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ORBIT AND SYSTEM MASS FOR THE VISUAL BINARY WDS 23186+6807AB

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ABSTRACT

A revised orbit, with period of 1505 yr, and system mass, $3.65 \pm 0.60\ M_{\odot}$, are presented for the visual binary WDS 23186+6807AB. The total mass is well in accord with estimates from the literature made on the basis of different methods. The G8 III spectral type of the primary is confirmed.

Key words: astrometry — binaries: visual — stars: individual (WDS 23186+6807AB = HD 219916)

1. INTRODUCTION

The bright (4.75 + 7.00 mag) visual binary WDS 23186+6807AB (*o* Cep = ADS 16666AB = STF 3001AB = HD 219916 = HIP 115088) was first resolved by F. G. W. Struve in 1832 (Struve 1837) with the 9.5 inch (24 cm) refractor at Dorpat. In 1912, S. W. Burnham (Aitken & Doolittle 1932) discovered a much fainter (∼13.0 mag) third component in the system at 45″ from the main pair.

The first orbit for the AB pair was calculated by Janssen (1929), who obtained a period of 177.2 yr, which has not further been confirmed, since the orbital motion is much slower than predicted. Twenty-six years later, Wierzbinski (1955, 1956) computed a period of 796 yr with the use of almost 100 observations. The maximal separation of 2″.95 he predicted for epoch 1942.0 was also not confirmed, indicating a larger orbital period.

Thus, despite the relatively small orbital arc covered by this system (∼45°), it seems reasonable to calculate an improved orbit and to minimize the observational residuals as well. For the calculation we have made use of a complete set of the available data, including two interferometric measurements performed recently with our speckle camera attached to the 1.5 m telescope of the Estación de Observación de Calar Alto (Almería, Spain). One of the obtained autocorrelation functions is presented in Figure 1. Apart from this, with the aim to clarify the somewhat differing data in the literature regarding the primary component's spectral classification, we obtained its spectrum using the 2.6 m telescope of the V. Ambartsumian Byurakan Astrophysical Observatory (BAO; Armenia).

2. SPECTRUM OF THE PRIMARY COMPONENT

The spectrum of the primary was first classified in the MK system by Roman (1952) as K0 III and confirmed by Stephenson (1960), who also classified the secondary component as F6 V and estimated the main and secondary components' absolute magnitudes M_V as +1.1 and +3.4, respectively. Later, Abt (1981) classified the spectrum of the primary as G8 III.

Thus, we are dealing with a pair comprising a cold giant and a hotter normal dwarf whose contribution to the composite spectrum is nevertheless undistinguishable, since the magnitude difference between the components, according to the Washington Double Star Catalog (WDS; Mason, Wycoff, & Hartkopf 2002),[4] is too large (Jaschek & Jaschek 1987).

Although the discrepancy between these classifications is not great, its clarification holds a certain interest. With the aim of estimating the spectral type and luminosity class of the primary, on 2000 December 3 we obtained its spectrum using the ByuFOSC spectral camera (Movsessian et al. 2000) attached to the Cassegrain focus of the 2.6 m telescope of the BAO, with a resolution of 5–6 Å. The spectrum was reduced using the standard IRAF environment. It is presented in Figure 2, where several indicative lines are marked (the intensity is given in arbitrary units).

An overview of the spectrum shows that the spectral features resemble those of a G rather than a K giant. In particular, the luminosity-sensitive Mg *b* (5173 Å) undoubtedly indicates a giant star of luminosity class III, demonstrating strong but rather thin absorption features.

The strongest feature of the spectrum is the G band, while the hydrogen Hα, Hβ, and Hγ lines are still quite pronounced. The strength of the Balmer lines and representative metallic lines Mg *b*, Fe I λ5269, Na D, and Ca I λ6439, as well as several other criteria (Jaschek, & Jaschek 1987; Gray 1992; Malyuto, Oestreicher, & Schmidt-Kaler 1997; Montes, Ramsey, & Welty 1999), indicate a late G spectral type rather than early K.

On the other hand, molecular bands typical of a K spectral type at 4584, 4626, 4761, and 4954 Å are practically absent, while according to the standard criteria, even at K0 their presence should already be noticeable.

