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THIRD CATALOGUE OF ORBITS OF VISUAL BINARY STARS

W. S. Finsen and C. E. Worley

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INTRODUCTION

This catalogue is a descendant of earlier catalogues of visual binary orbits published independently by the present authors (Finsen 1934, 1938; Worley 1963). We have collaborated in the production of the present catalogue in the belief that the combination of our independent resources and opinions would result in a more complete, accurate, and consistent catalogue than would have been achieved individually.

Initially, we each independently selected and graded a list of orbits. The lists were then compared and a final list was agreed on. In addition, Worley supplied most of the magnitudes and spectral types, and much of the astrophysical information for the Notes, while Finsen was principally responsible for scrutiny and editing of the published elements as well as for the editing and production of the actual catalogue.

For each orbit the Thiele-Innes elements have been computed anew from the published Campbell elements or vice versa. In Johannesburg most of the computations were made with an ICT 1500 or other electronic computer, but in several hundred cases an ordinary desk calculating-machine was used. In the comparatively few cases where both sets of elements were supplied by the orbit computer they were retained unaltered notwithstanding trivial discrepancies attributable to rounding-off. But gross discrepancies, as well as any other queries that came to mind, were always fully investigated and corrected whenever possible. Such corrections are indicated in the catalogue by an asterisk (*), as also are the cases where the elements have been transformed to conform to convention.

Finally, an important augmentation of the catalogue is the inclusion, for the first time, of astrometric and hyperbolic orbits. Inclusion of astrometric orbits needs no apology for the distinction between astrometric and visual pairs is largely artificial and, it is to be hoped, of a temporary nature; an astrometric binary may become a visual binary overnight as happened in the case of Ross 614. Their inclusion may also serve as a useful reminder to look for the unseen companion at the most favourable time. Hyperbolic orbits are of course much more controversial and the reality of the few that have so far been published may well be doubted, but the possibility of such orbits cannot be gainsaid. It therefore seemed desirable to make provision for the hyperbolic case and for the sake of completeness to include the few tentative orbits that have already been published.

The notation and conventions used in this catalogue are defined below.

Elliptic Orbits

P	Revolution period, in years.
$n = 360°/P$	Mean motion; *always positive.*
T	Epoch of periastron passage.
e	Eccentricity of true orbit.
a	Semi-axis major of true orbit, in seconds of arc.
i	Inclination of the plane of the true orbit to the tangent plane, i.e., the angle between the positive pole of the true orbit (from which the motion is seen to be direct) and the line of sight. For direct motion in the apparent orbit i ranges from 0° to 90°, for retrograde motion, from 90° to 180°. When i is 90°, the apparent orbit is a straight line through the primary.
☊	The position angle of the ascending node (where the radial velocity of *the companion relative to the primary* attains its maximum positive value) in the cases where this discrimination is possible. In such cases it is printed in italics and may have any value between 0° and 360°. Otherwise the node between 0° and 180° is arbitrarily chosen.
ω	The longitude of periastron, i.e., the angle in the plane of the true orbit from the ascending node to periastron, *taken always in the direction of motion.* It can therefore have any value between 0° and 360°. This is in agreement with the usual convention for spectroscopic binary orbits. When the ascending node is unknown, as is usually the case, ω is measured from the node as given (i.e., ☊ < 180°); should this eventually prove to be the *descending* node, both ☊ and ω should be increased by 180°.
A, B, C	The x, y, z coordinates of periastron, referred to the *centre* of the true (relative) orbit as origin.
F, G, H	The x, y, z coordinates of that point, in the plane of the true orbit, where the minor axis of the relative orbit intersects the auxiliary circle and which is 90° from periastron *in the direction of motion.* These coordinates are also referred to the *centre* of the true orbit as origin. (A, B, F, and G may also, for practical purposes, be regarded as referred to the centre of the apparent orbit, but this will be true for C and H only if the centres of the true and apparent orbits are regarded as coincident.)
L, N	Coefficients for the calculation of the relative radial velocity. To calculate them a knowledge of the parallax is required. The tabulated quantities pL, pN (p = absolute parallax) thus permit the calculation of the relative radial velocity as a function of the parallax.

