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THE NEW I.A.U. SYSTEM OF GALACTIC COORDINATES (1958 REVISION)

(PAPER I)

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Summary

The definition of a new system of galactic coordinates was recently announced by Sub-Commission 33b on behalf of the I.A.U. The present paper is the first of a series of five, which together form the final report of the Sub-Commission. It summarizes the observational evidence, given in detail in the other papers, relevant to setting up the new system, it discusses various considerations which were taken into account, and it concludes with a definition of the new system.

1. *Introduction*

The definition of a new system of galactic coordinates was recently announced by the I.A.U. Sub-Commission 33b on behalf of the International Astronomical Union.

The present series of papers is the detailed and final report of the Sub-Commission. The various investigations, decisions, and recommendations of both the Sub-Commission and the 1958 Moscow General Assembly are presented in general terms in this paper (Paper I), which is a coordinating paper. It is followed by four more detailed papers, prepared on behalf of the Sub-Commission, which discuss specific aspects of the investigation. These are:

Paper II. *A 21-cm determination of the principal plane of the Galaxy*, by C. S. Gum, F. J. Kerr and G. Westerhout.

Paper III. *Radio data relevant to the choice of a galactic coordinate system*, by C. S. Gum and J. L. Pawsey.

Paper IV. *Optical determinations of the galactic pole*, by A. Blaauw.

Paper V. *The position of the galactic centre*, by J. H. Oort and G. W. Rougoor.

Of the detailed papers, Paper II is an original analysis of combined Leiden and Sydney observations. The others present compilations of published and unpublished material and its bearing on the selection of a coordinate system. In addition, the papers bring out a number of physical relationships of general interest to the problem of galactic structure, such as the close relationship in the galactic disk between the distributions of the sources of the 21-cm radiation and of the radio continuum.

2. *Historical*

William Herschel in 1785 first realized the importance for investigations of the Milky Way System of a special coordinate system having its equator in the galactic plane, and from his time until 1932 various systems having poles

*Dr. Gum was unfortunately killed in a skiing accident in Switzerland on 1960 April 28, after the completion of this group of papers.

differing from each other by one or two degrees were used. The literature up to 1932 is summarized in the Introduction to the well-known *Lund Observatory Conversion Tables* prepared by Ohlsson (1932). For these Tables the pole at right ascension $12^h 40^m$, declination $+28°$ (1900·0), used by Pickering for his extensive researches at Harvard Observatory, was adopted by Ohlsson, and the zero point of longitude was taken at the intersection of the galactic plane and the celestial equator for the equinox 1900.0. The system of galactic coordinates thus defined became the standard one and we shall hereafter refer to it as the "old" galactic coordinate system. The recent *Lund Observatory Tables for the Conversion of Galactic into Equatorial Coordinates for the Epoch* 1958.0 (Ohlsson, Reiz and Torgård 1956) are also based on the old system.

The most extensive optical investigation since 1932 is that of van Tulder (1942). The mean position of the pole finally adopted by van Tulder deviated from the Ohlsson pole by about one degree. However, the need for a new pole was probably not very strongly felt at this time owing to the fact that the scatter of the poles derived from various groups of objects was of a similar order to, or larger than, the deviation itself. Perspectives began to change with the advent of radio surveys carried out at various frequencies during the last ten years or so. Almost without exception these surveys showed that, in the vicinity of the galactic centre, the maximum of the radio emission fell south of the old equator by something over a degree. The deviation is in the same sense as that found by van Tulder; in fact, the optical data of van Tulder, and also those examined more recently by Ashbrook and Duncombe (1952) and by Kirillova (1955), are in much closer agreement with the radio data than with the old pole.

On the basis of this type of evidence it has been thought for some time that a revision of the galactic coordinate system should be considered, and the International Astronomical Union at its General Assembly in Dublin in 1955 appointed Sub-Commission 33b "to investigate the desirability of a revision of the position of the galactic pole and of the zero point of galactic longitude".

The Sub-Commission's investigations had, by the time of the 1958 Moscow General Assembly, reached the stage where it could recommend that the time was opportune for the adoption of a new system of galactic coordinates. The Sub-Commission also formulated the principles which it considered should be used in selecting positions for the new pole and zero of longitude. There remained, however, some further study before the actual positions could be selected.

