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Orbits of 10 interferometric binary systems calculated by using the improved Koval'skij method[⋆]

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Abstract. Orbital elements are presented of 10 interferometric binary systems with no previous orbit determination: WDS 07143–2621 (FIN 323), WDS 12064–6543 (FIN 367Aa), WDS 12446–5717 (FIN 65), WDS 13320–6519 (FIN 369), WDS 13574–6229 (FIN 370), WDS 14189+5452 (CHR 137), WDS 14373–4608 (FIN 318 Aa), WDS 16115+0943 (FIN 354), WDS 17018–5108 (I 1306), WDS 17221–7007 (FIN 373). The method used (Koval'skij-Olević) is briefly described.

Key words. techniques: interferometric – stars: binaries: close

1. Introduction

Even though a large number of double and multiple systems has been discovered to date (WDS, Mason et al. 2003 contains over 84 000 systems), there is sufficient data for only a few thousand systems for the Keplerian motion to be clearly discerned.

The Sixth Catalog of Orbits of Visual Binary Stars (Hartkopf & Mason 2003) contains about 1700 pairs.

By the use of large-aperture telescopes and high resolution techniques (speckle interferometry, photo-electric occultation timing etc.) more precise data are supplied allowing the calculation of preliminary orbital elements from shorter observed arcs. Thereby the sample usable for various statistical analyses is enlarged such as: calculation of dynamical parallaxes and masses, studies of dynamical systems evolution etc.

From the Fourth Catalog of Interferometric Measurements of Binary Stars (Hartkopf et al. 2003) we selected 10 pairs exhibiting significant changes in position angles and separations, observed eight or more times. The systems concerned are: WDS 07143–2621 (FIN 323) = HIP 34981, WDS 12064–6543 (FIN 367Aa) = HIP 59050, WDS 12446–5717 (FIN 65) = HIP 62179, WDS 13320–6519 (FIN 369) = HIP 66005, WDS 13574–6229 (FIN 370) = HIP 68170, WDS 14189+5452 (CHR 137) = HIP 69958, WDS 14373–4608 (FIN 318 Aa) = HIP 71500, WDS 16115+0943 (FIN 354) = HIP 79337, WDS 17018–5108 (I 1306) = HIP 83321, WDS 17221–7007 (FIN 373) = HIP 84979.

There is a small number of optical observations of these pairs of minor precision.

2. Method of orbit calculation

The best known method of orbital element calculation is that of Thiele-van den Bos (Thiele 1883; Dommanget 1954; van den Bos 1926, 1932) developed by perfecting Thiele's method. It requires the knowledge of three normal places and an area constant $(t_i, \theta_i, \rho_i; 2C)$, $i = 1, 2, 3$.

In recent years two analytical methods of orbit determination have been proposed by Docobo (1985), Eichhorn (1985) and Eichhorn & Xu (1990).

One of the chief improvements of the method proposed by Docobo consists in its not requiring the knowledge of the area constant. The method is based on a mapping from the interval $(0, 2\pi)$ into the family of Keplerian orbits whose apparent orbits pass through three base points (normal places of high weight). In reality, that of Thiele-Innes-van den Bos is a particular case of this method.

CHARA developed an algorithm (Hartkopf et al. 1989; Mason et al. 1999) requiring preliminary knowledge of the period P, epoch of periastron passage T and eccentricity e. The orbits are calculated according to the "three-dimensional adaptive grid search technique".

Koval'skij proposed as early as 1872 an analytical method, based on determination of five geometrical orbital elements (Ω, i, ω, e and elipse parameter p) from five coefficients A_k ($k = 1, 2, 3, 4, 5$) of the conic Eq. (1a) (below). Two dynamical elements, the period P and the epoch of periastron passage T, are obtained from the Keplerian Eq. (2). The method is described in detail in Subbotin (1968).

$$F(\mathbf{A}, \mathbf{x}) = A_1 x_i^2 + A_2 y_i^2 + 2A_3 x_i y_i + 2A_4 x_i + 2A_5 y_i - 1 = 0 \qquad (1a)$$

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[⋆] Table 2 is only available in electronic form at `http://www.edpsciences.org` where $x_i = \rho_i \cos\theta_i$ and $y_i = \rho_i \sin\theta_i$; (θ, ρ) – polar coordinates of B component with respect to A in the system, for epoch t_i $(i = 1, 2, ..., n)$.

$$\frac{2\pi}{P}(t_i - T) = M(\theta_i, \Omega, \omega, i, e, a) \tag{2}$$

where M – mean anomaly and a – semimajor axis of ellipse.

To obtain acceptable orbital elements by this method the observational data should cover the entire orbit within at least one period. Failing this, it often happens that real elliptic solution cannot be obtained. However, even with the elliptic solution arrived at, it can be used only as a first approximation (Eichhorn 1985, 1990; Eichhorn & Xu 1990).

