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REFINING THE PARALLAX IN VISUAL DOUBLE STARS USING ORBITAL AND SPECTRAL DATA: APPLICATION TO THE SYSTEM OF THE K0 GIANTS, A 1808

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ABSTRACT

In this paper, we show how *Hipparcos* parallaxes of distant visual binaries ($\pi_{\rm Hip} \lesssim 10$ mas) can be refined. This is accomplished by using relevant orbital and spectral data. To this end, we study the pair of K0 giants, A 1808. A revised orbit of this system is presented that was calculated by taking into account a set of interferometric and visual measurements covering almost one orbital revolution. In addition, by analyzing its spectrum obtained with the 2.6 m telescope of the Byurakan Astrophysical Observatory (Armenia), we confirm the MK spectral type, K0III. On the basis of $B - V$ photometric data, we derived the extinction $A_V = 0.23 \pm 0.08$ mag as well as obtained a spectroscopic parallax ($\pi_{sp} = 3.19 \pm 0.21$ mas) with a much smaller relative uncertainty of 6.6% compared with that of *Hipparcos* (42.1%; $\pi_{\rm Hip} = 2.43 \pm 1.00$ mas). Accordingly, this system is now placed at 313 ± 21 pc. With the obtained spectroscopic parallax, a dynamical mass of $4.52^{+1.24}_{-0.90}\,\mathcal{M}_\odot$ is obtained, which agrees well with that expected from standard calibrations.

Key words: astrometry – binaries: visual – stars: individual (A 1808)

1. INTRODUCTION

The visual binary A 1808 (WDS 00516+2237 = HD 4934 = HIP 4030) was first resolved by Aitken in 1908 with the 36 inch telescope at Lick Observatory (Aitken 1908), reporting a brightness of 7.5 mag for each component. Estimates of 7.9 mag and 8.2 mag appear in the Washington Double Star Catalog (WDS; Mason et al. 2008) as well as the composite spectrum, K0III. The low-precision *Hipparcos* parallax of 2.43 ± 1.00 mas (Perryman et al. 1997) places this system at a distance of 412 ± 169 pc.

The first orbit of this pair was calculated by Docobo & Costa (1988), who obtained a period of 105 yr and a semimajor axis of $0\overset{''}{.}135$ with a high eccentricity of 0.736—a printing error in ω was corrected in Docobo & Costa (1992). Almost at the same time, Baize (1988, 1989) reported similar orbital elements. Since 1988, several accurate speckle interferometric measurements were carried out. The last two were obtained by us using the speckle interferometry camera of the R. M. Aller Astronomical Observatory attached to the 1.52 m and 6 m telescopes of the Observatorio Astronómico Nacional at Calar Alto, Spain (Docobo et al. 2001) and the Special Astrophysical Observatory, Russia (Docobo et al. 2006), respectively. A new orbit had already been calculated by taking into account these last measurements (Docobo & Andrade 2005). Here we present an improved orbit that fits better speckle measurements.

Besides this, several combined spectra were obtained with the 2.6 m telescope of the V. Ambartsumian Byurakan Astrophysical Observatory (BAO, Armenia). Orbital and spectral data were used to derive an accurate spectroscopic parallax and, consequently, the systemic mass.

2. ORBIT

Since 1908, a total of 64 measurements have been performed; 29 of those were accurate interferometric measurements taken from the Fourth Catalog of Interferometric Measurements of Binary Stars (Hartkopf et al. 2007) covering almost one orbital revolution. The orbit has been calculated by using the analytical method of Docobo (1985). All known observations and their residuals with respect to our orbit are given in Table 1. The columns list (1) observation epoch, (2) position angle, (3) separation, (4) number of nights, and (5) observer names according to their WDS codes. Columns 6 and 7 list O–C residuals in θ and ρ, respectively. Position angles are corrected for precession and referred to the J2000.0 equinox. Measurements with more than 15° offset in residuals in position angle for all orbits are given zero weight in the fit flagged.