On the basis of these recommendations, supplemented by detailed reports which may be regarded as preliminary drafts of the papers in this present series, the General Assembly passed a resolution endorsing the above recommendations and authorizing the Commission to define and announce the new system as soon as its studies were completed. In March 1959 the Commission completed its investigations, decided on the definition of the new system and communicated its decision to the General Secretary of the I.A.U. and to a number of astronomical journals throughout the world (Blaauw *et al.* 1959).

We shall present the considerations leading to the adoption of the new system by giving in Sections 3 and 4 the substance of the report of the Commission to the Moscow General Assembly, and in Section 5 the resolution passed by the General Assembly. Section 6 describes the considerations leading to the subsequent choice of the actual pole and zero of longitude. We conclude with extracts from

the text of the announcement defining the new system, which was communicated by the Commission to the General Secretary of the I.A.U.

3. *Evidence on the locations of the pole and centre of the Galaxy*

In examining the basis for a possible revision of the galactic coordinate system it was necessary first to determine the position, with respect to the Sun, of the galactic plane and of the centre of the Galaxy, and to estimate the uncertainties in these determinations. Any decision on the adoption of a new system depended on considerations such as the extent to which the old pole was misplaced from the true one, in relation to the current uncertainty or to expected improvements in the foreseeable future. Both optical and radio observations were examined but it turned out that radio ones were the more significant.

3.1. *The position of the pole.*—Evidence on the precise location of the galactic pole is based on the study of objects strongly concentrated towards the galactic plane. The relevant observations consist of (*a*) radio observations of the 21-cm line emitted by neutral interstellar hydrogen (H I regions); (*b*) radio observations of the continuum, mainly in the wavelength range 20 cm to 3·5 m; and (*c*) optical observations.

Of these, the effective optical observations are restricted to a relatively small region around the Sun, about 3000 pc in radius, i.e. to an area of 5 or 10 per cent of that accessible to radio observations; the objects concerned represent less than $\frac{1}{10}$ per cent of the total mass of the Galaxy. Observations of the 21–cm line pertain to the neutral hydrogen, which represents about 2 per cent of the total mass of the Galaxy, and which can be located over the greater part of the galactic plane out to a radius of about 15 kpc from the galactic centre. The radio continuum observations give only integrated effects along the line-of-sight and are most effectively used in checking a model based on other data.

The outstanding feature of the whole of the observations is the high degree of flatness of the layer of neutral hydrogen in the region of the Galaxy within about 7 kpc* of the centre (see Paper II). Within this area nearly all the points of maximum density of hydrogen in the direction normal to the galactic plane (smoothed over areas of about 1 kpc^2) lie within 20 pc of the mean plane of the layer (which is described as the "H I Principal Plane"). These deviations are less than 1 part in 700 of the diameter of the region. In the outer regions of the Galaxy systematic distortions of up to 800 pc occur (see Fig. 1, Paper II, p. 133). The high degree of flatness of the disk of interstellar gas in the inner region must be of fundamental physical significance and the H I principal plane appears to be the best reference plane for dynamical studies of the whole Galaxy. It thus seems reasonable to choose for the equatorial plane of the galactic coordinate system the plane through the Sun parallel to the H I principal plane. Available observations locate the corresponding galactic pole about 1°·5 from the old pole, with an uncertainty of about 0°·1.

Optical observations (see Paper IV) of different groups of objects give poles which are scattered over a range of several degrees and an optical determination of the pole depends on the choice of the group, or groups, of objects to be given the most weight. We have thought it proper to give the greatest weight to observations of the more distant objects (e.g. Cepheids, OB-stars, and open

*Throughout this series of papers the value $R_0 = 8{\cdot}2$ kpc has been adopted for the distance to the galactic centre. The large uncertainty in the absolute distance scale is not important in considering the choice of a galactic coordinate system.

clusters, at distances of about 3000 pc). This weighting corresponds to the assumption that, in the vicinity of the Sun, local irregularities and effects of selection are more serious than possible large-scale distortions. It is supported by the greater consistency of the results from the more distant objects. These selected optical data give consistent agreement with the H I pole to better than 1° for different optical groups (see Fig. 3, Paper IV, p. 168). Such a selection of a small percentage of the optical objects is indeed arbitrary, but the real difficulty is that it is impossible to observe optically a sample of Population I objects which is a representative sample of the whole Galaxy.