The Thiele-Innes constants A, B, F, G are equivalent to the classical or Campbell elements a, i, ☊, ω. When, owing to lack of radial velocity or other information, it is not possible to discriminate between the ascending and descending nodes, this is indicated by attaching double signs to C, H, pL, pN. The upper signs are correct if the node as given (i.e., ☊ < 180°) is in reality the ascending node; if this is the descending node the lower signs apply. Note also that:

Substitution of ☊ + 180° for ☊ reverses the quadrant in the apparent orbit and reverses the signs of A, B, F, G.

Substitution of $\omega+180°$ for ω reverses the quadrant in the apparent orbit and reverses the signs of A, B, F, G, C, H, pL, pN.

Substitution of $\Omega+180°$ for Ω *and* $\omega+180°$ for ω leaves the quadrant in the apparent orbit and the signs of A, B, F, G unchanged, but reverses the signs of C, H, pL, pN.

An orbit perpendicular to the line of sight, motion direct, is indicated by $i = 0$, $\Omega = 0$, so that ω is the position angle of periastron; if the motion is retrograde, by $i = 180°$, $\Omega = 0$, so that $360°-\omega$ is the position angle of periastron.

Circular Orbits

For a circular orbit, $e = 0$ and $\omega = 0$ and T is the epoch of nodal passage when the position angle equals Ω. If, in addition, the inclination is zero, Ω is also taken as zero and T is the time when the position angle is zero.

Parabolic Orbits

σ	Areal constant in the *true* orbit, expressed in square seconds of arc per annum.
q	Periastron distance in the true orbit, in seconds of arc.
$n = \sigma/q^2$	'Mean motion'.
A, B, C	The x, y, z coordinates of periastron, referred in this case to the primary (i.e., the focus) as origin.
F, G, H	The x, y, z coordinates of the point where the latus rectum intersects the circle in the true orbit plane with centre at the primary and radius q and which is 90° from periastron *in the direction of motion*. These coordinates are also referred to the primary as origin.

The remaining elements T, e $(= 1)$, i, Ω, ω, L, N are defined as for elliptic orbits.

Hyperbolic Orbits

The elements are defined as for parabolic orbits, except $n = \dfrac{2\sigma(e-1)^2}{q^2(e^2-1)^{\frac{3}{2}}}$ 'Mean motion'.

Unresolved Astrometric Binaries

The photocentre of an unresolved astrometric binary is designated by P. Aa,P, for example, refers to the orbit of the photocentre P relative to the barycentre of a visible component A and an invisible component a.

Ephemeris Calculation

For convenience, the formulae for ephemeris calculation are given below:

$$M = n(t-T)$$
$$x = \rho \cos\theta = AX + FY$$
$$y = \rho \sin\theta = BX + GY$$

Radial velocity of the companion relative to the primary $= L\dfrac{\partial X}{\partial M} + N\dfrac{\partial Y}{\partial M}$

Tables of X and Y for elliptic orbits were first published by Innes (1926) and for parabolic orbits by Finsen (1936). These tables are differenced for intervals of the argument M, facilitating extraction of the differential coefficients, but the former are unfortunately not free of errors. More recently Franz and Mintz (1964) published tables for both elliptic and parabolic orbits, with auxiliary tables giving first and second differences at intervals of ten degrees of the mean anomaly and 0·1 of the eccentricity.