Orbital elements are given in Table 2 along with corresponding uncertainties which were determined by taking into account the range of orbits with the smallest root mean squares (rms) of deviations in position angle and separation. Systemic mass and some other parameters obtained for A 1808 are also presented in Table 2. The orbit is graphically represented in Figure 1, where other calculated orbits are shown for comparison. Table 3 contains ephemerides up to 2015.0. Our previous orbit (Docobo & Andrade 2005) had been classified as grade 3 (reliable) according to criteria given by Hartkopf et al. (2001).

Some statistical results, of both the previous and improved orbits, are summarized in Table 4. The rms and absolute mean (AM) values for visual and interferometric measurements, separately and combined, are presented in Columns 2–7. Superscripts v, s, and $v + s$ indicate the visual, speckle, and combined contributions, respectively. Both rms and AM were derived by using the data weighting scheme defined by Docobo & Ling (2003).

In order to compare the accuracy of the recent orbits, we show rms–AM diagrams for position angle and separation in Figure 2. A short line indicates that both visual and interferometric measurements have similar uncertainties (given by the position

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Table 1
Measurements and O–C Residuals

t	θ (°)	ρ ($''$)	n	Observers	(O–C)$_\theta$ (°)	(O–C)$_\rho$ ($''$)
1908.800	209.2	0.200	3	A	1.7	−0.010
1917.770	212.1	0.200	2	A	−0.6	−0.015
1932.720	225.9	0.220	2	A	4.7	0.013
1934.82	222.8	0.230	1	Fur	0.3	0.026
1937.585	225.1	0.210	4	Vou	0.8	0.011
1944.640	224.1	0.170	3	Vou	−5.2	−0.012
1953.580	221.1	0.110	3	Mlr	−16.6	−0.040
1954.29	...	...	2	VBS	(238.5)	(0.147)
1958.66	...	...	1	B	(244.6)	(0.126)
1961.743	...	...	1	Cou	(250.5)	(0.108)
1961.98	227.0	0.100	1	B	−24.0	−0.006
1966.72	...	...	1	Mlr	(266.8)	(0.072)
1969.73	...	...	1	Cou	(289.9)	(0.046)
1969.74	...	...	1	Mlr	(290.0)	(0.046)
1969.82	...	...	1	Cou	(291.0)	(0.046)
1970.72	...	...	1	Mlr	(304.5)	(0.038)
1975.01	...	...	1	Mlr	(83.7)	(0.031)
1976.81	...	...	1	Cou	(120.0)	(0.042)
1976.966	112.4	0.100	1	Wor	−9.9	0.057
1980.850	128.4	0.140	3	Mlr	−26.7	0.069
1981.890	155.5	0.110	1	Cou	−4.4	0.032
1982.82	...	...	2	Hei	(163.6)	(0.084)
1982.832	160.8	0.093	1	Tok	−2.9	0.009
1983.711	170.1	0.082	1	McA	3.4	−0.008
1983.840	150.9	0.120	4	Cou	−16.2	0.029
1983.955	165.2	0.089	1	Bag	−2.2	−0.002
1984.778	171.1	0.091	1	Tok	1.2	−0.005
1984.848	170.4	0.103	1	Bag	0.4	0.006
1984.999	168.7	0.097	1	McA	−1.8	−0.000
1985.720	160.5	0.100	3	Cou	−11.8	−0.002
1985.734	169.3	0.100	1	Tok	−3.1	−0.002
1985.846	171.9	0.105	1	McA	−0.7	0.002
1985.854	173.8	0.106	1	McA	1.1	0.003
1985.953	195.2	0.150	1	Lbu	22.3	0.047
1986.496	175.4	0.105	1	Ism	1.2	−0.001
1986.580	174.9	0.108	1	Tok	0.5	0.001
1986.657	177.2	0.112	1	Bag	2.6	0.005
1986.810	179.3	0.127	1	Cou	4.4	0.019
1986.886	173.8	0.107	1	McA	−1.3	−0.002
1987.008	197.9	0.160	1	Lbu	22.6	0.051
1987.762	177.3	0.113	1	McA	0.4	−0.000
1988.666	180.0	0.118	1	McA	1.4	−0.000
1989.050	183.4	0.140	2	Lbu	4.0	0.020
1989.712	182.0	0.121	1	Hrt	1.5	−0.003
1989.719	179.7	0.127	2	Cou	−0.8	0.003
1989.840	177.3	0.140	2	Gii	−3.4	0.016
1990.755	182.4	0.128	1	Hrt	0.2	−0.000
1991.250	172.0	0.144	1	HIP	−11.0	0.013
1991.250	...	...	1	HIP	(183.0)	(0.131)
1991.894	184.0	0.132	1	Hrt	0.0	−0.002
1992.547	187.8	0.110	1	Lin	3.0	−0.027
1992.547	190.5	0.125	1	Doc	5.7	−0.012
1992.547	187.6	0.127	1	Cou	2.8	−0.010
1993.657	188.1	0.161	1	Lin	1.8	0.019
1993.657	188.9	0.152	1	Doc	2.6	0.010
1993.920	186.9	0.140	1	Hrt	0.2	−0.003
1994.708	187.7	0.147	1	Hrt	0.0	0.000
1995.763	188.9	0.145	1	Hrt	0.0	−0.006
1996.538	189.2	0.154	1	Hrt	−0.5	0.000
1998.663	191.9	0.159	1	Sca	−0.0	−0.003
1998.663	192.4	0.159	1	Sca	0.4	−0.003
1999.712	...	...	1	Doc	(193.0)	(0.165)
1999.723	197.5	0.165	1	Doc	4.5	−0.000
2004.990	197.3	0.182	1	Doc	−0.2	0.000

