unfortunate oversight beyond the WG's control, these resolutions never reached the IAU Executive Committee and so have not been published in IAU Transactions. They are worth reproducing here because they sum up very neatly the present situation with regard to reference systems.

1. That work be continued with high priority:
   (i) on the establishment of a Quasi-Inertial Radio Reference Frame;
   (ii) on continuing to improve the present Optical Fundamental Reference Frame, independently of the Radio Frame;
   (iii) on providing unique relations to link the two independent frames at any epoch.

2. That special attention be drawn to the deficiencies in the Southern Hemisphere in both the Optical and the Radio Reference Frames due to lack of observations.

Resolution 1(ii) echoes a resolution from the previous astrometric Colloquium (no. 48) held in Vienna expressing dissatisfaction with the existing stellar reference frame (Prochazka & Tucker, 1978 p. 597). Resolution 2 is related to the fact that, of the 233 sources in the IAU list, only a handful are situated South of Declination -45° and for these the radio positional accuracy is given as about 0".1 which is considerably worse than the average for the list. The need for further work on the optical reference system has been stressed at this symposium by Corbin and by Smith, with plans for future work given by Hughes.

2. INTERCOMPARISON OF RADIO AND OPTICAL POSITIONS

A prerequisite of an accurate intercomparison of optical and radio reference systems is a careful investigation of the off-set problem already alluded to. Off-sets can be distinguished from reference system inhomogeneities by comparing several objects in a small area of sky: a systematic off-set is almost certainly due to a local error in one or other of the reference systems, while significantly random off-sets must be due to the sources. An example is given in Section 3. To study this effect, extragalactic sources are convenient because of their freedom from proper motion. But galactic radio stars also make a valuable contribution once it can be shown in a given case that the radio-optical off-set is small (<0".003). The IAU working group is now selecting radio stars for addition to its list (which at present is confined to extragalactic sources). Progress is slow because each object has to be tested individually because although spectroscopic and other data might indicate a compact stellar system, the radio emission might nevertheless come from a considerably more extensive region, so rendering the system useless for astrometric purposes.

In contrast to the extragalactic sources, considerable numbers of radio stars are bright enough for direct observation by transit circles and astrolabes, and many have already acquired a very substantial observational history. Their VLBI positions are therefore of great importance for linking the reference frames together. These stars will play a vital role in the Hipparcos programme.

Plans for stopping the rotation of the Hipparcos instrumental reference

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system and for tying this system to the VLBI, have been described at this symposium by Duncombe & Hemenway (according to Fricke, 1967, FK4 has an absolute rotation rate approximately equal in magnitude to the Oort galactic rotation rate, 0".5 per century). Ground-based methods will also be important because in the long term the proper motions and system rotation will be derived more accurately than by a single Hipparcos mission of limited duration.

2.1. Candidate radio stars

Purely in the context of Hipparcos, the selection of optically bright candidates is mainly a matter of radio astrometry because for V<8.5 the Hipparcos Input Catalogue will be virtually complete and these stars will be measured automatically, whether wanted or not. The question of VLBI selection has been discussed at this symposium by Florkowski et al. and by Lestrade et al. Candidates have been selected from the following groups:

(i) binary and multiple stars.
The prototype is Beta Per (Algol). A list was drawn up by de Vegt for the IAU working group's Progress Report (Argue & de Vegt, 1982), with references to Walter (1977) and Wendker (1978). Astrolabe measurements have been reported at this symposium by Débarbat and by Noel.

(ii) RS CVn.
Close binary systems: when the active flaring region is in the chromosphere the system makes a compact astrometric object (radio-optical separation <0".003). A few hundred RS CVn systems with V<8.5 are known from optical spectral surveys (eg. Collier, 1982 and private communication), but most of these have not yet been examined by VLBI.

(iii) masers.
SiO. The maser catalogue by Engels (1979) lists 60 late-type stars with B<9, of which about 40 are SiO masers. These also are compact chromospheric emission objects but here the high line-frequencies (43, 86 GHz) pose instrumental difficulties.

H2O masers are fairly compact, within a few stellar radii, giving <0".010 systems.

OH masers are less compact, but Norris (1983) advocates the use of the sharp blue-shifted line component which represents amplified thermal emission in the line of sight of the star; the coincidence is therefore exact, irrespective of inhomogeneities in the circumstellar shell.

Thermal stars generally are too extended (0".1 to 1"); however a number will automatically be included in the Hipparcos programme simply by virtue of their brightness.