All these characteristics lead to the conclusion that the composite spectrum of WDS 23186+6807AB should be classified as G8 III rather than K0 III. Consequently, a somewhat higher temperature compared with the $T = 5110$ K obtained by McWilliam (1990) and a higher luminosity should be assigned to this star.

The components' magnitude difference values (measured at different epochs) given in the Second Photometric Magnitude Difference Catalog (Mason & Wycoff 2003)[5] vary between 2.2 and 2.5 mag. Taking into account that the luminosity difference between K0 III and G0 III spectral types is 0.2 mag (Gray 1992, p. 431) and adopting F6 V for

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[4] See http://ad.usno.navy.mil/wds/wds.html.

[5] See http://ad.usno.navy.mil/wds/dm2.html.

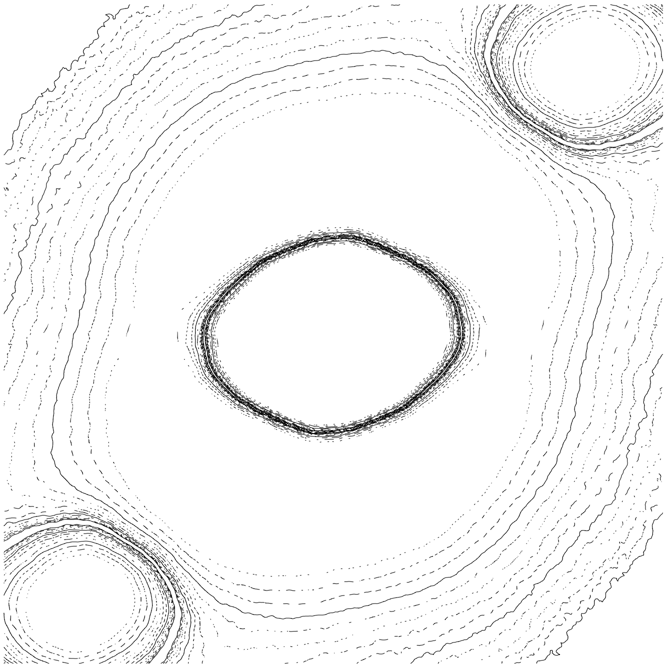

FIG. 1.—Autocorrelation function of WDS 23186+6807AB

the secondary, we obtain magnitude differences of 2.3 and 2.5 mag for Stephenson's (1960) and our classification, respectively.

3. ORBIT AND MASSES

To calculate the orbit, we used the analytical method from Docobo (1985). Table 1 presents all known observations and their residuals with respect to our orbit. In its first three columns, observation epoch (in fractional Besselian year), position angle (in degrees), and separation (in arcseconds) are given, followed by the number of nights and observer name (according to their WDS codes) in the next two columns. The observed-minus-calculated observational residuals in position angle ($\Delta\theta$) and separation ($\Delta\rho$) are given in the last two columns. Note that our calculated value of the separation is given in the last column (in parentheses) when it was not measured by the observer. A few measurements with relatively high residuals ($\Delta\theta > 5^\circ$ and/or $\Delta\rho > 0\farcs3$) were neglected because of low precision. In Table 2, the orbital elements (along with their corresponding errors) and the correction for precession applied in order to reference the position angle to epoch 2000.0 are given. An ephemeris is given in Table 3.

This orbit represents an improvement to that announced earlier in IAU Commission 26 Information Circular 146 (Docobo & Andrade 2002). Taking into account the obtained semimajor axis and period values given in Table 2, as well as the *Hipparcos* parallax (15.48 $\pm$ 0.55 mas; ESA 1997), the total mass of the system is 3.65 $\pm$ 0.60 $M_\odot$.

Recently, Zhao, Qiu, & Mao (2001) estimated the mass of the primary (along with those for a large sample of other red clump giants) from its position on the M_V–log $T_{\rm eff}$ diagram by interpolating evolutionary tracks given by Girardi et al. (2000) and VandenBerg et al. (2000), obtaining 2.55 $\pm$ 0.15 $M_\odot$ and a somewhat smaller 2.35 $\pm$ 0.15 $M_\odot$, respectively.

