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ORBITAL ELEMENTS FOR BU 1240 AB. NATURE OF THE C AND D COMPONENTS

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RESUMEN

En este trabajo se obtienen nuevos parámetros orbitales para la binaria WDS 05386+3030 = BU 1240 AB debido a la existencia de residuos sistemáticos respecto a las últimas mediciones realizadas con posterioridad a 1985. Se utilizó una combinación de métodos gráficos y analíticos para el cálculo. La órbita preliminar fue mejorada usando el método de corrección diferencial de W. D. Heintz. Se obtuvo la masa. La naturaleza de las componentes C y D fue estudiada usando la fotometría $BVIJHK$ y datos astrométricos y cinemáticos. Determinamos la naturaleza física de C y la óptica de D usando varios criterios.

ABSTRACT

New orbital parameters and masses for WDS 05386+3030 = BU 1240 AB were determined prompted by the large residuals seen in recent speckle measurements from 1985. A combined solution of graphical (to determine preliminary parameters) and analytical methods was used. The preliminary orbit was refined using the differential correction method by Heintz. The physical characteristics of the C and D components were studied using BVIJHK photometry, historical astrometry and kinematical data. Several criteria indicate a physical nature for C and an optical nature for D.

Key Words: binaries: general — binaries: visual — stars: individual (HD 37269, ADS 4229)

1. INTRODUCTION

For several years double-star amateurs have contributed to the astronomical community with interesting work, not only performing astrometry of many double stars (e.g., Le Beau 1989, 1990; Gili & Couteau 1997; Morlet, Salaman, & Gili 2000, 2002; Gili & Bonneau 2001; Salaman, Morlet, & Gili 2001; Salaman et al. 2005; Arnold 2006a,b,c,d; Daley 2006; Rica 2006a), but also studying their astrophysical properties (e.g., Rica 2005; Rica 2006a,b) such as photometry, spectral types, parallaxes, kinematics, etc. These works are complemented with others that study the nature of pairs using criteria which allow the classification of double stars as optical or physical (e.g., Shuart 2005; Rica 2006a,b). Other important contributions were the discoveries of new pairs some of these binary (i.e., physical double) stars (e.g., Greaves 2005, 2006; Rica 2005; Nicholson 2006; Varley & Nicholson 2006) and the calculation of new orbital parameters (e.g., Baize 1991, 1992, 1993, 1994; Alzner 2003, 2004, 2005; Mante 2005, 2006; Rica 2006c,d,e).

This paper provides improved orbital parameters for BU 1240 AB. The physical properties of the C and D components were studied using $BVIJHK$ photometry, historical astrometry and kinematical data. The nature for C and D was determined by the use of several criteria.

BU 1240 AB (WDS 05386+3030 = ADS 4229 = HD 37269 = HR 1914 = HIP 26536 = 26 Aur) was discovered by Burnham in 1892 (Burnham 1894). It is composed of two stars with V magnitudes of 6.29 and 6.21 (ESA 1997) and spectral types G8III and B9.5V (Buscombe 1998). The Hipparcos satellite determined their proper motions (-21.15 mas yr^{-1} in RA and -11.98 mas yr^{-1} in DEC) and parallax (0.0073±0.0010 arcsec). A distance of $137.2^{+20.8}_{-16.0}$ pc is inferred from the Hipparcos parallax. The similarity of the magnitudes of both components causes quadrant problems in position angle for some measures.

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TABLE 1

ORBITAL PARAMETERS FOR BU 1240 AB

	Starikova (1977)	Scardia (1982)	Scardia (1985)	This work
P [years]	53.34	52.771	53.275±0.330	52.735±0.156
T [BY]	1922.27	1921.777	1921.044±0.420	1974.927±0.026
e	0.56	0.6198	0.611±0.010	0.653 ± 0.002
a [″]	0.135	0.148	0.155±0.021	0.154 ± 0.001
i [°]	136.2	126.47	124.62±2.40	124.22 ± 0.29
ω [°]	340.2	324.10	319.12±3.10	309.07 ± 0.14
Ω [°]	147.5	139.18	137.61±2.70	127.08 ± 0.38
Residuals:				
RMS(θ)[°]	55.10	65.83	12.53	9.35
RMS(ρ)[″]	0.059	0.080	0.056	0.017
MA(θ)[°]	4.78	8.06	1.73	1.18
MA(ρ)[″]	0.012	0.015	0.011	0.004
$M_A+M_B[M_\odot]$	2.2±1.2	3.0±1.2	3.4±2.7	3.4±1.4
a^3/P^2	0.865×10^{-6}	1.164×10^{-6}	1.312×10^{-6}	1.313×10^{-6}