In order to enable this method to be applied even in cases where the observations cover a shorter arc of the orbit or there are gaps Olević introduced an improvement by using supplementary, fictive, observations. We named this method Koval'skij-Olević (KOVOLE).

The method has not been published in its entirety so far, so we present it here briefly.

We extend the polynomial (1a) with the system (1b) based on f fictive observations (θ'_l, ρ'_l) , $l = 1, 2, ..., f$.

$$\begin{aligned} F'(\mathbf{A}, \mathbf{x}') = {} & A_1 x_l'^2 + A_2 y_l'^2 + 2A_3 x'_l y'_l \\ & + \ 2A_4 x'_l + 2A_5 y'_l - 1 = 0 \end{aligned} \tag{1b}$$

where $x'_l = \rho'_l \cos\theta'_l,\ y'_l = \rho'_l \sin\theta'_l$.

The fictive position angles θ'_l are uniformly distributed along the part of the arc not covered with observations. Since second order centred curves exclusively are under consideration, the angles θ'_l will always be realized with the observations.

For radius-vectors ρ'_l are determined intervals $s_l = (\rho'_{l_{\max}} - \rho'_{l_{\min}})$ through which the orbit will certainly pass satisfying optimally the real observations along the arc L. These intervals can easily and accurately be determined provided sufficiently wide limits are taken.

Let ρ'_l take, in the interval s_l, discrete values with the step q, e.g. $q \leq 0\farcs001$.

Then the system [1(a)+1(b)] yields:

$$S = \prod_{l=1}^{f} s_l/q$$

sets of solutions for coefficients A_k.

The a priori weights w_i of the equations of conditions (1a) can be determined, e.g. in the way proposed by Mason et al. (1999). The equations of conditions (1b) are of equal weight G. This quantity is determined by Eq. (3), which enables the system (1b) to be of equal weight as the system (1a). This is of particular importance as it ensures the coherence of the real and fictitious measurements.

$$G = G(w_i, L, f) = \left(\sum_{1}^{n} w_i(360 - L)\right) / Lf. \tag{3}$$

For each one of S combinations one calculates the invariants U_1, U_2 and U_3 defined by matrices:

$$U_1 = [\,A_1 + A_2\,] \ ,$$

$$U_2 = \begin{bmatrix} A_1 & A_3 \\ A_3 & A_2 \end{bmatrix} ,$$

$$U_3 = \begin{bmatrix} A_1 & A_3 & A_4 \\ A_3 & A_2 & A_5 \\ A_4 & A_5 & 1 \end{bmatrix} .$$

In cases where the conditions are simultaneously satisfied:

$$\det U_2 > 0 \ \text{ and } \ (\det U_3/\det U_1) < 0$$

the solution yields a real ellipse (Korn & Korn 1961).

From the coefficients A_k satisfying the above conditions one calculates the geometrical orbital elements Ω, ω, i, e and a, and by applying the Keplerian Eq. (2) dynamical elements are derived: the period P and the epoch of periastron passage T.

The best solution is the one yielding $D = D_{\min}$, the function D being defined by:

$$D = \left(\sum_{1}^{n} w_i \left[(x_i - x_{c_i})^2 + (y_i - y_{c_i})^2\right]\right) / \sum_{1}^{n} w_i \tag{4}$$

where x_i, y_i are the observed rectangular coordinates and x_{c_i}, y_{c_i} are calculated rectangular coordinates.

From the corresponding covariation matrices the formal errors of orbital elements are derived.

By this method a better accordance is established between the geometrical parameters of the conic (Kepler's first law) and the dynamical parameters of the Keplerian equation which implies the area law (Kepler's second law).

Olević has made use of this method's idea since 1985 (Ćatović & Olević 1992). The method was complemented, being completely realized and tested only after a computer of adequate speed was put at our disposal. The suitable program has been designed by the author's collaborators P. Jovanović and Z. Cvetković.

3. Results

The orbital elements (equinox J2000) and the corresponding errors are listed in Table 1. These elements have been obtained from the interferometric measurements alone.

Table 2 contains the observational data used and their residuals. Asterisks (*) mark observations subjected to a change of quadrant. Double asterisks (**) indicate the measurements not used in the orbit calculation. The sign # indicate the optical measurements. The ephemeride values are given in brackets.

The ephemerides for 2003–2007 are given in Table 3.

Plots 1–10 (Fig. 1) give the fitted orbit, the line of nodes, the observed interferometric positions (dotes) and their corresponding ephemeride positions (open circles). The optical measurements and the corresponding ephemeride positions are marked by squares.

4. Notes on individual systems

WDS 07143–2621 = Fin 323 = Hip 34981. The measurements from 1952, 1953, 1954, 1977 and 1996 contain gross errors in the position angle (θ). These measurements have been ignored in the orbit calculation. The only optical measurement of

Table 1. Orbital elements.