Tables of X and Y are not available for hyperbolic orbits, but ephemeris calculation may be carried out as follows:

The analogue of Kepler's equation is $M = n(t-T) = e\tan F - 2{\cdot}3026\log_{10}\tan(45°+\tfrac{1}{2}F) = e\sinh f - f$ where F is the gudermannian of f. Solution of these transcendental equations may often be avoided by computing M for arbitrary values of F or f and interpolating. Then, in the usual notation,

$$X = \frac{r}{q}\cos v = \frac{e - \sec F}{e-1} = \frac{e - \cosh f}{e-1}$$

$$Y = \frac{r}{q}\sin v = \left(\frac{e+1}{e-1}\right)^{\frac{1}{2}}\tan F = \left(\frac{e+1}{e-1}\right)^{\frac{1}{2}}\sinh f$$

For hyperbolic orbits the dynamical parallax is $\dfrac{q}{e-1}\left(\dfrac{n^2}{4\pi^2 m}\right)^{\frac{1}{3}}$ where m is the sum of the masses.

Magnitudes

Combined magnitudes were selected in the following order of preference:

(*a*) Photoelectric V magnitudes taken from the catalogue of Blanco, Demers, Douglass, and FitzGerald (1968). In a few cases photoelectric magnitudes were obtained from other sources. It is gratifying to report that V magnitudes are now available for the majority of the pairs in this catalogue.

(*b*) Photometric visual magnitudes (two-decimal) from the Henry Draper Catalogue.

(*c*) Durchmusterung magnitudes corrected to the Harvard system.

(*d*) Uncorrected Durchmusterung magnitudes, plus a few values from miscellaneous sources.

Because the binaries included in this catalogue are generally close pairs, determination of individual photoelectric or photometric magnitudes for the components is impossible in most instances. For these cases one must know the difference of magnitude in order to assign the individual magnitudes.

In many cases photometric determinations of magnitude difference were found, obtained by a variety of techniques. In other cases visual estimates were used, emphasizing, where possible, recent estimates made by experienced observers using large telescopes.

The magnitudes so derived are given in the catalogue as follows:

(*a*) If there are individual photoelectric magnitudes, or a photoelectric combined magnitude and photometric difference of magnitude, then two-decimal values are given for both components.

(*b*) If there is a photoelectric combined magnitude but the difference of magnitude is based on visual estimates, then one-decimal values are given.

(*c*) In all other cases one-decimal values are given in italics.

Spectral Types

Spectral types are given in the following order of preference:

(*a*) MK (Yerkes) types, taken principally from the photoelectric catalogue compiled by Blanco, Demers, Douglass, and FitzGerald (1968). Values given in italics were classified at the U.S. Naval Observatory, Flagstaff Station, by Christy and Walker (1969). For these cases the procedure was to observe the composite spectrum and to infer the individual spectral types from the known difference of magnitude. While this procedure is open to several objections, the ordinary practice of quoting only a single spectral type for a double star is likewise not wholly satisfactory.

(*b*) Mt. Wilson types.

(*c*) Henry Draper types.

Grading of the Orbits

The orbits have been graded into five classes on a scale of 1 (definitive) to 5 (indeterminate). The grade assigned to an orbit takes into account the length and curvature of the observed arc as well as the number of observations and their reliability. The system has been tested at the Republic Observatory for many years and grades assigned independently by two individuals have nearly always been in excellent agreement. A rough guide to the criteria used is given below:

Grade 1	Definitive	Several revolutions, well observed.
2	Reliable	At least one revolution, well observed.
3	Preliminary	Elements (especially *P* and *a*) not likely to be grossly in error. In general, the observations define at least half of the orbit.
4	Premature	Individual elements entitled to little weight, but a^3/P^2 may be accepted with some confidence. In general, less than half of the orbit is defined by the observations.
5	Indeterminate	Observed arc very short with little curvature.

In cases where the difference of magnitude is small and there is doubt regarding quadrant interpretation, so that two or more widely differing sets of elements are possible, the ambiguity is indicated by the symbol A followed by the grade. For example, for ADS 1411 two solutions have been offered with periods of 165·4 years and 395·0 years, graded as A3 and A4 respectively, the grade being assigned on the assumption that the ambiguity has been resolved. In a few cases the possibility of ambiguity has been indicated despite the fact that the alternative interpretation has not been tested by orbit computation.