TABLE 2

EPHEMERIDES FOR BU 1240 AB

Epoch	θ [°]	ρ [″]
2008.0	330.7	0.209
2009.0	329.1	0.209
2010.0	327.5	0.209
2011.0	325.9	0.207
2012.0	324.3	0.205
2013.0	322.7	0.202
2014.0	321.0	0.199
2015.0	319.2	0.194
2016.0	317.3	0.189
2017.0	315.3	0.182
2018.0	313.1	0.174
2019.0	310.7	0.165
2020.0	308.0	0.154

Table 1 shows the orbital parameters, the root mean squared residuals RMS, the mean absolute residuals MA and the masses for some previous solutions and for the solution determined in this paper. Errors for the elements were calculated from the covariance matrix and the residuals to all observations. The total mass of the binary (± estimated standard error) was calculated (Scardia 1984). Table 2 lists ephemerides for the period 2008–2020. Table 3 shows the observations as they are listed in WDS database, and the residuals. Table 4 gives the astrophysical properties for BU 1240 AB.

2. METHOD OF ORBITAL CALCULATION AND OBSERVATIONS

All values of θ were corrected for precession and proper motion, then θ and ρ were plotted against time which allows the detection of measures with important errors (which were assigned zero weight) and quadrant problems. There were quadrant problem in 12 measures; among them, 8 measures were made by van Biesbroeck (1954, 1960, 1975).

A preliminary orbit was determined by geometric methods (Tanguay 2002; Argyle 2004). This initial orbit was improved using the Heintz (1978) differential correction method.

The initial weights were assigned using a data weighting scheme based on Hartkopf, McAlister, & Franz (1989), Mason, Douglass, & Hartkopf (1999), Seymour et al. (2002), and Docobo & Ling (2003). The initial θ weights were 5 times larger than the ρ weights (Heintz 1978).

After several iterations in the differential correction process the measures with residuals larger than 3σ were assigned zero weight. Later the non-zero weight measures were reassigned following the work of Irwin, Yang, & Walker (1996).

Since Burnham discovered it in 1892, BU 1240 AB has had 92 measures (29 speckle data, 7 other interferometric measures, 54 visual measures, 1 Hipparcos measure, and 1 CCD measure). The last data