In the radio continuum results (see Paper III) the important feature for our purpose is that, in the range of longitudes within about $\pm 60°$ of the galactic centre, where the H I layer is flat, the "ridge lines" of the continuum contour maps are very well defined and agree closely with one another and with the position of the H I layer. In directions where the H I layer is distorted, the continuum ridge line is ill-defined and appears to conform with the H I irregularities. The inference is that, on a large scale, the sources of the "disk component" of the continuum are distributed similarly to the H I regions. The agreement in the flat inner region is within the observational uncertainty of about $0°{\cdot}1$. The continuum observations therefore give strong support to a pole based on the H I observations.

3.2. *The height of the Sun above the plane.*—The distance z_0 of the Sun from the H I principal plane does not appear explicitly in the parameters of a galactic coordinate system, since the required system is necessarily based on a galactic plane through the Sun. But, even if the equatorial plane of the coordinate system were exactly parallel to the H I principal plane, objects in the latter plane will not be on the galactic equator if z_0 differs from zero. The distance of an object from the H I principal plane—presumably the plane of symmetry of the inner parts of the Galaxy—can only be determined when both its distance from the Sun and the value of z_0 are known. For physical reasons it is therefore important to know z_0. Fortunately, as found in Paper II, the Sun is in the H I principal plane within the errors of measurement, the derived value being $z_0 = +4\,\text{pc} \pm 12$ (estimated p.e.). It should be borne in mind in considering observational data, however, that an uncertainty of 12 pc in z_0 corresponds to an uncertainty of $0°{\cdot}09$ in the direction towards a point in the H I principal plane at a distance of 8 kpc from the Sun (e.g. the galactic centre).

The difference between the value of z_0 found from 21-cm line data, $+4\,\text{pc} \pm 12$ (Paper II), and the height of the Sun above the mean plane of the optically observed Population I objects, $+22\,\text{pc} \pm 2$* (Paper IV), need not imply that the mean plane of these objects differs from the H I principal plane throughout the whole Galaxy. The optical region contains an inadequate sample of the whole plane. Moreover the sample could well be biased because a large proportion of the region on which the optical determination is based is situated in those parts of the Galaxy where the neutral hydrogen disk is distorted.

3.3. *The longitude of the galactic centre.*—The (old) longitude of the galactic centre derived from various optical and radio studies (Papers III and V) is $l^{\text{I}} = 327°{\cdot}7 \pm 0°{\cdot}1$ (estimated p.e.). A more precisely determined position is that of the radio source Sagittarius A (17S2A) at $l^{\text{I}} = 327°{\cdot}68$, $b^{\text{I}} = -1°{\cdot}45$ (Paper III), which agrees with the previous direction to within $\frac{1}{5}$ of the

* Note that this error is an internal probable error and would underestimate the uncertainty if the data were subject to systematic bias.

observational uncertainty. We shall, on the basis of evidence presented in Paper V, assume that Sagittarius A is located at the galactic centre. However, even if this assumption later proved to be wrong, its adoption will not have appreciably degraded our placing of the zero of longitude.

4. *Arguments for setting up a new galactic coordinate system now*

The old system of galactic coordinates does not serve its purpose as well as it could because its pole is displaced from the pole of the H I principal plane and from that of Population I objects near the Sun by about 1°·5. Further, the longitude zero is in an inconvenient position, about 32° from the direction of the galactic centre. But if a new system is to be adopted now it may not be perfect for future refined studies. The Sub-Commission recommended a new system on the following grounds:

(1) The old pole is sufficiently seriously misplaced to make the discrepancy obvious for many observations (particularly radio ones). Hence observers might well use their own systems if the I.A.U. did not recommend a new one.

(2) The anticipated improvement in the position of the pole, by a factor of 10/1 or better, is substantial, and is unlikely to be much increased for many years.

