RAA 2021 Vol. **21** No. **3**, 58(4pp) doi: 10.1088/1674-4527/21/3/58

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Research in Astronomy and Astrophysics

Research on the HIP 18856 binary system

Polina Efremova[1], Arina Mitrofanova[2], Vladimir Dyachenko[2], Anatoly Beskakotov[2], Alexander Maksimov[2], Denis Rastegaev[2], Yury Balega[2] and Sergey Komarinsky[2]

[1] Kazan Federal University, Kazan 420008, Russia

[2] Special Astrophysical Observatory of the Russian Academy of Sciences, Nizhnij Arkhyz, Russia 369167; *arishka670a@mail.ru*

Received 2020 January 28; accepted 2020 March 21

Abstract The results of a study on the binary HIP 18856 and construction of its orbit are presented. New observational data were obtained at the BTA of SAO RAS in 2007-2019. Earlier, Cvetković et al. constructed the orbit for this system. However, it is based on six measurements, which cover a small part of the orbit. The positional parameters of the ESA astrometric satellite *Hipparcos* published speckle interferometric data (Mason et al., Balega et al., Horch et al.) and new ones were used in this study. Based on the new orbital parameters, the mass sum was calculated and the physical parameters of the components were found. The obtained orbital and fundamental parameters were compared with the data from the study by Cvetković et al.. The comparison shows that the new orbital solution is better than the old one, since it fits new observational data accurately. Also based on a qualitative evaluation performed by Worley & Heintz, the new orbit was classified as "reliable", which means data cover more than half of the orbit with sufficient quantities of residuals of measurements.

Key words: techniques: high angular resolution, speckle interferometry — stars: low-mass, fundamental parameters — stars: binaries: spectroscopic — stars: individual: HIP 18856

1 INTRODUCTION

As is known, the resolution of telescopes is limited by the influence of the atmosphere and the diffraction limit of the telescope. When observing objects with a long exposure, the images are blurred by an unsteady turbulent atmosphere that distorts the wavefront. An increase in resolution to the diffraction limit is possible due to the speckle interferometry method proposed by Labeyrie (1970). With short exposures of about 0.01–0.02 second, changes in interference patterns are small. Speckle interferometric images make it possible to observe the fine structure of objects, despite atmospheric distortions.

One way to apply this method is to obtain positional parameters of binaries with low-mass components and thereafter fundamental parameters directly from observational data. The monitoring of such objects is carried out at the 6-meter telescope of the Special Astrophysical Observatory of the Russian Academy of Sciences (SAO RAS) by the group of high-resolution methods in astronomy. A study of one such system - HIP 18856 - is presented in this paper. Section 2 presents a literature review, Section 3 is devoted to the description of speckle interferometric observations and their reduction, and Section 4 - to the orbit construction and determination of fundamental parameters. The results are discussed in Section 5.

2 LITERATURE REVIEW

The object in this study is the star HIP 18856 ($\alpha = 04^{\rm h}02^{\rm m}32.83^{\rm s}$, $\delta = +06°37'52.08''$, $V_{\rm mag} = 10.8^{\rm m}$). It was resolved as a binary by the *Hipparcos* astrometric satellite in 1991 (ESA 1997). Its binarity has been confirmed by speckle interferometric data obtained by different authors (Mason et al. 1999; Balega et al. 2006, 2007; Horch et al. 2012, 2017). Published positional parameters are presented in Table 1. For the system under study there is an orbital solution by Cvetković et al. (2016), constructed using six measurements published previously in the literature. Measurements cover less than half of the orbit, and the resulting orbital parameters have low accuracy (Table 2). The paper by Cvetković et al. (2016) also reports the spectral types and masses of the components of HIP 18856 and their mass sum (Table 3). To calculate the parameters of the object, the authors relied on the *Hipparcos* parallax and calculated the dynamical parallax $\pi_{\rm dyn} = 13.24 \pm 0.28$ mas. McDonald et al. (2012) computed the effective temperature of the object $T_{\rm eff} = 4800$ K, luminosity $L = 0.34\ L_{\odot}$ and determined the infrared excess $E_{\rm IR} = 1.181$, which probably indicates the existence of an additional component.