Name	FIN 323	FIN 367 Aa	FIN 65	FIN 369	FIN 370
WDS	07143–2621	12064–6543	12446–5717	13320–6519	13574–6229
HIP	34981	59050	62179	66005	68170
m	5.394–4.920	6.788–7.142	6.985–8.176	7.358–7.540	7.369–7.758
Sp.	B3IIIe	G8/K0III	A0IV/V	A8/A9IV	G3III/IV
P(yr)	194.28 ± 4.58	103.18 ± 5.81	118.34 ± 5.81	40.44 ± 0.91	26.12 ± 0.26
T	1972.81 ± 4.52	2055.22 ± 1.94	2065.09 ± 0.81	1994.64 ± 0.49	1967.02 ± 0.43
$a('')$	0.195 ± 0.012	0.152 ± 0.005	0.287 ± 0.015	0.192 ± 0.026	0.178 ± 0.020
e	0.577 ± 0.046	0.299 ± 0.011	0.525 ± 0.032	0.194 ± 0.058	0.140 ± 0.038
$i(^\circ)$	73.1 ± 1.4	146.2 ± 1.4	111.2 ± 1.3	57.0 ± 3.0	134.5 ± 4.0
$\Omega(^\circ)$	151.4 ± 0.8	127.0 ± 2.1	61.8 ± 0.9	30.4 ± 4.7	105.0 ± 4.8
$\omega(^\circ)$	50.6 ± 4.1	297.4 ± 3.1	113.7 ± 4.8	356.3 ± 11.7	148.0 ± 13.4
Name	CHR 137	FIN 318 Aa	FIN 354	I 1306	FIN 373
WDS	14189+5452	14373–4608	16115+0943	17018–5108	17221–7007
HIP	69958	71500	79337	83321	84979
m	V:6.47	6.216–6.503	7.193–7.515	7.226–7.267	5.897–6.456
Sp.	A5Vn	K0III	F0IV	A7V	B8/B9V
P(yr)	13.39 ± 0.77	242.48 ± 5.97	48.12 ± 5.62	62.29 ± 1.84	51.44 ± 2.66
T	1992.40 ± 0.70	2072.84 ± 3.88	1991.76 ± 3.71	2011.00 ± 0.47	1998.61 ± 2.16
$a('')$	0.090 ± 0.010	0.206 ± 0.003	0.142 ± 0.050	0.255 ± 0.009	0.105 ± 0.008
e	0.704 ± 0.122	0.166 ± 0.007	0.021 ± 0.020	0.670 ± 0.411	0.252 ± 0.084
$i(^\circ)$	112.1 ± 3.3	125.2 ± 0.6	92.1 ± 3.9	83.6 ± 4.2	47.1 ± 10.0
$\Omega(^\circ)$	35.6 ± 2.0	113.7 ± 0.9	82.7 ± 3.8	19.5 ± 1.5	116.7 ± 12.1
$\omega(^\circ)$	216.4 ± 5.7	256.8 ± 4.3	62.2 ± 60.1	107.7 ± 21.9	241.2 ± 28.6

Table 3. Ephemerides.

WDS	07143–2621		12064–6543		12446-5717		13320–6519		13574–6229	
t	θ	ρ	θ	ρ	θ	ρ	θ	ρ	θ	ρ
2003.0	330.0	.192	6.3	.172	105.9	.213	126.0	.103	162.9	.149
2004.0	330.4	.196	4.2	.173	104.2	.218	141.4	.111	150.4	.162
2005.0	330.8	.200	2.0	.173	102.6	.223	154.2	.124	139.7	.175
2006.0	331.2	.203	359.9	.174	101.2	.228	164.5	.138	130.4	.186
2007.0	331.6	.207	357.8	.175	99.7	.234	172.8	.154	122.0	.194
WDS	14189+5452		14373–4608		16115+0943		17018–5108		17221–7007	
t	θ	ρ	θ	ρ	θ	ρ	θ	ρ	θ	ρ
2003.0	353.2	.059	323.0	.180	264.0	.122	17.1	.224	56.9	.062
2004.0	324.4	.035	321.9	.181	263.6	.130	17.8	.212	68.9	.069
2005.0	254.5	.029	320.8	.182	263.3	.137	18.5	.197	78.7	.076
2006.0	154.6	.013	319.7	.184	263.0	.141	19.4	.178	86.9	.083
2007.0	45.4	.063	318.7	.185	262.8	.143	20.5	.153	93.8	.090