Table 2
Results for A 1808

Orbital elements	Value	Other parameters	Value
P (yr)	111.16 ± 0.80	π_s (mas)	3.19 ± 0.21
T	1973.50 ± 1.50	d (pc)	313 ± 21
e	0.787 ± 0.080	A_V (mag)	0.23 ± 0.08
a ($''$)	$0.122^{+0.010}_{-0.001}$	m_i (mag)[a]	7.91 ± 0.07
i (°)	$29.3^{+15.0}_{-2.0}$	$\mathcal{M}$ ($M_\odot$)	$4.52^{+1.24}_{-0.90}$
Ω (°)	49.2 ± 20.0	$\mathcal{M}_i$ ($M_\odot$)[a]	$2.26^{+0.88}_{-0.64}$
ω (°)	341.3 ± 25.0	Spectral type	K0III
Precession (°)	+0.0014		

Note. [a] The subscript "i" indicates individual component.

Table 3
Ephemerides

t	θ (°)	ρ ($''$)
2009.0	200.5	0.191
2010.0	201.2	0.194
2011.0	201.9	0.196
2012.0	202.6	0.198
2013.0	203.2	0.199
2014.0	203.9	0.201
2015.0	204.5	0.203

of extreme points) and, therefore, are fitted in a similar way. In contrast, a long line indicates that both types of measurements have very different uncertainties. Instead of dealing with two types of measurements, we can use the total contribution, the value of which is given by a third point in the polygonal line. In any case, if points over the line are located near the origin, it indicates that corresponding uncertainties are close to zero. By applying this to both the previous and new orbits for A 1808, we conclude that our last orbit fits the speckle measurements better than the others do, simultaneously maintaining a very good fit for the visual ones.