The mass of component B can be estimated both from the catalog of Belikov (1995) and from the tables given by Gray (1992), taking into account its spectral type of F6 V (Stephenson 1960). These two sources yield similar values, 1.18 $\pm$ 0.09 and 1.29 $M_\odot$, respectively. Adopting the first value, we obtain system masses of 3.73 $\pm$ 0.17 and 3.53 $\pm$ 0.17 $M_\odot$ according to the Girardi et al. and VandenBerg et al. models, respectively. The mass estimates

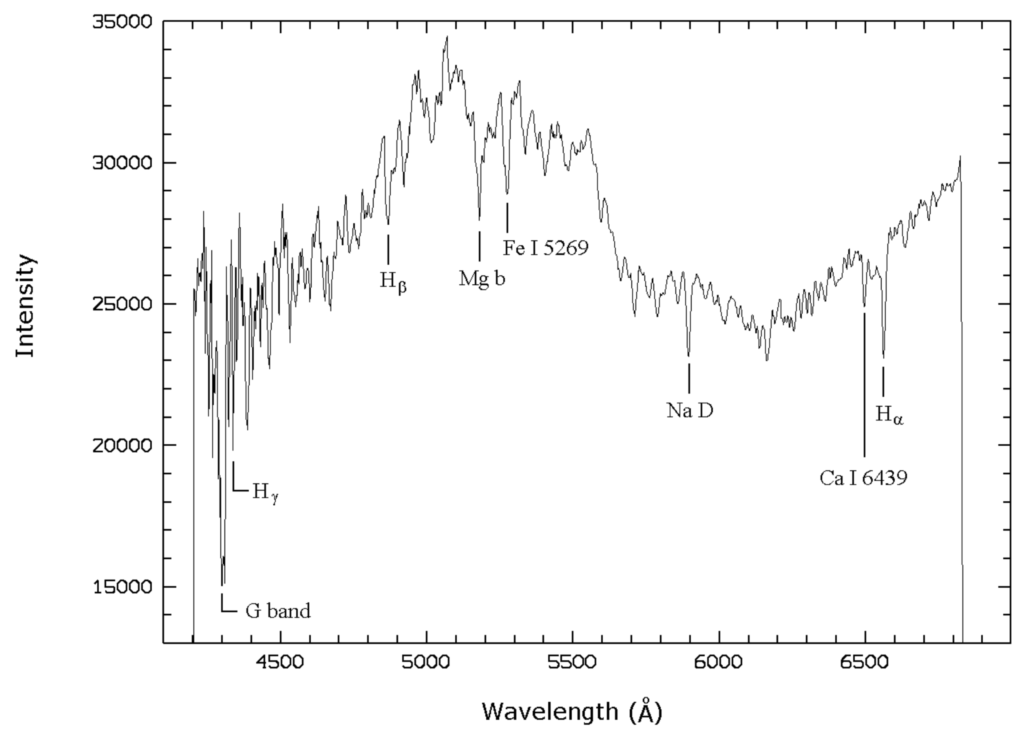

FIG. 2.—Spectrum of WDS 23186+6807AB obtained at the 2.6 m telescope of the Byurakan Astrophysical Observatory. Several representative absorption lines are marked. The intensity is given in arbitrary units.