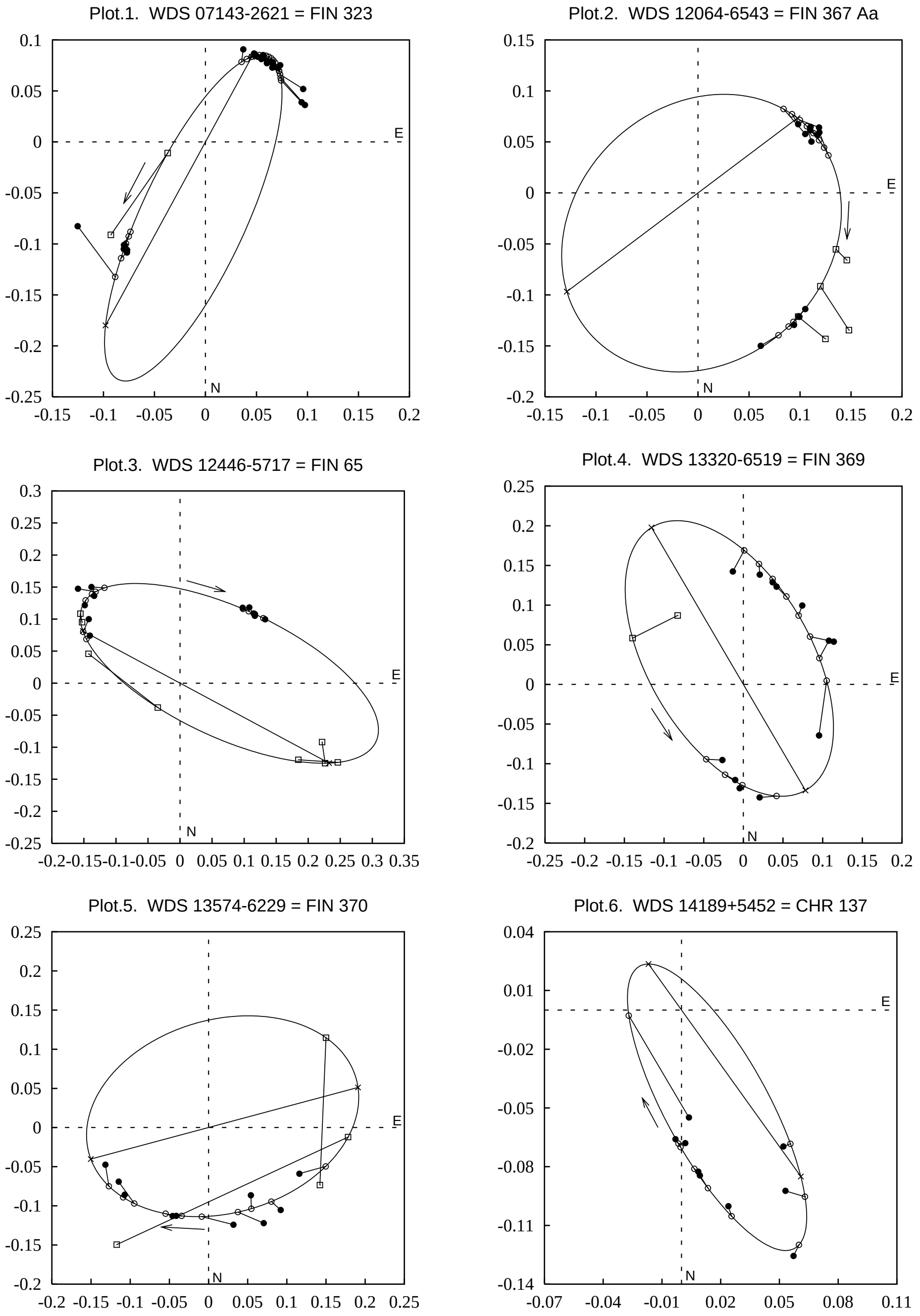

Fig. 1. Plots 1–10 (Fig. 1) give the fitted orbit, the line of nodes, the observed interferometric positions (dotes) and their corresponding ephemeride positions (open circles). The optical measurements and the corresponding ephemeride positions are marked by squares.

1980.230 is also ignored for the same reason. To achieve a better data fitting one had to change the quadrant either in Finsen's measurements or in those after 1977. We opted for the quadrant change.

WDS 12064–6543 = Fin 367 Aa = Hip 59050. The three optical measurements lie close to the calculated ellipse pretty well.

WDS 12446–5717 = Fin 65 = Hip 62179. The wrong quadrants in the measurements of 1991.25 (Hip) and 1993.093 (Hrt) are probably due to a lapse of the magnitude difference of 1.2. Of the four optical measurements only that of 1945.12 contains a large error.

WDS 13320–6519 = Fin 369 = Hip 66005. The normal place formed for the instant 1960.57, including also the measurement made on the occasion of its discovery, has a large error and was omitted from the orbit calculation. The single optical measurement of 1983.177 is imprecise.

WDS 13574–6229 = Fin 370 = Hip 68170. Since its discovery (1960) the pair completed its whole period (P = 26.125 yr). Both optical measurements contain large errors in the position angle.

WDS 14189+5452 = CHR 137 = Hip 69958. This short period system (P = 13.392 yr, a = $0''.090$) contains a large error in the interferometric measurement of 1991.3271.