3 OBSERVATIONS AND DATA REDUCTION

The observations of HIP 18856 were carried out at the Big Telescope Alt-azimuth (BTA) of the SAO RAS (classical reflector, $D = 6$ m, $F = 24$ m) in 2007–2019. Speckle images were obtained using a speckle interferometer (Maksimov et al. 2009) installed at the primary focus of the telescope. We used EMCCDs, which provide high sensitivity together with high time resolution: PhotonMAX-512B (until 2010), Andor iXon+ X-3974 (2010–2014) and Andor iXon Ultra 897 (since 2015). The observational data are a series of 1940 (until 2010) and 2000 short-exposures (with an exposure time of 20 ms) images. Speckle interferograms on 2008 December 13 were obtained utilizing a $\times 20$ micro-lens (field of view 3.7″) and a $\times 16$ micro-lens (field of view 4.4″) on the other observational nights. Interference filters 600/40 nm and 800/100 nm were used. HIP 18856 observations were carried out under good and excellent weather conditions, with seeing 0.8″–2.0″.

Power spectra, autocorrelation functions and reconstructed images, that allow for the determination of the true position of the secondary relative to the primary, are results of the reduction of speckle interferometric observations. The analysis of power spectra and autocorrelation functions was described by Balega et al. (2002) and Pluzhnik (2005), and image reconstruction was done applying the bispectral analysis method (Lohmann et al. 1983). Positional parameters and the magnitude differences between components are listed in Table 1. The columns correspond to: epoch of observations in fractions of the Besselian year, telescope, interference filter $\lambda/\Delta\lambda$, θ is the position angle, ρ is the angular separation, Δm - magnitude difference and reference. The accuracy of the parameters is due to the limiting angular resolution of the telescope, local atmospheric parameters at the time of observations and aberrations of the entire optical path from the mirror of the telescope to the detector in the speckle interferometer. The actual measurement accuracy of Δm is about 0.1 mag, and the table lists formal errors corresponding to the model selection method.

4 ORBIT CONSTRUCTION

The orbit of HIP 18856 was constructed based on the positional parameters from Table 1: a preliminary

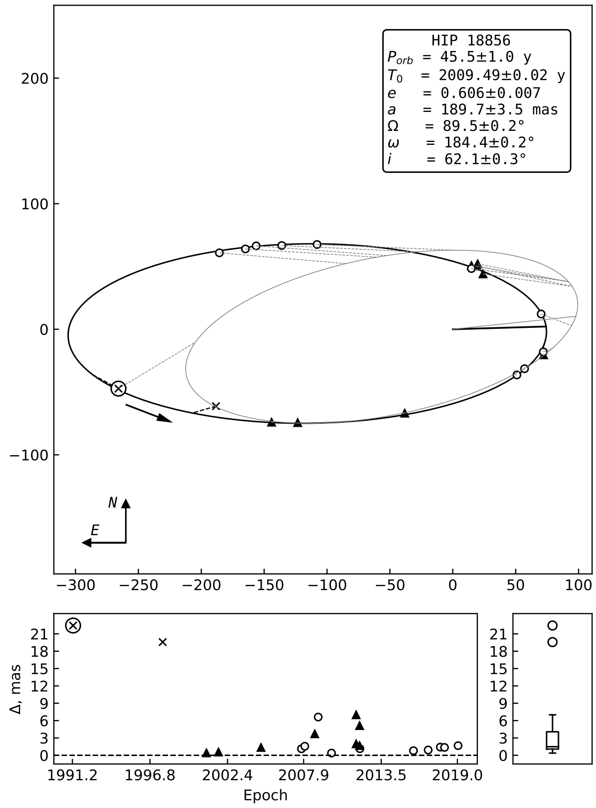

Fig. 1 Orbital solutions for HIP 18856.

orbital solution was found following the Monet method (Monet 1977), and the final orbit - employing the ORBIT software package (Tokovinin 1992). During the construction of the orbit, we found that the positions of the published measurements 2008.6996 (Horch et al. 2012) and 2011.6894 (both measurements) (Horch et al. 2017) must be changed by 180°.

Figure 1 displays a comparison of two orbits: the orbit by Cvetković et al. (2016) is marked with gray, and improved orbit marked with black; triangles correspond to published data; open circles - new data; crosses - data with large values of residuals; a point placed in a large circle is the first measurement for the system; the arrow signifies the direction of motion of the secondary. Δ - residuals showing the difference between the observed and modeled value; the dashed line on the residual plot indicates the orbital solution.