(3) A galactic coordinate system is sufficiently accurately placed when the scatter of the objects or groups of objects considered is much greater than the uncertainty in the position of the plane due to observational errors, or due to poor sampling of the objects from which the plane is determined. The proposed system appears to satisfy this condition for the great majority of both optical and radio objects.

(4) This is a time in the history of astronomy when a great increase in the number of studies involving the use of galactic coordinates is anticipated. Consequently the introduction of a new system now, rather than in a few years, should avoid a considerable amount of conversion between the old and the new coordinate systems.

5. *The resolution adopted by the* 1958 *General Assembly*

The Sub-Commission, at a joint meeting of Commissions 33 and 40, recommended the adoption in the near future of a new galactic coordinate system. It recommended a latitude and longitude system similar to the old one, but with the zero of longitude in the direction of the galactic centre, since this direction is now known with reasonable accuracy. This arrangement facilitates studies of the degree of symmetry of the Galaxy about the meridian plane through the galactic centre. Indeed, to further this objective, the Sub-Commission tentatively recommended a longitude system like the terrestial one with positive and negative longitudes, but it was decided at the Moscow meeting that the 0–360° system was preferable.

This meeting passed a resolution with the following clauses, which was subsequently endorsed by the General Assembly:

(*a*) That a standard system of galactic coordinates be adopted for which the pole is based primarily on the distribution of neutral hydrogen in the inner parts of the galactic system.

(*b*) That the zero of longitude be chosen near the longitude of the galactic nucleus, that longitude be counted from 0° to 360°, in the same direction as in the current system, and that latitude be counted in the conventional manner from −90° through 0° to +90°.

(*c*) That Commission 33b be authorized to define the exact values of the coordinates of the pole and of the zero of longitude immediately after the final reduction of the relevant observations is finished.

(*d*) That Commission 33b be charged with the communication of these values to the members of the I.A.U. and to all interested institutions and individuals.

(*e*) That Commission 33b be charged with the supervision of the publication of tables, accurate to 0°·01, necessary for the conversion from galactic into equatorial coordinates and vice versa, and from coordinates based on the Lund pole into the newly defined system and vice versa, and of two conversion charts.

(*f*) That the new galactic coordinates be designated by the same symbols as the old galactic coordinates.

(*g*) That the revised system be referred to as galactic coordinates (1958 revision).

6. *Choice and specification of the final coordinate system*

Following the adoption of this resolution by the I.A.U., the Sub-Commission completed its reduction of the relevant observations and proceeded to the definition of the actual coordinate system. The intention was to choose a system which is so oriented that the direction of the pole is perpendicular to the mean plane of the Galaxy, and the zero of longitude passes through the galactic centre. These directions are known with limited accuracy and suitably rounded values for the various coordinates were chosen on the basis of considerations outlined below.

One innovation in the method of specification was made In the old system the zero of longitude was defined as one of the intersections of the galactic equator with the celestial equator for a given epoch. The new system has a zero which must be specified numerically. Various methods of specification might have been adopted, but it was decided to use the position angle at the north galactic pole with respect to the equatorial pole because this angle is one of the quantities used directly in conversion formulae from equatorial to galactic coordinates.

The system was intended to be, as far as practicable, fixed in the sky (independent of precession) and accurately reproducible. To this end the new system was defined by a geometrical definition (of infinite precision) in terms of equatorial coordinates for a given epoch. The epoch chosen was 1950.0, the standard epoch nearest to the present time. Conversions to other epochs are limited in accuracy only by the accuracy with which precession is known.

The choice of numerical values was based on the following considerations.