TABLE 3

OBSERVATIONS AND O-C RESIDUALS

			Scardia 1985		This work		
Epoch	θ [°]	ρ [″]	$\Delta\theta$[°]	$\Delta\rho$[″]	$\Delta\theta$[°]	$\Delta\rho$[″]	References
1892.00	344.4	0.15	−2.9	−0.050	−4.2	−0.028	1
1892.84	354.2	0.22	8.4	0.016	7.3	0.038	2
1893.942	342.5	0.16	−1.4	−0.049	−2.2	−0.028	2
1893.98	346.4	0.2	2.6	−0.009	1.8	0.012	3
1896.13	338.8	0.21	−1.6	−0.006	−1.8	0.014	3
1899.179	352.9	0.22	17.8	−0.001	17.5	0.015	4
1900.2	346.4	0.28	12.2	0.058	12.7	0.073	5
1900.55	332.0	0.21	−1.7	−0.012	−1.2	0.003	6
1901.12	336.4	0.22	3.5	−0.001	4.1	0.012	7
1901.28	333.1	0.18	0.5	−0.041	1.1	−0.028	8
1902.19	330.0	0.24	−1.3	0.020	−0.6	0.031	9
1903.13	332.5	0.21	2.7	−0.009	3.4	0.001	10
1903.14	319.1	0.2	−10.7	−0.019	−10.0	−0.009	11
1905.69	319.8	0.19	−6.1	−0.021	−5.3	−0.017	6
1908.11	321.8	0.12	0.1	−0.079	0.7	−0.080	12
1910.13	320.8	0.21	3.1	0.027	3.3	0.019	13
1910.2	316.1	0.16	−1.4	−0.023	−1.3	−0.031	14
1914.090	323.2	0.22	16.8	0.084	14.5	0.061	15
1914.1	308.3	0.2	2.0	0.064	−0.3	0.041	16
1914.95	297.7	0.14	−4.9	0.017	−8.4	−0.008	17
1915.180[a]	326.6	0.19	(25.1)	(0.071)	(21.2)	(0.044)	15
1915.22	294.6	0.22	−6.7	0.102	−10.7	0.075	16
1923.18[b]	283.7	0.286	(−19.7)	(0.213)	(−29.1)	(0.228)	18
1924.13	118.7	0.14	8.0	0.065	2.2	0.071	19
1939.43[b]	176.0	0.18	−4.3	0.015	−6.8	0.033	20
1939.94[a]	335.2	0.18	(−23.8)	(0.011)	(−26.0)	(0.029)	21
1943.76[b]	167.0	0.19	−3.5	−0.003	−4.1	0.017	20
1944.81[b]	170.4	0.19	2.0	−0.008	1.6	0.011	22
1945.96[b]	167.5	0.21	1.1	0.006	1.1	0.026	20
1948.78[b]	168.6	0.17	6.9	−0.044	7.5	−0.026	20
1950.09[b]	164.6	0.24	5.0	0.023	5.8	0.040	23
1950.19	335.7	0.2	−3.8	−0.018	−2.9	−0.001	24
1951.05[b]	160.5	0.19	2.3	−0.029	3.4	−0.013	20
1952.16	339.0	0.19	2.5	−0.031	3.7	−0.015	25
1953.00[b]	159.1	0.2	3.8	−0.021	5.1	−0.007	26
1953.78	331.8	0.21	−2.3	−0.012	−0.9	0.002	27
1954.79[b]	152.9	0.2	0.3	−0.021	1.8	−0.009	26
1956.17	327.5	0.17	−3.1	−0.049	−1.5	−0.039	28
1958.09	326.1	0.19	−1.5	−0.025	0.2	−0.017	29
1960.71	322.1	0.2	−1.2	−0.003	0.5	−0.001	30
1961.82	311.1	0.16	−10.1	−0.036	−8.6	−0.036	31
1961.86	316.4	0.18	−4.8	−0.015	−3.3	−0.016	31
1962.09[b]	123.9	0.22	−16.8	0.026	−15.4	0.025	32
1962.14	322.6	0.19	2.0	−0.003	3.4	−0.005	34
1962.963	316.4	0.17	−2.6	−0.017	−1.3	−0.020	35
1966.08[b]	137.5	0.19	6.3	0.036	6.5	0.024	36
1966.322	308.6	0.15	−1.8	−0.001	−1.7	−0.014	37
1969.952	295.3	0.15	3.4	0.059	−2.1	0.035	38
1971.14[a]	272.6	0.16	(−5.1)	(0.093)	(−17.2)	(80.068)	39
1975.9564	132.0	0.06	1.0	−0.010	−0.3	0.001	40
1976.9231	116.0	0.067	−1.3	−0.007	0.0	−0.002	41
1977.0870	113.6	0.068	−1.6	−0.007	0.0	−0.003	41
1977.1798	113.5	0.078	−0.5	0.003	1.2	0.007	42
1979.0364	90.2	0.081	−0.5	0.004	0.1	0.002	43
1979.181	89.2	0.1	0.2	0.023	0.7	0.021	44
1979.1921	91.7	0.086	2.9	0.009	3.3	0.007	45
1979.7709	83.2	0.08	1.3	0.002	1.0	−0.001	43
1980.1534	78.4	0.087	1.0	0.008	0.2	0.006	46
1980.7210	70.9	0.075	−0.1	−0.006	−1.6	−0.008	46
1980.7773	68.7	0.082	−1.7	0.001	−3.2	−0.001	47
1982.7607	59.3	0.083	9.1	−0.007	5.9	−0.007	48
1982.863	50.2	0.083	0.9	−0.008	−2.3	−0.008	49

TABLE 3 (CONTINUED)

Epoch	θ [°]	ρ [″]	Scardia 1985 Δθ[°]	Scardia 1985 Δρ[″]	This work Δθ[°]	This work Δρ[″]	References
1983.0475	48.9	0.095	1.2	0.003	−2.1	0.004	48
1983.9340[a]	44.5	0.117	(4.1)	(0.019)	(0.6)	(0.021)	50
1984.16	43.0	0.12	4.3	0.021	0.8	0.023	51
1984.787	35.6	0.102	1.4	−0.002	−2.1	0.002	52
1984.94	41.2	0.12	8.0	0.015	4.5	0.019	53
1985.743	31.5	0.107	3.4	−0.004	0.0	0.001	54
1985.8407	30.7	0.105	3.1	−0.007	−0.2	−0.001	48
1986.81	25.3	0.109	3.0	−0.010	0.0	−0.003	53
1986.8893	24.4	0.112	2.5	−0.008	−0.5	−0.001	55
1987.04	26.6	0.11	5.5	−0.011	2.5	−0.004	56
1988.162	21.0	0.14	5.0	0.010	2.5	0.019	57
1988.2490	18.2	0.122	2.6	−0.009	0.1	0.000	55
1988.2545	18.3	0.122	2.7	−0.009	0.2	0.000	55
1988.6609	16.6	0.124	2.7	−0.010	0.4	0.000	58
1988.816	13.3	0.145	0.0	0.010	−2.3	0.020	59
1988.8708	15.3	0.118	2.3	−0.018	0.0	−0.008	60
1989.17	14.8	0.17	2.9	0.032	0.8	0.042	61
1989.2294	14.2	0.129	2.5	−0.010	0.4	0.001	58
1991.0271[a]	6.0	0.178	(0.5)	(0.025)	(−0.9)	(0.038)	62
1991.25	4.0	0.14	−0.8	−0.014	−2.1	−0.001	63
1993.2023	357.6	0.153	−1.7	−0.016	−2.4	−0.001	64
1995.7686	353.8	0.166	0.4	−0.019	0.6	−0.003	65
1995.9296	353.6	0.171	0.6	−0.015	0.8	0.001	65
1996.8718	351.5	0.174	0.4	−0.018	0.9	−0.001	66
1997.1255	350.3	0.174	−0.3	−0.019	0.2	−0.003	66
1997.8245	349.1	0.173	−0.2	−0.024	0.6	−0.007	67
1999.8888	344.8	0.185	−0.8	−0.021	0.4	−0.005	68
1999.8888	344.4	0.187	−1.2	−0.019	0.0	−0.003	68
1999.8888	344.9	0.188	−0.7	−0.018	0.5	−0.002	68
2004.095	338.5	0.203	−0.4	−0.016	1.5	−0.001	69