The average estimates of the residuals were 2.2° for θ and 6 mas for ρ. After excluding outliers (in Fig. 1, these are marked with crosses), discrepancies for ρ and θ were 1.3 mas and 2.1° respectively, which indicate a good fitting of observational data with a new orbital solution. The orbits depicted in Figure 1 are very different from each other, and the published solution does not fit observational data obtained after 2008. It is worth noting that Cvetković et al. (2016) used the measurement

Table 1 HIP 18856 Positional Parameters and Magnitude Difference between Components

Date	Telescope	$\lambda/\Delta\lambda$, nm	θ, °	ρ, mas	Δm, mag	Reference
1991.25	*Hipparcos*		100.0	270		ESA (1997)
1997.7182	2.1-m Otto Struve	560/45	108.0	198		Mason et al. (1999)
2000.8758	BTA	800/110	117.2 ± 0.6	162 ± 2	0.3 ± 0.09	Balega et al. (2006)
2001.7530	BTA	800/110	121.1 ± 0.6	144 ± 2	0.19 ± 0.34	Balega et al. (2006)
2004.8214	BTA	800/110	150.3 ± 0.7	77 ± 2	0.28 ± 0.05	Balega et al. (2007)
2007.7372	BTA	600/40	234.9 ± 0.1	63 ± 1	0.76 ± 0.01	this work
2007.9776	BTA	600/40	240.7 ± 0.2	65 ± 1	0.75 ± 0.02	this work
2008.6996	3.5-m WIYN	698/39	74.3	75	0.43	Horch et al. (2012)
2008.9522	BTA	600/40	259.7 ± 0.2	76 ± 1	2.35 ± 0.03	this work
2009.9083	BTA	800/100	279.9 ± 0.1	71 ± 1	0.97 ± 0.04	this work
2011.6894	3.5-m WIYN	692/40	151.5	50.2	0.35	Horch et al. (2017)
2011.6894	3.5-m WIYN	880/50	159.5	54.0	0.68	Horch et al. (2017)
2011.9407	3.5-m WIYN	692/40	339.3	55.7	0.69	Horch et al. (2017)
2011.9407	3.5-m WIYN	562/40	343.8	52.8	0.05	Horch et al. (2017)
2011.9560	BTA	800/100	344.2 ± 0.1	51 ± 1	0.52 ± 0.01	this work
2015.8303	BTA	800/100	58.4 ± 0.1	127 ± 1	0.50 ± 0.01	this work
2016.8869	BTA	800/100	64.6 ± 0.1	151 ± 1	0.53 ± 0.02	this work
2017.7714	BTA	800/100	67.2 ± 0.1	170 ± 1	0.62 ± 0.02	this work
2018.0721	BTA	800/100	68.7 ± 0.1	177 ± 1	0.56 ± 0.01	this work
2019.0494	BTA	800/100	72.0 ± 0.1	195 ± 1	0.56 ± 0.01	this work

Table 2 Orbital Parameters of HIP 18856

P_{orb} (year)	T_0 (year)	e	a (mas)	Ω (°)	ω (°)	i (°)	Reference
35.441 $\pm$0.517	2010.303 $\pm$0.410	0.366 $\pm$0.115	159.0 $\pm$1.2	102.0 $\pm$3.3	166.1 $\pm$9.5	64.9 $\pm$2.5	Cvetković et al. (2016)
45.5 $\pm$1.0	2009.49 $\pm$0.02	0.606 $\pm$0.007	189.7 $\pm$3.5	89.5 $\pm$0.2	184.4 $\pm$0.2	62.1 $\pm$0.3	this work

Table 3 Fundamental Parameters of HIP 18856 and System Components

	Parallax	$M_{V,A}$, m	Sp_A	$\mathfrak{M}_A$, $\mathfrak{M}_\odot$	$M_{V,B}$, m	Sp_B	$\mathfrak{M}_B$, $\mathfrak{M}_\odot$	$\sum\mathfrak{M}$, $\mathfrak{M}_\odot$
Cvetković et al. (2016)	*Hipparcos*	6.43 ± 0.48	K2	0.81	6.87 ± 0.72	K3	0.79	1.12 ± 0.67
this work	*Hipparcos*	6.99 ± 0.06	K4	0.72	7.75 ± 0.06	K6	0.65	1.16 ± 0.69
	Gaia	6.89 ± 0.06	K4	0.72	7.64 ± 0.06	K5.5	0.66	1.35 ± 0.12

2008.6996 (Horch et al. 2012), the positional angle of which should be changed by $180°$. The orbital parameters of HIP 18856 obtained in this work and published by Cvetković et al. (2016) are presented in Table 2. The columns feature: $P_{\rm orb}$ is the orbital period of the system, T_0 is the epoch of passing the periastron, e is the eccentricity of the orbit, a is the semimajor axis, Ω is the longitude of the ascending node, ω is the argument of the periastron, i is the inclination of the orbit and the references to publications. Thus, the orbit of HIP 18856 was improved due to long-term speckle interferometric observations at the BTA of the SAO RAS (in particular, the orbital period and the semimajor axis were significantly increased).