3. MK SPECTRAL TYPE, SPECTROSCOPIC PARALLAX, AND SYSTEMIC MASS

The precise, photoelectrically measured combined apparent brightness of 7.16 mag in the V band is given in the fundamental photometric catalog of Mermilliod et al. (1997), whereas the MK spectral-type K0III was assigned by Yoss (1961) and Stephenson & Sanwal (1969). Data on the magnitude difference between the components are somewhat uncertain. While (Aitken 1908) assigned equal brightness to both components, a $\Delta m = 0.2$ mag was measured by Couteau (1987) with a 74 cm refractor at Nice, which appears in the Second Photometric Magnitude Difference Catalog (Mason & Wycoff 2005). A similar value ($\Delta m = 0.29$) can be readily found in the WDS Catalog. Meanwhile, a highly accurate $\Delta m = 0.00 \pm 0.13$ mag was measured by Docobo et al. (2006) in 2004 with a 545 nm filter. Hereafter we adopt the combined magnitude $V = 7.16$ mag, $\Delta m = 0.00 \pm 0.13$ mag and as a result, we obtain individual brightnesses of 7.91 ± 0.07 mag.

A highly uncertain *Hipparcos* parallax of 2.43 ± 1.00 mas in addition to the period and semimajor axis of our orbit leads to a systemic mass of $10 \pm 13\,\mathcal{M}_\odot$. This is too large for a couple of K0 giants, as a mass of $2.2 - 2.4\,\mathcal{M}_\odot$ can be assumed for each component according to standard calibrations (Schmidt-Kaler 1982; Gray 2005). We stress that the very large relative uncertainty in mass determination is almost entirely originated

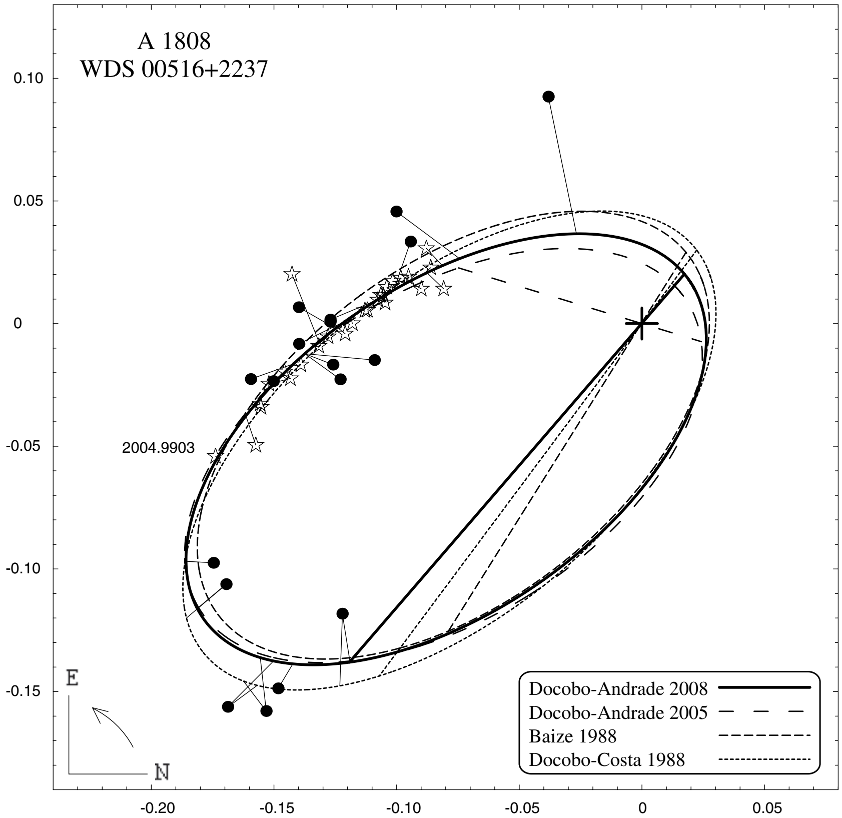

Figure 1. The calculated apparent orbit of A 1808 (solid line) and previous orbits. The points and stars represent visual and interferometric measurements respectively, the arrow shows the direction of the motion. The scale on both axes is in arcseconds, and each measurement is connected to its predicted position by an O−C line. The line passing through the primary star is the line of nodes. The last measurement is indicated with its date.