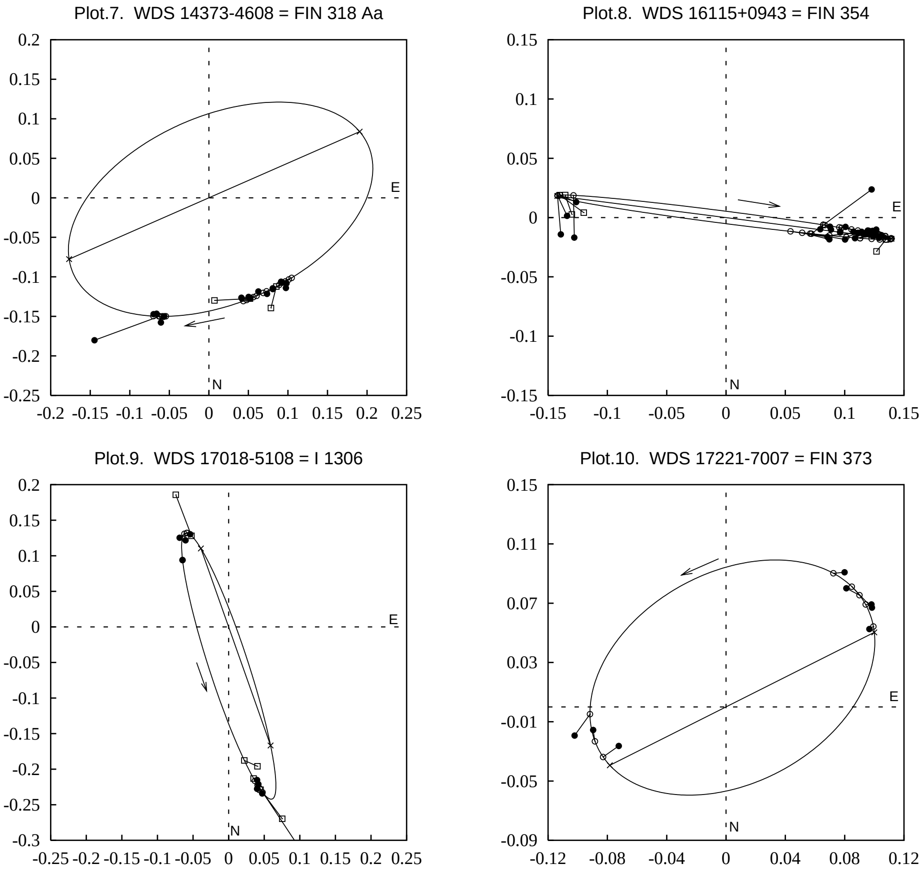

Fig. 1. continued.

WDS 14373–4608 = Fin 318 Aa = Hip 71500. The components of this triple system are denoted A, a and B in the WDS catalog and as A, B and C in the Hipparcos catalog. The component C has a Hip 71502 entry. The system has two optical measurements, one of them from 1964.61 containing a considerable error in the position angle.

WDS 16115+0943 = Fin 354 = Hip 79337. For the first four normal places formed by the discoverer (Finsen) from the observations made between 1959 and 1962, the quadrants have been changed. In 1963–1966 he made four separate measurements, failing, however, to measure the position angle. According to our calculation this pair with a 48 yr period and 92° inclination almost completed a whole revolution in the period concerned. The three optical measurements contain small errors; for the measurements of 1960.544 and 1961.59 the quadrants have been changed.

WDS 17018–5108 = I 1306 = Hip 83321. In five attempts in the interval 1960-1965 Finsen failed to measure the position angle (θ), while the separation could only be estimated. The ephemerides show that in the time interval concerned $\rho \leq 0\overset{\prime\prime}{.}1$ which gives the pair's apparent magnitude (6.4–6.5), rendered precise measurements difficult. In three (1926.51, 1929.32 and 1985.33) out of four optical measurements the quadrant was changed. The accuracy is within the limits expected with this kind of measurement.

WDS 17221–7007 = Fin 373 = Hip 84979. This, according to our calculated short-period system (P = 51.441 yr), has no optical measurements.

Gaps in the observations, easily seen in the plots for the Finsen pairs, discovered at the South African Astronomical Observatory ($\varphi = -26\overset{\circ}{.}2$) appeared after the discoverer's death. In the southern hemisphere, until recently, the number of observations has been insufficient to continue the study of the motion of systems with high negative declinations.

5. Conclusions

In spite of difficulties met in the calculation of the orbital elements of the selected pairs, such as short arcs covered with observations, large gaps between two consecutive groups of observations and high inclinations, we obtained elements with small relative errors. Contributing to this was, on the one hand, enhanced accuracy of measurements thanks to the use of new techniques and, on the other, the KOVOLE method employed.

The obtained orbital elements are preliminary ones.

In view of the relatively short periods these systems should more often be included in interferometric observational programs. By so doing we might in the near future, obtain definite orbital elements. As these systems have their trigonometric parallaxes already determined by the Hipparcos mission, the sums of their masses may be determined. This is particularly important because the greater part (seven) of these systems, according to their spectral type, belong to the main sequence.

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Online Material

Table 2. Observations and residuals.