General

The derivation of the Thiele-Innes constants and their use in orbit computation has been described in earlier issues of these *Circulars*.‡ The more important sources have been assembled and included in the References.

Reference should also be made to the *Catalogue d'Éphémérides des vitesses radiales relatives des composantes des étoiles doubles visuelles dont l'orbite est connue* by J. Dommanget and O. Nys (1967), and the *Sixth Catalogue of the Orbital Elements of Spectroscopic Binary Systems* by A. H. Batten (1967) which have been extensively consulted in the compilation of this catalogue. We must also not omit acknowledgment of our indebtedness to the invaluable *Circulaire d'Information* issued three times a year by P. Muller of the Meudon Observatory on behalf of Commission 26 of the IAU; it is to be wished that orbit computers would make more use of this medium for early (if condensed) publication of their work.

Finally, our grateful thanks are due to R. F. Harrington, P. Hers, A. P. Klugh, and S. W. Postma for their aid in writing programmes for the electronic computers in Washington and Johannesburg.

DESCRIPTION OF THE CATALOGUE

Most of the data presented in the catalogue are readily identifiable by the column headings and have been explained in the Introduction. However, brief explanations of the less obvious items are for convenience given below:

A dagger (†) following the star's designation indicates that it is referred to in the Notes following the catalogue, where it is identified by its right ascension and declination condensed into a five-figure group followed by a positive or negative four-figure group.§

An asterisk (*) indicates correction of an error, or transformation to conform to the conventions of this catalogue. This has been omitted in the trivial case when the quadrants of *both* Ω and ω have been reversed.

‡ The Thiele-Innes constants or elements have been rightly so named, but the method of orbit computation generally referred to as the Thiele-Innes method should properly be called the Thiele-van den Bos method.

§ This differs from the usage of the IDS in retaining the familiar algebraic signs + and −. The IDS was forced by the limitations of its print-out equipment to substitute N and S, and even E and W (for proper motions) for these signs, and the traditional discoverers' designations were reduced to monotonous abbreviations using only Roman capitals. There seems to be little justification for unnecessary perpetuation of these admittedly makeshift expedients.

Magnitudes are given in *italics* when no photoelectric determinations of the combined magnitude, or of individual magnitudes, are available.

Spectral types are given in *italics* when they have been inferred from the composite spectrum, as explained in the Introduction.

The node ☊ is given in *italics* when it is known to be the ascending node.

P indicates the photocentre of a visible and an invisible component; e.g., Aa,P refers to the orbit of the photocentre of a visible component A and an invisible component a relative to their barycentre.

Parabolic and hyperbolic orbits are identifiable by their eccentricities and by the replacement of P and a by σ (the areal constant in the true orbit) and q (the periastron distance).

The date following the computer's name is that of the last observation or normal place used in deriving the orbit.

The symbol A associated with the 'grade' indicates an ambiguous case.

The closing date of this catalogue may, for practical purposes, be taken as 1970.0. It contains 795 orbits of 696 systems (counting triples as two systems). There are 6 parabolic orbits, 8 hyperbolic orbits, and 39 orbits of unresolved systems of which 29 are based on variable proper motions. Of the elliptic orbits, approximately 8 per cent. are of grade 1, 18 per cent. of grade 2, 34 per cent. of grade 3, 32 per cent. of grade 4, and 8 per cent. of grade 5.