TABLE 1

Observational Data and Residuals

t	θ (deg)	ρ (arcsec)	n	Observer	$\Delta\theta$ (deg)	$\Delta\rho$ (arcsec)
1832.84	174.5	2.35	3	StF	−1.8	0.03
1834.02	174.7	2.30	1	Da	−2.1	−0.03
1834.95	173.4	2.5	...	Smy	−3.7	0.2
1842.8	179.4	2.54	1	Mad	−0.6	0.15
1844.43	179.8	2.28	1	Mad	−0.7	−0.12
1851.87	183.0	2.70	1	Stt	−0.1	0.26
1852.65	184.6	2.20	2	Mad	1.2	−0.25
1855.95	184.4	2.54	9	D	−0.0	0.07
1856.92	186.4	2.53	...	Jc	1.6	0.05
1858.44	186.8	2.47	2	Se	1.5	−0.02
1858.62	186.5	2.60	2	Mrt	1.1	0.11
1861.01	183.9	...	8	Pwl	−2.2	(2.50)
1861.87	186.9	2.62	3	Mad	0.5	0.11
1864.68	186.7	2.47	6	D	−0.6	−0.06
1866.97	185.3	2.56	1	Se	−2.7	0.02
1872.8	187.7	2.57	3	WS	−2.1	−0.01
1874.36	190.1	2.6	4	Gld	−0.2	0.0
1874.84	190.7	2.56	3	WS	0.2	−0.03
1874.85	189.3	2.81	3	WS	−1.2	0.22
1875.18	191.8	2.45	4	D	1.2	−0.14
1877.75	191.4	2.48	3	Dob	0.0	−0.13
1879.828	193.2	2.72	4	HI	1.3	0.10
1879.9	193.0	2.60	3	Hod	1.0	−0.02
1879.91	193.0	2.79	3	Sbk	1.0	0.17
1879.93	194.6	2.73	3	Sbk	2.6	0.11
1881.76	192.9	2.81	2	Big	0.4	0.18
1882.04	192.3	2.59	3	Je	−0.3	−0.04
1882.41	193.8	2.74	7	Hal	1.1	0.10
1883.36	191.0	2.83	7	Eng	−2.0	0.19
1885.89	194.7	2.75	3	HI	1.0	0.09
1889.05	195.5	2.71	2	Cel	0.9	0.03
1891.03	195.3	2.60	6	StH	0.1	−0.09
1892.88	194.8	2.81	3	Jns	−0.9	0.11
1895.84	193.6	2.76	3	Cls	−2.9	0.04
1899.42	196.2	2.82	2	Coh	−1.3	0.08
1901.72	197.7	2.96	1	StH	−0.4	0.21
1901.87	201.6	2.92	5	Dob	3.5	0.16
1902.02	197.5	2.61	3	Maw	−0.7	−0.15
1902.2	201.5	3.00	7	Dob	3.3	0.24
1902.62	198.3	2.68	3	Hu	−0.0	−0.08
1902.64	197.0	2.97	1	Thi	−1.3	0.21
1902.9	199.0	2.94	2	Dob	0.6	0.18
1903.7	198.9	2.94	1	Thi	0.3	0.17
1908.69	199.8	2.93	4	Dob	−0.1	0.13
1909.56	200.2	2.84	4	Has	0.0	0.04
1909.77	198.8	3.09	2	Sto	−1.4	0.29
1910.83	201.2	2.75	3	Vou	0.7	−0.06
1910.93	204.4	2.72	1	Sto	3.9	−0.09
1911.89	199.8	3.01	1	Sto	−0.9	0.19
1912.03	200.3	...	3	Ben	−0.5	(2.82)
1912.8	203.3	2.98	3	Jam	2.3	0.16
1912.83	201.8	2.69	3	Neu	0.8	−0.13
1912.86	201.8	3.12	1	Sto	0.8	0.30
1913.01	200.3	2.97	1	Gui	−0.7	0.15
1913.78	202.3	2.94	1	Gui	1.1	0.11
1913.95	202.3	2.68	4	Doo	1.0	−0.15
1914.53	200.4	2.67	4	Rab	−1.0	−0.16
1914.75	201.8	2.93	4	BrF	0.3	0.10
1915.57	200.1	2.86	3	Rab	−1.6	0.02
1917.75	202.0	2.802	1	Hzg	−0.2	−0.047
1920.9	201.3	2.90	4	Cha	−1.7	0.03
1921.73	203.4	2.92	4	Dob	0.2	0.05
1923.84	204.4	2.78	4	B	0.7	−0.10
1925.559	204.0	2.84	1	Baz	−0.1	−0.05