WDS 07143-2621 = FIN 323						
t	θ	ρ	n	Obs.	$\Delta\theta$	$\Delta\rho$
1952.5000**	112.1	.102	7	*Fin*	−16.7	.006
1953.2300**	110.1	.104	7	*Fin*	−20.0	.007
1954.2300**	118.1	.109	2	*Fin*	−13.7	.010
1955.2600	137.1	.100	9	*Fin*	3.4	.000
1955.3100	135.5	.102	1	*Fin*	1.7	.002
1956.2100	135.5	.105	8	*Fin*	0.2	.004
1958.2400	139.6	.102	5	*Fin*	1.1	−.001
1959.2500	140.8	.101	5	*Fin*	0.7	−.003
1960.2400	137.8	.098	6	*Fin*	−3.8	−.006
1961.2900	141.8	.098	5	*Fin*	−1.4	−.006
1962.2700	142.7	.100	5	*Fin*	−2.1	−.003
1963.2460	145.9	.102	5	*Fin*	−0.4	.000
1964.2830	148.4	.098	8	*Fin*	0.4	−.002
1965.2730	145.8	.098	5	*Fin*	−3.9	.000
1966.2780	150.5	.099	4	*Fin*	−1.0	.004
1967.2820	151.0	.099	8	*Fin*	−2.4	.008
1968.3210	157.6	.098	6	*Fin*	2.0	.012
1980.2300$^{\diamond *}$	134.4	.13	–	*Wor*	28.1	.091
1989.9336*	142.0	.129	1	*Hrt*	1.1	.010
1990.9137*	142.6	.132	1	*Hrt*	0.7	.006
1991.2500*	144.0	.131	1	*Hip*	1.7	.002
1993.0953*	144.6	.133	1	*Hrt*	0.6	−.008
1996.1752*	123.4	.150	1	*Msn*	−22.9	−.009

Table 2. continued.

WDS 12064-6543 = FIN 367 Aa						
t	θ	ρ	n	Obs.	$\Delta\theta$	$\Delta\rho$
1960.5100	118.8	.120	3	*Fin*	−15.1	.003
1961.5000	124.5	.119	3	*Fin*	−4.9	−.001
1962.5000	118.4	.135	3	*Fin*	−6.7	.012
1963.4700	114.4	.122	2	*Fin*	−6.7	−.003
1964.4830	115.9	.130	4	*Fin*	−1.1	.003
1965.4940	119.2	.126	3	*Fin*	6.1	−.004
1966.4830	120.4	.128	3	*Fin*	11.0	−.003
1967.4880	116.5	.133	3	*Fin*	10.8	.000
1979.2000$^{\diamond}$	65.7	.16	–	*hz*	−0.8	.014
1984.3800$^{\diamond}$	47.7	.20	–	*hz*	−3.9	.049
1989.3033	42.7	.155	1	*McA*	3.6	−.001
1989.3900$^{\diamond}$	41.1	.19	–	*hz*	3.1	.034
1990.3491	39.3	.157	1	*Hrt*	2.9	.000
1991.2500	36.0	.140	1	*Hip*	2.0	.002
1993.0930	22.3	.162	1	*Hrt*	−7.1	.002

Table 2. continued.

WDS 12446-5717 = FIN 65						
t	θ	ρ	n	Obs.	$\Delta\theta$	$\Delta\rho$
1928.4300$^{\diamond *}$	237.2	.22	–	*Fin*	−6.3	−.055
1930.4800$^{\diamond *}$	247.6	.24	–	*J*	6.3	−.018
1945.1200$^{\diamond}$	252.3	.15	2	*Vou*	−65.4	.098
1952.4700	242.3	.159	2	*Fin*	−2.9	−.002
1953.4700	235.0	.174	3	*Fin*	−7.4	.003
1956.4100$^{\diamond}$	238.2	.18	–	*B*	3.0	−.009
1959.5000	230.8	.192	2	*Fin*	1.7	−.004
1961.5100	: 224.6	: .191	3	*Fin*	−0.4	−.004
1962.5000	227.3	.217	1	*Fin*	4.3	.023
1964.5260	222.7	.204	3	*Fin*	3.9	.014
1989.3033	140.4	.153	1	*McA*	0.6	.001
1990.3463	137.6	.160	1	*Hrt*	1.2	.005
1991.2500*	312.0	.157	1	*Hip*	−1.5	−.001
1991.3894	132.6	.159	2	*Hrt*	−0.5	.000
1993.0930*	306.9	.166	1	*Hrt*	−1.1	.001

Table 2. continued.