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ADS or DM α (1900)	Star δ	Magnitudes Spec. Types		P T	e n	a i	ω Ω	A B	F G	C H	pL pN	Eq., Grade Ephemeris	Computer, last observation Reference
48 h m 0 0·2	OΣ 547† +45 16	8·94 dK6	9·04 dMo	y 362·3 1710·0	0·52 0·9937	" 6·179 62·3	° 276·58 19·07	" +1·6014 −2·4654	" +5·6939 +2·3166	" ∓5·4348 ±0·6269	∓25·58 ±2·95	1950 5 1956–1970	U. Güntzel-Lingner 1954 *Astr. Nachr.*, **282**, 183; 1955.
				1506·68 1969·44	0·50000 0·2389	11·6975* 56·59*	350·43* 174·42*	−11·3757 +2·1881	−2·5537 −6·1321	∓1·6234 ±9·6273	∓1·84 ±10·90	2000 5 1960–2000	J. Hopmann 1961 *Ann. Univ.-Sternw. Wien*, **26**, 7; 1964.
61 0 1·0	Σ 3062 +57 53	6·43 dG4	7·19 dG8	106·83 1943·05	0·450 3·36984	1·432 44·4	278·8 *219·1*	−0·8077 +0·6465	−0·9995 −1·0140	−0·9901 +0·1533	−15·81 +2·45	1 1958–1972	P. Baize 1957 *J. Observateurs*, **40**, 197; 1957.
102 0 3·8	Σ 2 +79 10	6·6 A3	6·9	300 1888·2	0·575 1·200	0·686 113·2	330·1 169·9	−0·6091 −0·0283	−0·2956 +0·2906	∓0·3143 ±0·5466	∓1·79 ±3·11	3 1954–1964	W. D. Heintz 1952 *Mon. Not. R. astr. Soc.*, **114**, 603; 1954.
148 0 6·9	β 1026 +53 4	7·3 *A7 Vn*	8·1 *F2 V*	68·5 1919·89	0·79 5·255	0·225 38	75·0 72·6	−0·148 +0·108	−0·110 −0·195	±0·1336 ±0·0358	±3·32 ±0·89	2 1962–1985	O. J. Eggen 1961. Orbit I. *Astr. J.*, **70**, 38; 1965.
161 0 8·2	OΣ 2 AB† +26 25	6·7 F5	7·5	693·5 1963·77	0·836 0·5191	1·018 119·08	266·50 *182·42*	+0·0829 −0·4908	−1·0141 −0·0730	−0·8880 −0·0543	−2·18 −0·13	1900 4 1950–1970	S. Arend 1954 *Bull. astr. Obs. r. Belgique*, **4**, 222; 1956.
207 0 10·6	Σ 13 +76 24	6·8 B9	7·1	1600 1830·0	0·50 0·225	1·26 135·7	304·0 81·0	−0·6282 +0·8129	+0·6615 +0·9528	∓0·7296 ±0·4921	∓0·778 ±0·524	2000 5 1955–1980	W. D. Heintz 1959 *Astr. Nachr.*, **285**, 255; 1960.
221 0 11·5	OΣ 4 +35 56	8·2 *F6 V*	8·9 *F9 V*	112·5 1908·1	0·56 3·200	0·40 153·9	106·3 118·7	+0·3563 +0·0671	+0·0960 −0·3852	±0·1689 ∓0·0494	±2·56 ∓0·75	2 1950–1970	P. Muller 1957 *Bull. astr., Paris*, **24**, 2; 1963.
246 0 12·7	Grb 34† +43 27	8·07 M3 V	11·04 M6 V	3020 2318	0·250 0·1192	43·94 57·39	75·78 *55·99*	−12·993 +21·791	−28·651 −32·053	+35·8791 +9·0921	+20·26 +5·13	1900 5 1950–2000	J. Hopmann 1956 *Mitt. Univ.-Sternw. Wien*, **9**, 153; 1957.