Table 4
Statistical Results

Orbit	$\Delta\theta^{v+s}_{\rm rms}$	$\Delta\rho^{v+s}_{\rm rms}$	$\Delta\theta^{v}_{\rm rms}$	$\Delta\rho^{v}_{\rm rms}$	$\Delta\theta^{s}_{\rm rms}$	$\Delta\rho^{s}_{\rm rms}$
	$\Delta\theta^{v+s}_{\rm AM}$	$\Delta\rho^{v+s}_{\rm AM}$	$\Delta\theta^{v}_{\rm AM}$	$\Delta\rho^{v}_{\rm AM}$	$\Delta\theta^{s}_{\rm AM}$	$\Delta\rho^{s}_{\rm AM}$
Docobo–Andrade 2008	2.°35	0.″0061	5.°24	0.″0191	1.°99	0.″0038
	−0.°05	−0.″0002	−0.°47	0.″0050	−0.°02	−0.″0006
Docobo–Andrade 2005	2.°54	0.″0071	6.°30	0.″0219	2.°02	0.″0044
	−0.°15	0.″0014	0.°64	0.″0066	−0.°21	0.″0010
Baize 1988	4.°89	0.″0072	6.°62	0.″0187	4.°75	0.″0055
	4.°13	0.″0030	1.°96	0.″0093	4.°29	0.″0023
Docobo–Costao 1988	2.°70	0.″0067	5.°32	0.″0175	2.°41	0.″0051
	−1.°12	−0.″0031	−1.°46	0.″0009	−1.°09	−0.″0034

by the more than 40% uncertainty in the *Hipparcos* parallax. The contribution of the *Hipparcos* parallax to the overall uncertainty in the mass calculation is 99.52% and the remaining part is due to uncertainty in the semimajor axis (0.47%), while the contribution of the period is practically negligible. Since our orbit is of rather good quality, such a discrepancy can be attributed to either incorrect MK type or to a poorly determined *Hipparcos* parallax (assuming that there are no additional bodies in the system). Note that the Baize–Romani algorithm (see Heintz 1978) cannot be applied to this system (and hence the dynamical parallax cannot be derived) because its components are supposed to be giant stars.

In order to verify that it belongs to the class of giants, we obtained several slit spectra of A 1808 on 2005 September 20, with the spectral camera, SCORPIO (Afanasiev et al. 2005), which is a multi-regime, prime focus focal reducer attached to the 2.6 m telescope of the Byurakan Astrophysical Observatory (Armenia). The 600 lines mm^{-1} grating grizm with a resultant linear dispersion of 1.7 Å element^{-1} and a resolution of 3.5–4.0 Å (two pixels) covering the spectral range ∼ 4000–7500 Å was used. A detailed description of the observations and reduction procedure as well as of the MK classification criteria can be found in Tamazian et al. (2006).

One of the spectra is shown in Figure 3 on which several representative spectral lines are marked. A careful application of standard classification criteria (Jaschek & Jaschek 1987; Keenan & McNeil 1989; Gray 2005) allowed us to conclude that we are indeed dealing with the spectrum of a K0 giant. Therefore, any possible error in the determination of its combined spectral type and luminosity class should be discarded.