WDS 13320-6519 = FIN 369						
t	θ	ρ	n	Obs.	$\Delta\theta$	$\Delta\rho$
1960.5700**	56.2	.115	3	*Fin*	−36.9	.010
1961.5600	: 117.3	: .121	2	*Fin*	7.7	.020
1962.5400	115.5	.126	5	*Fin*	−10.6	.023
1963.5590	143.5	.124	4	*Fin*	1.7	.013
1964.5430	161.4	.130	7	*Fin*	7.0	.007
1965.5630	164.2	.134	4	*Fin*	−0.7	−.004
1966.5390	171.7	.140	3	*Fin*	−1.3	−.013
1967.5800	185.5	.143	2	*Fin*	5.4	−.026
1983.1770$^{\diamond}$	223.7	.12	2	*Wor*	−23.7	−.031
1989.3036	344.5	.099	1	*McA*	10.8	−.006
1990.3437	355.2	.121	1	*Hrt*	6.5	.005
1991.2500	358.0	.131	1	*Hip*	−1.5	.004
1993.0984	8.2	.144	1	*Hrt*	−8.5	−.003

Table 2. continued.

WDS 13574-6229 = FIN 370						
t	θ	ρ	n	Obs.	$\Delta\theta$	$\Delta\rho$
1960.5700	63.3	.130	3	*Fin*	−8.0	−.028
1962.5800	41.4	.140	3	*Fin*	1.4	.016
1963.5610	30.2	.141	5	*Fin*	11.3	.027
1964.5620	14.6	.128	6	*Fin*	19.2	.014
1965.5810	338.1	.122	3	*Fin*	4.8	−.001
1966.5680	301.3	.134	4	*Fin*	−14.1	−.002
1967.5780	290.0	.140	2	*Fin*	−10.3	−.008
1980.2260$^{\diamond}$	62.8	.16	2	*Wor*	−64.7	−.029
1985.3400$^{\diamond}$	322.0	.19	–	*hz*	235.9	.011
1989.3036	32.1	.102	1	*McA*	4.4	−.015
1991.2500	340.0	.120	1	*Hip*	−3.0	.002
1993.0983	308.8	.137	1	*Hrt*	−0.4	−.004

Table 2. continued.

WDS 14189+5452 = CHR 137

t	θ	ρ	n	Obs.	$\Delta\theta$	$\Delta\rho$
1987.2698	13.5	.103	1	*McA*	−0.2	−.005
1988.1683	6.4	.085	1	*McA*	−2.1	−.007
1988.6653	6.0	.083	1	*McA*	1.4	.002
1989.1564	: 357.4	: .066	1	*McA*	−2.2	−.004
1989.2273	1.7	.068	1	*McA*	2.9	.000
1991.3271**	4.0	.055	1	*McA*	88.1	.028
1994.2214	36.8	.087	1	*Hrt*	−2.4	−.001
1995.2318	29.9	.107	2	*Hrt*	−3.6	−.008
1997.1320	24.5	.138	1	*Hrt*	−2.1	.004

Table 2. continued.

WDS 14373-4608 = FIN 318 Aa

t	θ	ρ	n	Obs.	$\Delta\theta$	$\Delta\rho$
1951.5300	41.2	.142	2	*Fin*	−4.4	−.003
1952.4900	40.9	.140	4	*Fin*	−3.1	−.004
1953.5600	40.7	.150	2	*Fin*	−1.4	.007
1955.5900	41.2	.142	1	*Fin*	−0.9	.002
1956.4900$^{\diamond}$	29.6	.16	–	*B*	−7.9	.019
1957.5900	42.4	.146	1	*Fin*	4.6	.005
1959.5800	35.2	.141	3	*Fin*	1.7	−.001
1960.5900	31.4	.142	1	*Fin*	0.0	.000
1962.5900	28.0	.134	4	*Fin*	0.9	−.007
1963.5890	22.7	.137	4	*Fin*	−2.2	−.003
1964.6040	18.3	.134	5	*Fin*	−4.3	−.004
1964.6100$^{\diamond}$	3.3	.13	–	*B*	−19.1	−.008
1965.5980	22.0	.135	4	*Fin*	1.6	−.001
1966.5860	18.2	.133	2	*Fin*	0.2	.000
1989.3037	339.4	.160	1	*McA*	−0.9	.000
1990.3464	: 339.3	: .161	1	*Hrt*	0.7	−.001
1991.2500	339.0	.169	1	*Hip*	1.9	.006
1991.2500**	: 321.3	: .231	1	*Fab*	−16.0	−.069
1991.3895	335.8	.161	1	*Hrt*	−1.1	−.002
1993.0989	334.6	.163	1	*Hrt*	0.4	−.002

Table 2. continued.