[a]Observations with residual in parentheses are not used for orbital calculations because of large residuals or other problems.

[b]Quadrant subject to change for orbital calculations.

References — (1)Burnham 1894; (2) Barnard 1898; (3) Schiaparelli 1909; (4) Lewis 1899; (5) Bowyer 1900; (6) Aitken 1914; (7) Bryant 1901; (8) Lewis 1901; (9) Bryant 1902; (10) Bowyer 1903; (11) Bryant 1903; (12) Lewis 1908; (13) Bowyer 1921; (14) Lewis 1921; (15) Rabe 1923; (16) Bryant 1921; (17) Aitken 1923; (18) Maggini 1925; (19) Aitken 1927; (20) van Biesbroeck 1954; (21) Wilson 1941; (22) Voute 1955; (23) Markowitz 1956; (24) Muller 1950; (25) Muller 1954b; (26) van Biesbroeck 1960; (27) Muller 1954a; (28) Muller 1956; (29) van den Bos 1960; (30) Worley 1962; (31) Couteau 1962; (32) Holden 1963; (33) van den Bos 1962; (35) Worley 1967; (36) van Biesbroeck 1975; (37) Worley 1972; (38) Worley 1978; (39) Wilson 1979; (40) McAlister 1977; (41) McAlister & DeGioia 1979; (42) McAlister & Hendry 1982a; (43) McAlister & Hendry 1982b; (44) Worley 1989; (45) McAlister & Hartkopf 1984; (46) McAlister et al. 1983; (47) Dudinov et al. 1982; (48) McAlister et al. 1987; (49) Tokovinin 1983; (50) Bonneau et al. 1984; (51) Couteau 1985; (52) Tokovinin 1985; (53) Couteau 1987; (54) Tokovinin & Ismailov 1988; (55) McAlister et al. 1989; (56) Heintz 1987; (57) Gili 1991; (58) McAlister et al. 1990; (59) Couteau 1989; (60) Ismailov 1992; (61) Le Beau 1990; (62) Balega et al. 1993; (63) Hipparcos Catalog (ESA 1997); (64) Hartkopf et al. 1994; (65) Hartkopf et al. 1997; (66) Hartkopf et al. 2000; (67) Horch et al. 1999; (68) Horch et al. 2002; (69) Scardia et al. 2005.

point in 2004.095 was made by Scardia et al. (2005) using a 1.0 m telescope of the Brera Astronomical Observatory (Italy) and a speckle camera.

Four previous orbital solutions were determined by Baize (1956), Starikova (1977) and Scardia (1982, 1985). The Starikova orbit is a revision of the Baize orbit's dynamic elements.

Table 3 lists all known observations of BU 1240 AB, as they are listed in WDS database, and the residuals of the observed position angle and/or angular separations with respect to the calculated orbits by Scardia (1985) and in this work. The epochs for the measures which presented quadrant problems are labelled by a "b" flag. Observation with residuals in parentheses were assigned zero weight. Baize rejected the measures made in 1914.09, 1915.18, 1923.18 and 1939.94. Except for the first point, the others measures were also rejected in this paper. In