With a reliable MK spectral type K0III, we can adopt $M_V = +0.2$ mag (Gray 2005) for each component in order to estimate the spectroscopic parallax. Assuming no extinction, we obtain a parallax of 2.87 ± 0.16 mas (distance 348 ± 19 pc) and a systemic mass of $6.22^{+1.35}_{-1.04}\,\mathcal{M}_\odot$ which is much closer to the

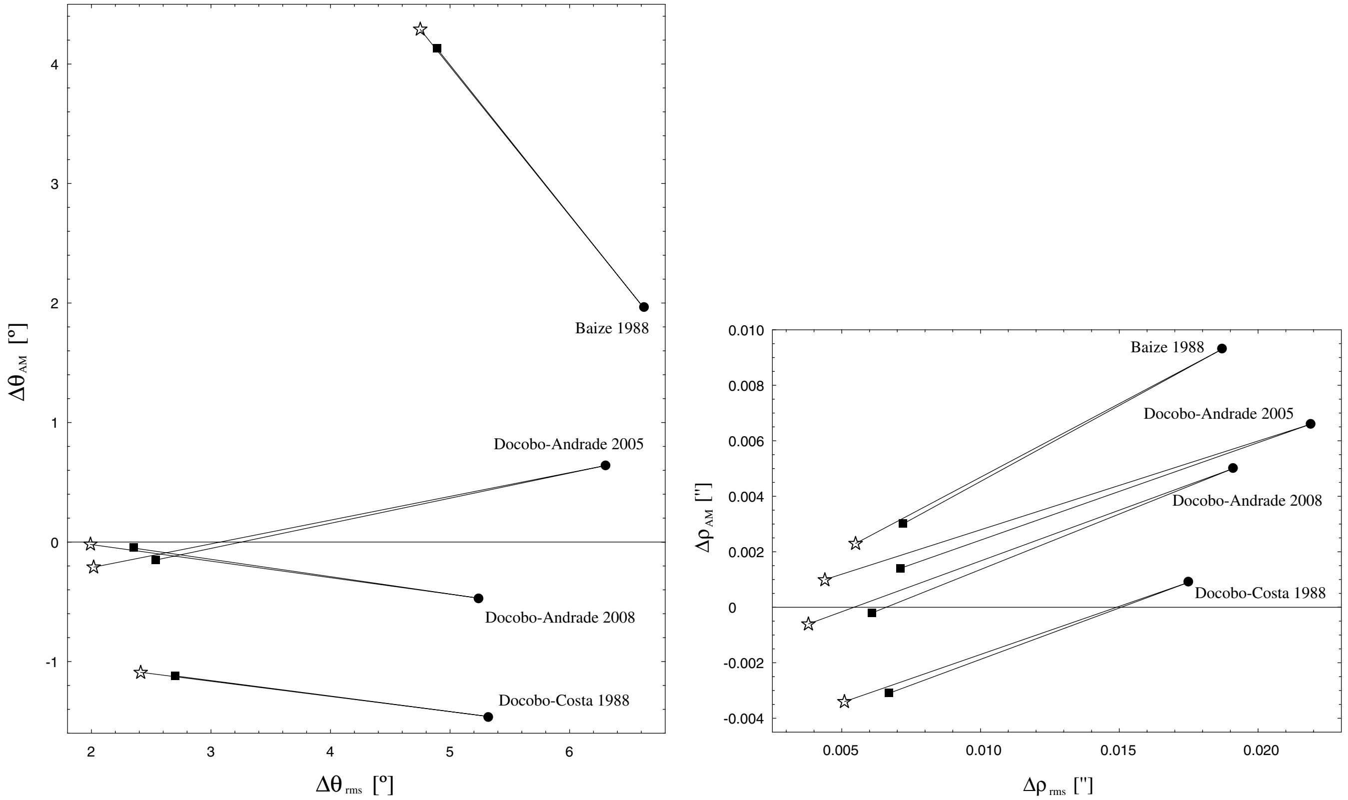

Figure 2. rms–AM diagrams for position angle and separation. Each polygonal line contains three rms–AM points for a given orbit. Visual and interferometric measurements are indicated by filled circles and empty stars respectively. The filled squares indicate the contribution of both measurement types.