6.1. *The pole.*—Referring to Paper II we find that the adopted solution for the H I principal plane has a pole at the position:

$$\left.\begin{aligned}\alpha &= 12^{h}\,49^{m}\,02^{s} \pm 30^{s}\ \text{(estimated p.e.)}\\ \delta &= 27^{\circ}22'{\cdot}7 \pm 7'\ \text{(estimated p.e.)}\end{aligned}\right\} \quad (1950.0).$$

This solution is based on the region of the Galaxy within 7 kpc of the galactic centre. The radio continuum surveys are not suitable for deriving a pole, but they can be used to obtain the deviation, Δ, of the actual pole from that of the old coordinate system (Paper III). The values of Δ derived from the two most accurate continuum surveys, on the assumption that the longitude (old system) of the true pole approximates to that of the H I pole, are:

$$\Delta = 1^{\circ}{\cdot}42 \pm 0^{\circ}{\cdot}05\ \text{(p.e.)} \qquad 85\ \text{Mc/s}$$

$$\Delta = 1^{\circ}{\cdot}55 \pm 0^{\circ}{\cdot}04\ \text{(p.e.)} \qquad 1390\ \text{Mc/s}.$$

In Fig. 1 the H I pole position is plotted, with its uncertainty circle. The Δ values for the continuum are represented by short lines—corresponding to the fact that poles anywhere on these lines would yield the same Δ values. Also on the figure a slightly longer line indicates positions exactly 90° from the radio source Sagittarius A, assumed to be at the galactic centre, which has the following coordinates (Paper III)

$$\alpha = 17^h\,42^m\,37^s \qquad (1950.0).$$
$$\delta = -28^\circ\,57'$$

The diagram is plotted in terms of 1950.0 equatorial coordinates, and the position of the old pole is shown for comparison.

No optical data are shown because, as concluded in Paper IV, they are based on an inadequate sample of the Galaxy, and may be influenced by observational selection. However, the radio position is concordant with the optical evidence.

Adopting the principle that the new pole is to be based primarily on the H I observations, with the radio continuum and optical results used for check purposes, a very satisfactory pole with a convenient degree of rounding in its specification is at the position

$$\alpha = 12^h\,49^m \qquad (1950.0).$$
$$\delta = +27^\circ{\cdot}4$$

This is shown in Fig. 1.

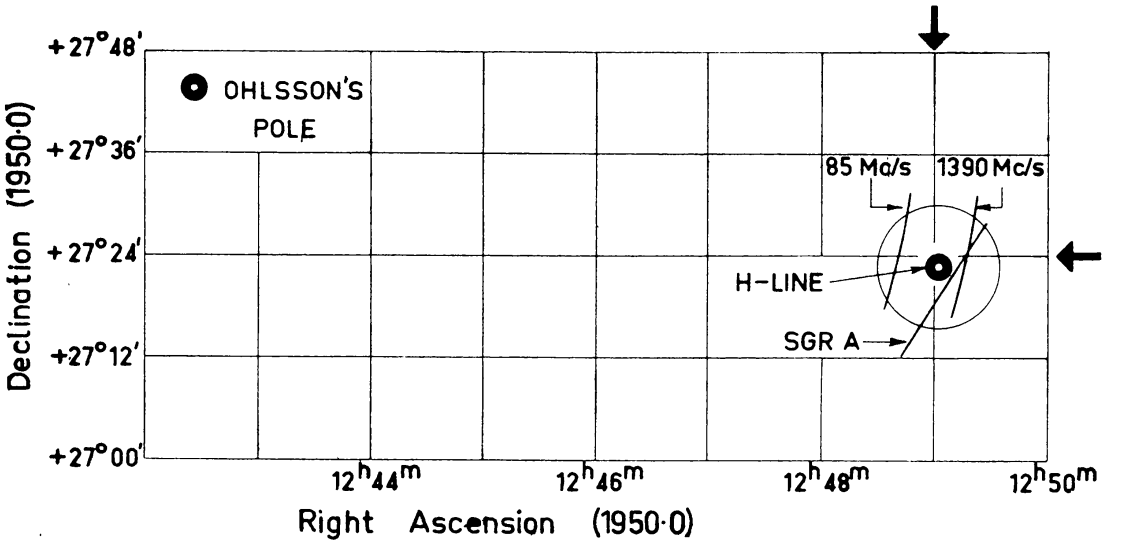

FIG. 1.—*Comparison of the position of the pole of the* H I *principal plane with various radio continuum data, and with the position of the old galactic pole. The coordinates of the new pole are indicated by heavy arrows.*

6.2. *The longitude zero.*—Adopting the above positions of Sagittarius A and the galactic pole, the position angle at the new galactic pole of the great circle passing through Sagittarius A is $\theta = 123^\circ\,00'\,30''$. This value may be conveniently rounded to $\theta = 123^\circ$.