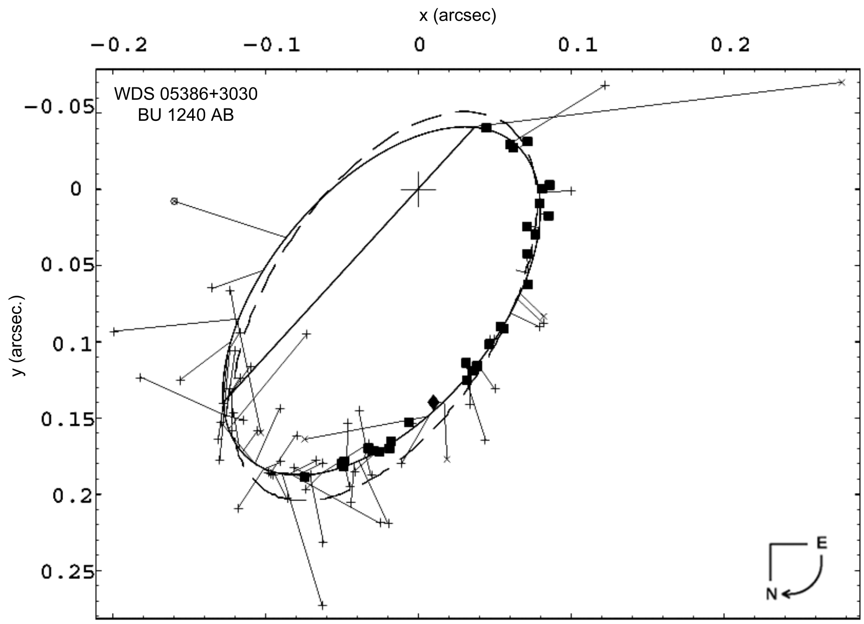

Fig. 1. Apparent orbit for BU 1240 AB.

the orbital solution of Scardia for 1985 seven measures were rejected (1899.179, 1914.090, 1915.180, 1923.182, 1939.862, 1940.079, and 1962.092). The measures for 1899.179, 1962.092 (for these two measures I decreased their weights due to their large residuals), and 1914.090 were retained in my calculation. The measures for 1939.862 and 1940.079 performed by Wilson are not listed in the WDS data base, which lists a 4 nights Wilson' measure (1941) for 1939.94. This measure is likely to be the weighted average of the measures for 1939.862 and 1940.079.

Based on the orbit of 1985, Scardia calculated a dynamic parallax of 0.0056 arcsec using the method of Baize & Romani (1946) with a total mass of 7.3 solar masses and a semi-major axis of 27.6 AU The previous orbit, of grade 2 (in the grading scheme used in the Sixth Catalog of Orbits of Visual Binary Stars [Hartkopf, Mason, & Worley 2001]), was calculated 23 years ago.

Since then, BU 1240 AB has 25 additional data points which cover an arc of 52 degrees. Among these new measures there are 16 speckle points and 4 visual measures. Speckle points show clearly a significant deviation ffrom the previous orbit. After the previous orbit was calculated 16 speckle data were obtained by McAlister et al. (1989), McAlister, Hartkopf, & Franz (1990), Hartkopf et al. (1994, 1997, 2000), and Horch et al. (1999, 2002); and 4 visual measures were performed (Couteau 1989; Le Beau 1990). Interferometric points cover an arc of 147 degrees and show a clear and significant deviation from the previous orbit allowing an improvement of the orbital parameters of the orbit.

In Figure 1 the new apparent orbit is drawn together with the observational data; the x and y scales are in arcseconds. The solid curve represents the newly determined orbit, while the dashed curve represents the previous orbit. The line passing through the origin indicates the line of nodes. Speckle measures are shown as filled squares, visual interferometric observations are showed as open circles, visual measures as plus signs, and measures from the ESA Hipparcos instrument are indicated as filled diamonds. The rejected observations are shown as crosses. All measures are connected to their predicted positions on the new orbit by $O-C$ lines.

3. ANALYSIS OF RESULTS

Table 1 shows the orbital parameters, root mean squared residuals RMS, the mean absolute residuals MA, the masses, and the a^3/P^2 values for some previous solutions and for the solution determined in this paper. The T parameter is expressed in Besselian years. The RMS and MA are in both cases weighted averages calculated using the data-weighting commented in § 2.

The a^3/P^2 values are nearly identical for the new and for the previous orbit of Scardia (1985), but the new orbit leads to smaller residuals especially in ρ, where the residuals were reduced by a factor of 3.