The fundamental parameters of the components and the system were determined by two independent methods: relying on Kepler's third law (Eqs. (1) and (2)) and the Pogson's relation. Apparent magnitude of the object in V-band from the SIMBAD database, the average magnitude difference in the 600/40 filter (assuming this value is close to the value in the V-band) and the table of fundamental parameters of the main sequence stars published by Pecaut & Mamajek (2013) were used in the second method. It should be noted that the characteristics were determined for the *Hipparcos* (van Leeuwen 2007) and *Gaia* (Gaia Collaboration 2018) parallaxes, which are an additional indicator of the correctness of the obtained orbit.

$$\sum\mathfrak{M} = \frac{(a/\pi)^3}{P_{\rm orb}^2}, \qquad (1)$$

$$\sigma(\mathfrak{M}) = \sqrt{\frac{9(\sigma_\pi)^2}{\pi^2} + \frac{9(\sigma_a)^2}{a^2} + \frac{4(\sigma_{P_{\rm orb}})^2}{P_{\rm orb}^2}} * \mathfrak{M}. \qquad (2)$$

The fundamental parameters determined by the two methods for the parallaxes of the *Hipparcos* (π_{Hip} = 14.17 ± 2.79 mas) and *Gaia* (π_{Gaia} = 13.4777 ± 0.2577 mas) missions and obtained by Cvetković et al. (2016) are presented in Table 3. It should be noted that the errors in parameters are primarily due to errors in parallax. The resulting mass sums and the characteristics of the components are in good agreement with each other, which confirms the correctness of the constructed orbit.

5 DISCUSSION

Long-term monitoring of HIP 18856 was carried out with the group of high-resolution methods in astronomy at the SAO RAS utilizing the 6-m telescope from 2007 to 2019, which made it possible to improve the orbit of the system. The positional parameters obtained in this study doubled the number of available published observational data. The new orbit fits speckle interferometric observations obtained after 2008 better than the previous one found by Cvetković et al. (2016). The errors of mass sum are 59% when calculating using the parallax of the *Hipparcos* mission and 9% using the parallax of the *Gaia* mission. This low accuracy of the mass sum applying the *Hipparcos* parallax is due to its own low accuracy (it should be noted that the third power of this value is used in Eq. (1)). The fundamental parameters determined by two independent methods and utilizing two parallaxes are in good agreement with each other. For a qualitative analysis of the obtained orbital solution, we referenced the classification of orbits by Worley & Heintz (1983). This classification is based on number of observational data, their residuals and orbit coverage. Orbits are graded from 1 (“Definitive”) to 5 (“Indeterminate”). The new orbit of HIP 18856 is “reliable” - this means that the measurements cover about half of the orbit with sufficient values of residuals of measurements. Monitoring of HIP 18856, carried out for approximately 28 years (starting with the *Hipparcos* mission), made it possible to construct an accurate orbit, which is not always available for objects with longer orbital periods.

This study affirms the importance of long-term monitoring of speckle interferometric binaries. Despite the fact that orbits have already been constructed for many such systems, they are not always correct, especially if these orbital solutions are obtained utilizing a small amount of observational data. The use of new observational data minimizes errors in orbital parameters. Additionally, high accuracy of the obtained parameters of speckle-interferometric binaries will reveal new relationships between the characteristics of systems and their components. Such studies will not only improve our knowledge of the fundamental parameters of binaries, but also reveal inaccuracies in data from space missions.

Acknowledgements The reported study was funded by RFBR, project number 20–32–70120. The work was performed as part of the government contract of the SAO RAS approved by the Ministry of Science and Higher Education of the Russian Federation. This work has made use of data from the European Space Agency (ESA) mission *Gaia* (`https://www.cosmos.esa.int/gaia`), processed by the *Gaia* Data Processing and Analysis Consortium (DPAC, `https://www.cosmos.esa.int/web/gaia/dpac/consortium`). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the *Gaia* Multilateral Agreement. This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France.

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