7. *Announcement of the new system*

After reaching agreement the Commission, on 1959 March 25, communicated its definition of the new system with some explanation to the General Secretary of the I.A.U. The sections of this communication which are not already covered in the present paper are given below.

7.1. *Definition of the galactic coordinate system* (1959 *revision*):

(*a*) The new north galactic pole lies in the direction

$$\alpha = 12^h\,49^m,\ \delta = +27^\circ{\cdot}4 \text{ (equinox 1950.0)}.$$

(*b*) The new zero of longitude is the great semi-circle originating at the new north galactic pole at the position angle

$$\theta = 123^\circ$$

with respect to the equatorial pole for 1950.0.

(*c*) Longitude increases from 0° to 360°. The sense is such that, on the galactic equator, increasing galactic longitude corresponds to increasing right ascension. Latitude increases from −90° through 0° to +90° at the new north galactic pole. The system is therefore similar to the Ohlsson system of coordinates.

The above quantities are to be regarded as exact so that the new galactic coordinates may be computed to any desired accuracy in terms of right ascension and declination for the equinox 1950.0.

7.2. *Other useful values* (*restricted accuracy*).—The quantities which follow have been computed from the definition but are given only to an accuracy of the nearest integer in the last digit.

(*a*) *The* 1900.0 *values corresponding to those in the definition*

New pole $\left.\begin{array}{l}\alpha = 12^h\,46^m{\cdot}6\\ \delta = +27^\circ 40'\end{array}\right\}$ 1900.0.

New longitude zero at position angle $\theta = 123^\circ\,04'$ (1900.0).

(*b*) *The old galactic coordinates of the new pole*

$$l^{\mathrm{I}} = 347^\circ{\cdot}7,\quad b^{\mathrm{I}} = +88^\circ{\cdot}51.$$

(*c*) *Position of the point of zero longitude and latitude* (*new system*), $l^{\mathrm{II}} = 0$, $b^{\mathrm{II}} = 0$

In equatorial coordinates

$$\begin{array}{llll}\alpha = 17^h\,39^m{\cdot}3, & \delta = -28^\circ\,54' & (1900.0)\\ \alpha = 17^h\,42^m{\cdot}4, & \delta = -28^\circ\,55' & (1950.0).\end{array}$$

In old galactic coordinates

$$l^{\mathrm{I}} = 327^\circ{\cdot}69,\quad b^{\mathrm{I}} = -1^\circ{\cdot}40.$$

7.3. *Nomenclature.*—At the Moscow General Assembly it was decided that the symbols l, b should be retained for galactic longitude and latitude respectively. Commission 33b suggests that, during the transition period, the symbols l^{I}, b^{I} should be used for the old system and l^{II}, b^{II} for the new one. Apart from these superscripts, it should be made quite clear whether the galactic coordinates used in any publication are based on the old or the new system.

7.4. *Conversion tables.*—In accordance with a decision taken at the Moscow Assembly, conversion tables from equatorial into galactic coordinates and vice versa, and from the old and new galactic coordinate systems into each other, will soon be published under the supervision of Commission 33b by the Lund Observatory.

Acknowledgments.—In conclusion we wish to thank the many astronomers who assisted us in our work; in particular F. J. Kerr who has played a part in these studies equivalent to that played by the various members of the Sub-Commission.

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References

Ashbrook, J., and Duncombe, R. L., 1952, *A. J.*, **56**, 204.
Blaauw, A., Gum, C. S., Pawsey, J. L., and Westerhout, G., 1959, *I.A.U. Information Bulletin* No. 1; also, for example, *M.N.*, **119**, 422.
Kirillova, T. S., 1955, *A. J.* (*U.S.S.R.*), **32**, 192.
Ohlsson, J., 1932, *Ann. Lund. Obs.*, **3**.
Ohlsson, J., Reiz, A., and Torgård, I., 1956, " Lund Observatory Tables for the conversion of galactic into equatorial coordinates for the Epoch 1958.0 ".
van Tulder, J. J. M., 1942, *B.A.N.*, **9**, 315.