TABLE 4

ASTROPHYSICAL DATA FOR WDS 05386+3030 = BU 1240 AB

V_{A+B}[a]	$+5.40\pm0.01$
$(B-V)_{A+B}$[a]	$+0.45\pm0.02$
$(V-I)_{A+B}$[a]	$+0.53\pm0.01$
ΔV[b]	$+0.33\pm0.09$
V[g]	A: $+6.00\pm0.05$. B: $+6.33\pm0.05$
$\mu(\alpha)_{A+B}$[mas/year]	-19.1 ± 1.0[f]; -21.2 ± 1.0[a]
$\mu(\delta)_{A+B}$[mas/year]	-8.3 ± 1.0[f]; -12.0 ± 0.6[a]
Spectral Types	A: G8 III[c,d]. B:A1 IV:[c]; B9.5 V[d]
π [m.a.s][a]	7.29 ± 0.96
$E(B-V)$	$+0.04$[e]
Mass [1=1$M_\odot$]	A: 2.1 ± 1.0[g]. B: 3.0 ± 0.4[g]
Semiaxis major [AU][g]	$21.1^{+3.2}_{-2.4}$

[a]Hipparcos Catalog (ESA 1997).
[b]Washington Double Star Catalogue (Mason et al. 2003).
[c]Ginestet & Carquillat (2002).
[d]13th General Catalogue of MK Spectral Classification (Buscombe 1998).
[e]Parsons & Ake (1998).
[f]Tycho-2 catalog (Høg et al. 2000).
[g]This work.

The new orbit fits well the recent speckle measures. The new elements have been published in Information Circular N° 158 edited by Commission 26 of the IAU.

The eccentricity is larger than in the previous orbit. The period is smaller than previously, but very similar to the orbit of Scardia (1982). The determination of the new grade for BU 1240 AB did not change the last grade, so the orbit continues to be of grade 2 (Hartkopf, private communication). In the next years the epoch of periastron passage will be determined.

Table 1 lists masses which were calculated taking into account the standard deviation for the Hipparcos trigonometric parallax (orbits of 1977 and 1982) and the formal errors for the elements (orbits of 1985 and the one calculated in this paper). A total mass of 3.4 $M_\odot$ was obtained, in agreement with that of the previous orbit. The Hipparcos parallax is the main contribution to the mass error. The formulae of Scardia (1984) were used to calculate the mass error.

The averaged differential photometry of $\Delta V = +0.33\pm0.09$ was obtained using historical data from the Washington Double Star Catalog (WDS). An apparent magnitude of +6.33 was calculated for the secondary component. According to Allen's tables (1973), the stellar mass is $3.0\pm0.4\,M_\odot$ (Table 4).

The main component is not a main-sequence star so the mass-luminosity relation cannot be used. Theoretical studies indicate small masses for giant stars of about 1.0 $M_\odot$ (Scalo, Dominy, & Pumphrey 1978) while empirical studies indicate larger masses for late G giants of between 2.7 $M_\odot$ and 3.1 $M_\odot$ (Russell & Moore 1940; Beer 1956; Stephenson & Sanwal 1969). In the first case the total mass would be about 4.0 $M_\odot$ and in the second case about 6.0 $M_\odot$. According to the masses obtained for the previous and the new orbit, the main component could be a low mass giant star.

Ginestet & Carquillat (2002) classified the secondary component as a suspected sub-giant of spectral type A1 changing the mass parameter.

Erg (1929) announced a variability for HD 37269 (=BU 1240 AB) which ranges between +5.40 and +5.45 magnitude. HD 37269 was catalogued as NSV 2485. A search in the literature showed that no later study has been carried out to determine the possible variability of BU 1240 AB. Surely the cause of this possible change in magnitude is its binary nature.

4. COMPONENTS C AND D

4.1. *Consulting Astronomical Literature*

The astronomical literature was consulted in order to obtain photometry, astrometry and kinematic data. VizieR, Simbad (Wenger et al. 2003) and the "services abstract" tools were used from the website of Centre De Données Astronomiques de Strasbourg.

Photometry in the B, V and I bands came from the Hipparcos (ESA 1997) and Tycho-2 catalogs (Høg et al. 2000). Infrared J, H and K photometry came from the Two Micron All Sky Catalogue (Cutri et al. 2000, hereafter 2MASS). Proper motion came from Tycho-2 catalog. This catalog was chosen because the Hipparcos proper motions could be affected by Keplerian motion due to its smaller baseline. Historical astrometric data were kindly supplied by Mason[3]. Spectral types and other astrophysical data were taken from other sources.

4.2. *Spectral Type and Luminosity Class Estimate*

Some of the main astrophysical properties are spectral types and luminosity classes. Spectral types and luminosity classes were obtained through photometric and kinematic data. Several tables which relate photometric colours with spectral types were used (Bessell & Brett 1988), with absolute magnitudes and bolometric corrections from Zombeck (1990).

A computer program was designed to transform magnitudes to Jy (1Jy $= 10^{-23}$erg sec^{-1} cm^2 Hz^{-1}) and to compare automatically the spectral distribution with those deduced from the tables.