283 0 15·4	h 1018 +67 7	8·4 G5	8·9	163·4 1943·0	0·96 2·2032	1·24 88·5	230·4 84·9	−0·0453 −0·7895	+0·1055 +0·9498	∓0·9551 ∓0·7901	∓9·97 ∓8·25	3 1950–1970	P. Muller 1956 *J. Observateurs*, **40**, 48; 1957.
281 0 15·5	β 1015 +11 45	8·7 F5	8·9	254·4 1957·4	0·65 1·4151	0·49 33·7	243·0 27·6	−0·0289 −0·4250	+0·4727 +0·0383	∓0·2422 ∓0·1234	∓1·62 ∓0·83	4 1958–1968	P. Baize 1958 *J. Observateurs*, **41**, 175; 1958.
293 0 15·8	OΣ 6† +66 27	7·7 *B8 V*	8·3 *A1 V*	200 1923·0	0·80 1·800	0·444 108·0	180·0* 147·4	+0·3740* −0·2392*	−0·0739* −0·1156*	0·0000 ∓0·4223	0·00 ∓3·60	3	G. Van Biesbroeck 1951 *Publ. Yerkes Obs.*, **8**, part 6, 169; 1954.
				240 1927·0	0·80 1·500	0·46 103·0	184·3 147·3	+0·3825 −0·2550	−0·0850 −0·0680	∓0·0336 ∓0·4469	∓0·24 ∓3·18	3 1950–1970	P. Muller 1953 *J. Observateurs*, **37**, 61; 1954.
0 21·3	α Phe Aa,P† −42 51	2·38 Ko III		10·538 1903·236	0·335 34·162	0·072 110·4	3 *221*	−0·0551 −0·0462	−0·0136 +0·0214	+0·0035 +0·0674	+0·57 +10·91	1 rev.	H. L. Alden *Astr. J.*, **46**, 189; 1938.
363 0 22·0	A 431 −8 26	8·9 *G5 V*	8·9 *Ko V*	54 1951·0	0·65 6·67	0·365 111·2	293·4 21·6	+0·0915 +0·1677	+0·3355 +0·0762	∓0·3123 ±0·1351	∓9·86 ±4·27	3 1950–1970	P. Muller 1953 *J. Observateurs*, **37**, 62; 1954.
371 0 22·7	Hu 1007 +63 11	9·7	9·9	198·53 2060·86	0·473 1·8134	0·458 53·51	103·26 117·03	−0·1885 −0·2143	+0·2585 −0·3690	±0·3587 ∓0·0845	±3·08 ∓0·73	5 1965–1995	A. S. da Silva, M. C. Balca 1962 *O Instituto de Coimbra*, **131**; 1968.
−21°57 0 23·3	B 1909 −20 53	7·2 G2 IV	7·2	5·625 1937·95	0·60 64·00	0·134 59·7	174·7 119·0	+0·059 −0·120	+0·065 +0·022	±0·011* ∓0·116*	±3·3* ∓35·1*	A1 1 rev.	W. H. van den Bos 1953. Orbit I. *Union Obs. Circ.*, **6**, 279; 1956.
				11·25 1940·88	0·00 32·00	0·214 69·8	0·0 119·0	−0·104 +0·187	−0·065 −0·036	0·000 ±0·201	0·0 ±30·5	A1 1 rev.	W. H. van den Bos 1953. Orbit II. Ibid.
434 0 26·2	OΣ 12 +53 58	5·5 B8	5·8	640 1958·0	0 0·5625	0·586 47·7	0 174·4	−0·5832 +0·0572	−0·0385 −0·3925	0·0000 ±0·4334	0·00 ±1·15	2000 5 1960–2000	W. D. Heintz 1960 *Veröff. Sternw. München*, **5**, 247; 1963.
450 0 27·0	A 111 AB† −5 44	9·2 *Ko V*	9·3 *K1 V*	10·755 1940·80	0·570 33·47	0·1692 129·6	59·8 161·3	−0·0505 +0·1158	+0·1560 +0·0044	±0·1128 ±0·0655	±17·86 ±10·38	2 1 rev.	W. H. van den Bos 1962 *Republ. Obs. Johannesb. Circ.*, **7**, 112; 1966.