1925.73	204.2	2.90	1	Ber	0.0	0.00
1926.83	204.7	2.98	3	Kom	0.3	0.08
1928.08	205.3	3.14	3	Kom	0.6	0.23
1928.93	204.3	2.98	3	Kom	−0.6	0.07
1929.82	202.8	2.95	3	Kom	−2.4	0.03
1929.85	206.1	3.08	4	Dob	0.9	0.16
1930.65	201.7	3.12	8	Baz	−3.7	0.20
1930.83	204.7	2.66	2	Smw	−0.7	−0.26
1930.87	207.0	3.01	3	Arm	1.6	0.08
1931.77	206.6	2.86	6	Smw	1.0	−0.07
1932.02	205.0	2.99	3	Kom	−0.7	0.06
1932.79	205.6	2.86	4	StG	−0.3	−0.08
1934.74	206.0	3.00	3	Rab	−0.3	0.05
1935.06	207.1	2.72	4	Baz	0.7	−0.23
1935.89	206.7	2.99	5	Rab	0.1	0.04
1937.68	207.2	2.93	1	Hzg	0.2	−0.03
1937.8	206.0	3.00	2	Mlr	−1.0	0.04
1937.84	208.8	2.92	3	Woy	1.8	−0.04
1937.88	207.4	2.87	4	Rab	0.4	−0.09
1938.87	205.9	3.04	1	Mlr	−1.4	0.07
1938.88	207.8	2.90	5	Rab	0.5	−0.07
1939.76	206.6	2.77	3	Scd	−0.9	−0.21
1939.87	207.7	2.858	1	Str	0.2	−0.117
1939.87	207.5	2.913	6	Rab	0.0	−0.062
1940.82	209.7	3.03	1	Fox	2.0	0.05
1940.89	207.9	2.901	7	Rab	0.2	−0.080
1940.89	208.8	3.13	4	Dur	1.1	0.15
1941.89	205.7	2.84	1	Sem	−2.3	−0.15
1941.9	205.4	2.92	1	Sem	−2.6	−0.07
1941.9	207.9	2.88	1	Sem	0.0	−0.11
1941.9	208.1	2.885	5	Rab	0.1	−0.102
1942.86	209.8	2.85	1	Dur	1.6	−0.14
1942.91	207.8	2.931	8	Rab	−0.4	−0.061
1946.76	207.8	3.01	2	Mlr	−1.3	−0.00
1946.82	208.8	2.886	4	Rab	−0.3	−0.128
1948.8	209.6	2.872	5	Rab	0.0	−0.153
1949.518	209.4	3.018	1	LO	−0.3	−0.011
1949.67	208.8	3.22	3	Mlr	−0.9	0.19
1949.69	210.5	3.001	1	Wie	0.8	−0.029
1949.79	209.9	2.959	7	Rab	0.2	−0.071
1949.85	208.5	2.79	2	Pre	−1.2	−0.24
1950.04	212.3	...	1	All	2.5	(3.03)
1950.9	210.4	2.912	6	Rab	0.4	−0.124
1951.72	209.9	3.14	4	Mlr	−0.2	0.10
1951.86	210.3	2.957	9	Rab	0.1	−0.084
1952.787	210.7	3.014	1	LO	0.3	−0.033
1953.707	210.8	3.097	1	Gzl	0.2	0.045
1953.76	209.8	3.20	3	Ces	−0.8	0.15
1953.87	210.9	2.929	8	Rab	0.3	−0.123
1954.767	210.6	3.001	1	Gzl	−0.2	−0.056
1954.91	210.7	2.925	8	Rab	−0.1	−0.133
1955.68	209.5	3.02	3	Dju	−1.5	−0.04
1955.72	211.4	2.99	3	Mlr	0.4	−0.07
1955.87	210.7	2.951	8	Rab	−0.4	−0.112
1956.75	210.4	3.03	2	Br	−0.8	−0.04
1957.9	210.8	3.046	1	Rab	−0.7	−0.028
1957.92	211.2	3.087	1	Rab	−0.3	0.013
1958.45	210.9	3.05	3	B	−0.7	−0.03
1959.565	211.9	3.068	1	LO	0.0	−0.015
1959.778	211.9	3.096	1	USN	0.0	0.012
1959.805	211.9	3.047	1	USN	0.0	−0.037
1959.86	214.5	2.94	2	Arc	2.6	−0.15
1960.783	212.2	3.086	1	USN	0.0	−0.004
1960.786	212.3	3.094	1	USN	0.2	0.004