Infrared two-colour diagrams (Bessell & Brett 1988) and reduced proper motion diagrams (Jones 1972; Salim & Gould 2002; Nelson et al. 2003) were used. Reduced proper motion diagrams are very useful to distinguish dwarfs from giants, subdwarfs or white dwarfs.

4.3. *Interstellar Reddening*

When the studied object is located on or near the galactic plane it is important to determine the interestellar absorption and correct the reddened astrophysical data. Maps by Burstein & Heiles (1984) and Schlegel, Finkbeiner, & Davis (1998) were used. The obtained values were scaled to the initial distance using the cosecant law of van Herk (1965).

4.4. *Studying the Nature of the Visual Doubles*

Several criteria were used to determine if the components are gravitationally bound. These criteria make use of photometric, astrometric, kinematic and spectroscopic data.

The relative proper motion is the projected angular velocity of the secondary with respect to the primary star. This must be equal to the difference between individual proper motions of the components. It was calculated by plotting rectangular coordinates $x = \rho \sin \theta$ and $y = \rho \cos \theta$ (after correction of θ for precession and proper motion) against time. The slope of the weighted linear fit gave the value of the relative proper motion in arcsec yr^{-1}.

The criteria used to determine if the components describe a Keplerian motion analyze photometric, astrometric, kinematical and spectroscopic data (Dommanget 1956; van de Kamp 1961; Sinachopoulos 1992).

Dommanget (1956) establishes a criterion for the non-periodicity of the relative motion of the components of a double star for which the apparent relative velocity is known. This criterion starts with the expression for the energy integral (in the two body problem) and employs the mass-luminosity relationship calculating a lower limit for the dynamical parallax of the stellar system. In a number of cases of visual binaries, this criterion permits the classification of the motion as non-periodic (i.e. parabolic, hyperbolic, or rectilinear) and therefore the classification as an optical double star.

The criterion of van de Kamp (1961) starts with the equation of energy determining a critical value for a parabolic orbit. The motion of a stellar system, therefore, is periodic or non-periodic depending on whether the observed projected critical value is below or above the true critical value.

The criterion of Sinachopoulos (1992) studies the compatibility of the observed relative proper motion with that dynamically allowed one. The tangential velocity, i.e. the observed relative proper motion, is compared with the maximum orbital velocity that follows from Kepler's third law.

4.5. *The C Component*

In 1783 William Herschel performed for the first time the relative astrometry of component C (a star of magnitude 8.41, Høg et al. 2000), with respect to the AB pair. Although Struve was not the first to measure AB-C (Struve measured it in 1828) the system was catalogued as STF 753 AB-C. Since then it has been measured 67 times, lastly by Debackere (2006) in 2005.03. The position angle and the angular separation have not significantly changed (268–269 degrees and 12.3 arcsec). Hoffleit & Warren (1991) in the Bright Star Catalog list it as a physical companion to the AB binary.

Tokovinin (1997) in his Multiple Star Catalog (MSC) analyzed the nature of the C component, based on its photometric distance, proper motions and hypothetical parallax. Tokovinin concluded that C is gravitationally bound to the AB binary.

[3]Brian Mason maintains the Washington Double Star Catalog (i.e., WDS) at the U.S. Naval Observatory.

The author of this paper decided to confirm the physical nature of C. The relative motion of C with respect to AB is $\Delta x = +1.4 \pm 0.9$ mas year^{-1} and $\Delta y = -1.0 \pm 0.5$ mas year^{-1}. 11 measures were rejected for the calculation because of large residuals with respect to the linear fit. The rejected measures were made before 1960 by Maedler (1842, 1856). Others came from WFC and WFD which are catalogs matched with the WDS. WFC measures were done on Astrographs or similar instruments. WFD are measures from Transit Circle programs. The baseline of the measures used was 180 years. We calculated the proper motion of C using the proper motion of AB (from Tycho-2) and the relative motion of C with respect AB: $\mu(\alpha) = -17.7 \pm 1.3$ mas year^{-1} and $\mu(\delta) = -9.3 \pm 1.1$ mas year^{-1} agrees with Tycho-2 and Hiparcos within an error of 2σ.

The spectral type of C is A3V (Buscombe 1998). In this work a spectral type of A6V was obtained based on $BVJHK$ photometry taken from Tycho-2 and 2MASS catalogs and corrected for interstellar reddening. Parsons & Ake (1998) estimated $E(B-V) = 0.04$. Using maps of Paresce (1984) a value of $E(B-V) = 0.1$ was obtained. A final value of $E(B-V) = 0.06$ was obtained as a weighted mean.

The Baize (1947) relation was used to determine a stellar mass of $2.1 M_{\odot}$. Tokovinin determined a value of $1.7 M_{\odot}$ due to a hotter spectral type.