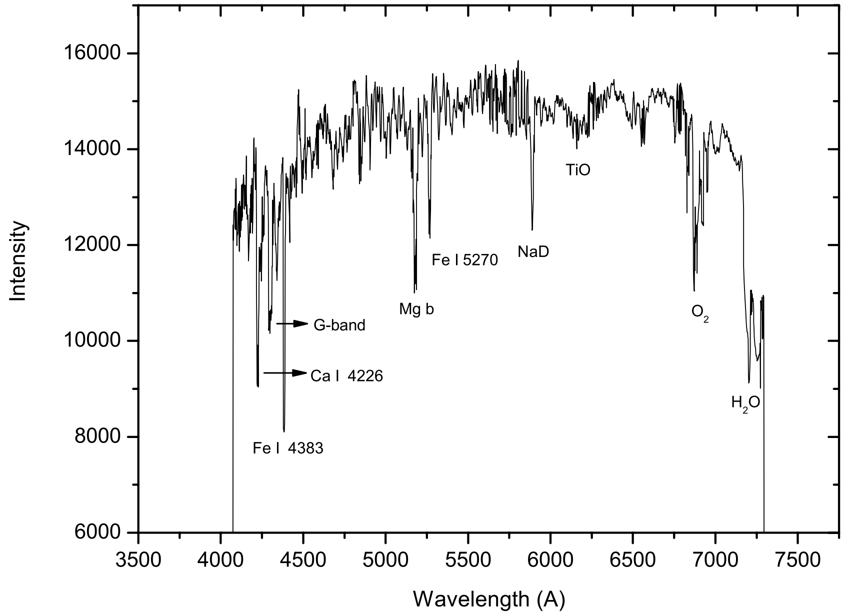

Figure 3. Combined spectrum of A 1808. Several representative spectral lines are marked along with telluric O_2 (B band) and H_2O bands. Intensity is given in arbitrary units.

mass expected for a couple of K0 giants. The remaining mass excess of about 1.6 $\mathcal{M}_\odot$ disappears when interstellar extinction is taken into account. To this end, we proceed according to the well-known relationships:

$$\begin{aligned} E_{B-V} &= (B-V) - (B-V)_0 \\ R &= 3.30 + 0.28\,(B-V)_0 + 0.04\,E_{B-V} \\ A_V &= R \times E_{B-V}, \end{aligned} \tag{1}$$

where $(B-V)$ represents the measured color and $(B-V)_0$ represents the intrinsic color. Taking $(B-V) = 1.063$ from Mermilliod et al. (1997) and $(B-V)_0 = 1.00$ from Schmidt-Kaler (1982), $A_V = 0.23 \pm 0.08$ mag is obtained. It leads to a spectroscopic parallax of 3.19 ± 0.21 mas (distance 313 ± 21 pc) and a systemic mass of $4.52^{+1.24}_{-0.90}\,\mathcal{M}_\odot$, which is in good agreement with that expected from standard calibrations. In fact, it corresponds to an individual mass of $\mathcal{M}_i = 2.26^{+0.88}_{-0.64}\,\mathcal{M}_\odot$ (assuming a quadratic distribution of the combined uncertainty).

A spectroscopic parallax of 3.19 ± 0.21 mas is consistent with that measured by *Hipparcos* (2.43 ± 1.00 mas), though it is at the upper limit of the uncertainty bars. The new solution provides a larger than *Hipparcos* parallax and, hence, places A 1808 at a distance of 313 ± 21 pc instead of 412 ± 169 pc inferred from *Hipparcos*. Consequently, a substantially lower systemic mass of $4.52^{+1.24}_{-0.90}\,\mathcal{M}_\odot$ is obtained. Moreover, we emphasize that the new solution yields more accurate results ($\sigma_{\pi_s}/\pi_s \simeq 6.6\%$ against $\sigma_{\pi_{\rm Hip}}/\pi_{\rm Hip} \simeq 41.2\%$). Hopefully, the obtained uncertainties will be reduced in the future thanks to the very long baseline interferometric measurements as well as to data obtained from future GAIA and SIM missions.

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