3. OBSERVATIONAL

Figure 1 shows a plot of the differences in Declination between optical and radio positions (ordinates) plotted as a function of Right Ascension. Symbols with horizontal bars have been taken from de Vegt & Gehlich (1982); those without, from Zacharias (1983). A systematic trend, with amplitude of order 0".2 to 0".3 between RA 8h and 10h is evident in both series. Both teams were using different telescopes so there is no question of an instrumental artefact - their only common feature, apart from the radio positions, was the system AGK3RN, a subset of IRS, as optical reference. The four de Vegt & Gehlich points lying between RA 8h and 10h have Declinations lying within the range +20^o and +40^o, hence it appears that in this confined area of sky there is a systematic error in either AGK3RN or the radio catalogue, or in both. The radio positions had been taken

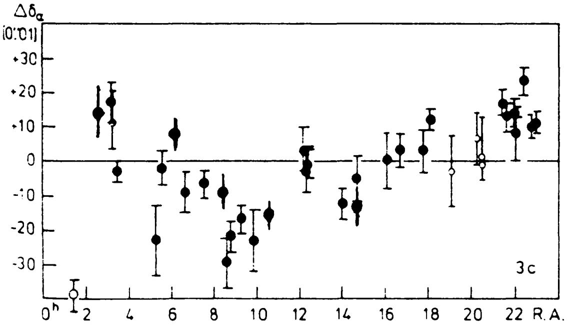

Figure 1. Declination differences (optical minus NRAO) vs. Right Ascension. Optical: de Vegt & Gehlich (1982 - horizontal bars); Zacharias (1983).

either directly from NRAO (Wade & Johnston, 1977), or from other catalogues that had been transformed to NRAO by de Vegt & Gehlich.

A similar comparison substituting JPL 1983-3 VLBI positions for NRAO has been made by Fanselow *et al.* (1984) and is reproduced here in Figure 2. In this case only the optical positions are in common with Figure 1. Again, a trough between 8h and 10h is evident. Fanselow *et al.* reject precession and other constants as possible causes for this trend - JPL had used the IAU 1976 precession -and give the cause as "unexplained". It seems unlikely that both radio systems should have been distorted similarly and to this extent; the working group had found that the individual catalogues were aligned to within their formal errors as quoted in Section 1.3 above: more likely the trouble lies mainly in AGK3RN. Improvements to the optical system using ground-based methods progress only very slowly, but the quantum leap envisaged for Hipparcos at the end of the present decade is expected to lead to a homogenisation of the optical system to a degree comparable to that now being achieved for VLBI, at the millisecond of arc level, and to the alignment of the optical and radio systems to this accuracy.

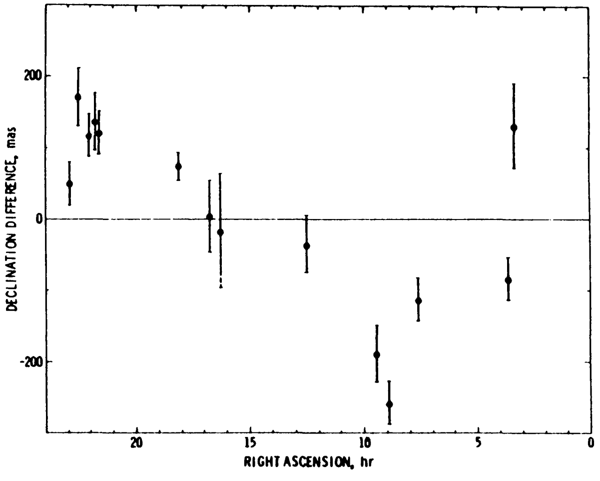

Figure 2. Declination differences (de Vegt & Gehlich, 1982, minus JPL 1983-3) vs Right Ascension.

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Discussion:

LIESKE: You showed a graph pertaining to the difference between the optical positions of de Vegt and the VLBI positions in the JPL 1983-3 catalogue, and you mentioned that the VLBI catalogue had employed the new IAU value of precession. Does this imply that the optical frame also was based upon the J2000 system, or was some sort of re-reduction to the "old" system attempted, or do the differences represent a mixture of systems?

de VEGT: The B1950 system was used with the "old" precession for optical positions. The VLBI positions were "reduced" to the old system by using the old precession and adding elliptic aberration back into the positions. The comparison of optical and radio is based not on the Wade and Johnston catalogue alone but on a combined catalogue including VLBI (see the paper by deVegt and Bell 1982). All these catalogues agree to 0".03 on the northern hemisphere. Our comparison optical-radio is restricted strictly to the northern hemisphere.

ARGUE: I read your paper very carefully — the VLBI positions were transferred to the Wade and Johnston system.