A spectroscopic distance of 163 pc was obtained and, within the errors, agrees with the distance to AB.

According to the criterion of Dommanget (1956) the lower limit of the dynamical parallax for STF 753 AB-C corresponds to a maximum distance of 246 pc. The spectroscopic distance of C calculated in this work is 34 percent smaller. The criterion of van de Kamp (1961) was also used. The true critical value for a parabolic orbit is 477.7 AU^3 yr^{-2} while the observed projected critical value is of 55.2 AU^3 yr^{-2}, about 8.7 times smaller than the true value. The tangential velocity corresponding to the observed relative proper motion for STF 753 AB-C is 1.29 km s^{-1}. Using the criterion of Sinachopoulos (1992) a maximum orbital velocity of 1.56 km s^{-1} was calculated.

According to all the criteria used, the component C is physically bound to the AB binary. The estimated orbital period is about 46,000 years (a circular face-on orbit is assumed). Tokovinin determined a shorter period of 25,000 years because he considered the angular separation as the semi-major axis.

4.6. *The D Component*

A faint star of about 11.5 magnitude is located at more than 30 arcsec SE of the AB binary. It was listed as the D component which was first measured by Morton in 1856 (cited by Lewis 1906). Burnham measured it 16 years later and it was cataloged as Burnham 90 AB-D (BU 90 AB-D) because he was the first astronomer to publish its measures. This pair has been measures 18 times, lastly in 2002 by the Washington Speckle Interferometry team (Mason et al. 2004). Since its first measure the angular position remained fixed at 113 degrees and the separation increased from 32.4 to 34.8 arcsec. The angular apparent motion of D with respect to AB is $\Delta x = +19.4 \pm 1.9$ mas year^{-1} and $\Delta y = -4.6 \pm 1.2$ mas year^{-1}. 18 measures were used with a base line of 120 years. The proper motion of D was calculated using the proper motion of AB and the relative motion of D. A value of $\mu(\alpha) = +0.4 \pm 2.1$ mas year^{-1} and $\mu(\delta) = -12.6 \pm 1.6$ mas year^{-1} was obtained. The WDS catalog (Mason, Wycoff, & Hartkopf 2003) lists $\mu(\alpha) = +16$ mas year^{-1} and $\mu(\delta) = -17$ mas year^{-1}. The source of the D proper motion listed in WDS is unknown (Mason, private communication). It is not from Hipparcos or Tycho-2, the predominant source of WDS proper motions and, in fact, the listed value for D appears also in earlier editions of the WDS (Worley & Douglass 1994, 1997) and in the IDS (Jeffers, van den Bos, & Greeby 1963). There is no proper motion for it in the ADS (Aitken 1932), so it was likely added at Lick Observatory sometime between the 1930s and 1960s. Given the very long timebase associated with my determination of the proper motion and the number of historical measures used, the proper motion determined in this work should be more accurate than the one currently in the WDS (Mason, private communication).

A spectral type for the D component is not listed in the literature. According to our study, the D component is a K1 red giant located at about 870 pc (spectral type and distance were corrected for reddening).

The interstellar map of Paresce (1984) is only valid up to a maximum distance of 250 pc, so the catalog of Neckel & Klare (1980) was used. About 9 stars located at less than 30 minutes of arc were selected from this catalog. They were plotted in a reddening-distance graphic. A logarithmic fit was plotted.

A recursive method was used to obtain an unreddened spectral type and distance. It first determines the reddening (using the catalog of Neckel & Klare

1980) using reddened photometry. With this initial reddening the photometric data can be corrected. The preliminary photometric distance is used to obtain a new value for the reddening. This value corrects the initial photometric data. A new photometric distance is obtained and the process is repeated until no significant change is produced. Generally in two or three iteration the data converge. A value of $E(B-V) = 0.40$ was obtained.

The photometric distance and the relative angular motion of D with respect to AB indicate the optical nature of the D component.

5. CONCLUSIONS

The large residuals obtained for the last orbital solution calculated in 1985 by Scardia indicated that a revision was needed. A combined solution of geometrical and analytical methods was used to determine new orbital elements. The new orbit shows a nearly equal value for a^3/P^2 as the last orbit but decreases the residuals, especially for recent measures.

The mass calculated using the orbital parameters and the Hipparcos parallax is slightly smaller than the mass determined using the mass-luminosity relation, although the mass for the yellow giant star is unknown. The Hipparcos parallax is the main contributor to the mass error.

The astrophysical properties of the C and D components and their physical relation with the AB close pair were studied. The physical nature for C was confirmed and a period of about 46,000 yr was estimated. Component D is a K1III giant with no physical relation to other components.

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