WDS 16115+0943 = FIN 354

t	θ	ρ	n	Obs.	$\Delta\theta$	$\Delta\rho$
1959.5800*	96.2	.140	1	*Fin*	13.2	−.003
1959.6100*	89.8	.134	4	*Fin*	6.8	−.009
1960.5440$^{\diamond *}$	88.2	.12	–	*VBS*	5.7	−.021
1960.6400*	84.5	.127	1	*Fin*	1.8	−.014
1961.5900$^{\diamond *}$	89.0	.13	–	*B*	6.8	−.007
1962.6400*	97.9	.129	5	*Fin*	15.8	.000
1963.6350	–	< .122	1	*Fin*	(261.4)	(.121)
1963.6380**	: 133.	: .111	1	*Fin*	128.5	−.010
1964.6540	–	< .114	1	*Fin*	(260.9)	(.100)
1965.6350	–	< .104	1	*Fin*	(260.4)	(.097)
1966.6430	–	< .102	1	*Fin*	(259.8)	(.083)
1976.2963	83.1	.080	1	*McA*	−2.8	−.002
1976.3699	85.2	.088	1	*McA*	−.7	.005
1976.4573	83.7	.089	1	*McA*	−2.1	.005
1977.3338	82.8	.097	1	*McA*	−2.4	.001
1977.4813	83.3	.097	1	*McA*	−1.8	−.001
1978.1501	85.8	.101	1	*McA*	1.0	−.006
1978.6173	83.9	.108	1	*McA*	−.6	−.004
1979.5291	83.5	.112	1	*McA*	−.7	−.009
1980.1597	85.0	.120	1	*McA*	1.0	−.007
1980.4766	83.7	.124	1	*McA*	−.1	−.005
1980.7225	81.1	.110	1	*McA*	−2.7	−.021
1981.4568	84.1	.119	1	*McA*	.6	−.016
1981.4677	83.4	.119	1	*McA*	−.1	−.016
1981.4731	83.5	.119	1	*McA*	.0	−.016
1983.0702	84.9	.121	1	*Hrt*	1.8	−.019
1983.4200	82.9	.125	1	*McA*	−.1	−.015
1983.4282	82.6	.130	1	*Hrt*	−.4	−.010
1983.7151	85.6	.127	1	*McA*	2.7	−.013
1984.3730	83.7	.132	1	*McA*	1.0	−.008
1984.3757	84.0	.126	1	*McA*	1.3	−.014
1985.4843	84.1	.126	1	*McA*	1.7	−.010
1985.5100$^{\diamond}$	77.4	.13	–	*Cou*	−4.9	−.006
1986.4098	84.0	.127	1	*McA*	1.8	−.003
1987.2726	84.9	.124	1	*McA*	3.1	.000
1988.2501	83.3	.122	1	*McA*	1.9	.008
1988.2527	83.2	.118	1	*McA*	1.8	.004
1989.2275	84.1	.115	1	*McA*	3.2	.013
1990.2625	83.5	.112	1	*Hrt*	3.2	.024
1991.2500	101.	.125	1	*Hip*	21.6	.053
1991.3191	79.7	.102	1	*Hrt*	.3	.031
1991.7258	78.2	.089	1	*Hrt*	−0.6	.024
1992.3075	79.3	.087	1	*Hrt*	1.4	.032

Table 2. continued.

WDS 17018-5108 = I 1306						
t	θ	ρ	n	Obs.	$\Delta\theta$	$\Delta\rho$
1926.5100$^{\diamond *}$	199.9	.36	–	*I*	9.9	.144
1929.3200$^{\diamond *}$	196.2	.28	–	*Vou*	4.5	.047
1952.4800$^{\diamond}$	202.2	.20	–	*B*	−0.4	.062
1953.6200	202.9	.141	5	*Fin*	−1.4	−.003
1953.6600	209.2	.143	1	*Fin*	4.8	−.002
1954.6100	206.8	.136	2	*Fin*	1.0	−.009
1959.6900	215.0	.114	4	*Fin*	0.1	.000
1960.6900	–	$<$ .113	1	*Fin*	(217.1)	(.105)
1960.7000	–	$<$ .105	1	*Fin*	(217.2)	(.105)
1962.6800	–	$<$ .108	1	*Fin*	(224.0)	(.086)
1963.6630	–	$<$ .109	1	*Fin*	(228.8)	(.076)
1964.6980	–	$<$ .107	1	*Fin*	(235.2)	(.066)
1985.3300$^{\diamond *}$	191.8	.20	–	*hz*	4.9	.011
1989.3038	10.6	.219	1	*McA*	0.8	.000
1990.3496	10.8	.225	1	*Hrt*	0.4	−.001
1991.2500*	190.0	.231	1	*Hip*	−0.9	.000
1992.4550	11.4	.239	1	*Hrt*	−0.2	.002

Table 2. continued.

WDS 17221-7007 = FIN 373						
t	θ	ρ	n	Obs.	$\Delta\theta$	$\Delta\rho$
1960.6900	119.2	.110	3	*Fin*	−0.3	.001
1962.6800	125.8	.120	4	*Fin*	0.1	−.001
1963.6720	135.2	.114	4	*Fin*	6.7	−.009
1964.7000	124.8	.119	3	*Fin*	−6.5	−.003
1966.7120	139.2	.121	3	*Fin*	2.0	.004
1989.3066	280.9	.104	1	*McA*	5.3	.005
1991.2500*	100.0	.091	1	*Hip*	−4.2	−.002
1992.4496	290.1	.077	1	*Hrt*	−0.9	.000