TABLE 1—*Continued*

t	θ (deg)	ρ (arcsec)	n	Observer	$\Delta\theta$ (deg)	$\Delta\rho$ (arcsec)
1960.807	212.2	3.099	1	USN	0.0	0.009
1961.76	213.6	3.20	4	B	1.3	0.10
1961.793	212.2	3.101	1	USN	−0.1	0.006
1961.796	212.2	3.091	1	USN	−0.1	−0.004
1961.799	212.7	3.077	1	USN	0.4	−0.018
1961.96	211.1	2.99	5	Hei	−1.2	−0.11
1962.925	212.1	3.086	18	Hei	−0.5	−0.015
1964.91	211.3	3.00	4	Hei	−1.7	−0.11
1965.836	215.1	2.83	1	Pop	1.9	−0.29
1965.84	212.5	2.88	5	Dur	−0.7	−0.24
1965.849	213.0	3.03	2	Dju	−0.2	−0.09
1967.88	215.1	3.08	3	Dur	1.5	−0.05
1967.883	213.9	3.17	1	USN	0.3	0.04
1970.622	214.3	3.122	1	USN	0.1	−0.019
1970.726	214.3	3.111	1	USN	0.1	−0.031
1970.731	214.3	3.112	1	USN	0.1	−0.030
1970.734	214.0	3.093	1	USN	−0.2	−0.049
1973.685	213.1	3.19	1	Rak	−1.7	0.03
1975.77	212.7	3.10	1	Wie	−2.5	−0.07
1978.67	214.6	3.145	3	Tor	−1.2	−0.038
1979.79	214.7	3.362	2	Tor	−1.3	0.173
1979.81	215.6	3.06	3	Wie	−0.4	−0.13
1980.71	215.3	3.241	3	Tor	−0.9	0.048
1981.62	218.6	3.10	1	Ary	2.2	−0.10
1981.75	214.4	3.19	2	Hei	−2.0	−0.01
1982.911	215.7	3.22	4	Sca	−0.9	0.01
1983.8	215.3	3.276	1	Tor	−1.5	0.067
1984.825	218.3	...	1	Doc	1.3	(3.21)
1984.858	218.9	3.06	1	Doc	1.9	−0.15
1987.669	216.5	3.21	2	Doc	−1.1	−0.02
1988.623	217.7	3.31	1	Doc	−0.0	0.08
1991.25	218.2	3.278	1	HIP	−0.0	0.032
1991.45	218.3	3.27	1	TYC	0.0	0.02
1991.79	220.3	3.35	3	Kzn	2.0	0.10
1994.15	219.8	3.55	4	Ary	1.0	0.29
1994.892	220.9	3.25	3	Doc	2.0	−0.01
1995.77	223.2	3.21	4	Ctt	4.1	−0.06
1995.811	220.3	3.4	1	May	1.2	0.1
1996.84	219.4	3.10	2	Alz	0.0	−0.17
1997.521	220.3	3.244	1	Hor	0.9	−0.033
1997.82	219.5	3.36	2	Alz	0.0	0.08
1999.719	219.7	3.35	1	WSI	−0.2	0.06
2000.513	219.8	3.245	1	Doc	−0.2	−0.047
2000.64	219.0	3.26	2	Alz	−1.0	−0.03
2001.559	220.2	3.302	1	Doc	0.0	0.005

TABLE 2

Orbital Elements

Element	Value
P (yr)	1505 ± 40
T	1692 ± 20
e	0.439 ± 0.020
a (arcsec)	3.13 ± 0.12
i (deg)	16.0 ± 4.0
Ω (deg)	4.5 ± 4.5
ω (deg)	93.0 ± 20.0
Precession (deg)	−0.0027

TABLE 3

Ephemeris

t	θ (deg)	ρ (arcsec)
2003.0	220.5	3.30
2005.0	220.8	3.31
2007.0	221.2	3.32
2009.0	221.6	3.33
2011.0	221.9	3.34
2013.0	222.3	3.35
2015.0	222.7	3.36

obtained with Gray's value are 3.84 ± 0.15 and 3.64 ± 0.15 $M_\odot$ for the Girardi et al. and VandenBerg et al. models, respectively.

It is evident that both model estimates are well in accord with our directly determined system mass. However, it is worth noting that our estimate, 3.65 ± 0.60 $M_\odot$, nearly coincides with that of the VandenBerg et al. (2000) model (3.64 ± 0.15 $M_\odot$) when the Gray (1992) value is adopted for the B component's mass.

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