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Orbital and physical parameters of the close binary system GJ 9830 (HIP 116259)

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Abstract We present the complete set of physical and geometrical parameters of the visual close binary system GJ 9830 for the first time by applying Al-Wardat's complex method. This method combines magnitude difference from speckle interferometry, synthetic spectral energy distributions of the binary components which are constructed based on grids of Kurucz blanketed models (ATLAS9), and the orbital solution using Tokovinin's dynamical method to estimate the parameters of individual components. The analysis of the system by employing synthetic photometry resulted in the following set of parameters: $T_{\rm eff} = 6220 \pm 100\,{\rm K}$, $\log g = 4.30 \pm 0.12$, $R = 1.10 \pm 0.08\,R_\odot$ for the primary component and $T_{\rm eff} = 4870 \pm 100\,{\rm K}$, $\log g = 4.60 \pm 0.11$, $R = 0.709 \pm 0.07\,R_\odot$ for the secondary component. The recently published dynamical parallax from the *Gaia* space mission was used to calculate the total mass of the binary system as $1.75 \pm 0.06\,\mathcal{M}_\odot$, which coincides with those estimated using Al-Wardat's method as $\mathcal{M}^A = 1.18 \pm 0.10\,\mathcal{M}_\odot$, $\mathcal{M}^B = 0.75 \pm 0.08\,\mathcal{M}_\odot$. The analysis of the system reveals that both components are characteristic of main sequence stars and have an age of around $1.4 \pm 0.50\,$Gyr. The evolutionary tracks and isochrones of the system's components are discussed, and the fragmentation process is suggested as the most likely process for the formation of the system.

Key words: binaries: close — binaries: visual — stars: fundamental parameters — technique: synthetic photometry-stars: individual: GJ 9830

1 INTRODUCTION

The physical and geometrical parameters, especially in close binary systems, play a definitive role in understanding more problems in the formation and evolution of those binaries. One of those problems is the stellar mass which gives insight into the evolution of binary systems. A precise parallax of the binary system, especially from the *Gaia* astrometric mission (Gaia Collaboration 2018), is vital in enhancing the value of absolute magnitudes and binary orbits with reliable stellar masses.

Speckle interferometry (Balega et al. 2002; Tokovinin et al. 2010; Mason et al. 2011) and adaptive optics (Roberts et al. 2005, 2011) are modern high-resolution techniques that can be employed at ground based observations and are instrumental in resolving close visual binary systems. Speckle interferometry is a significant technique for the study of visual and spectroscopic binary stars, and is utilized to measure the position angles (θ), separation angles (ρ) and magnitude differences (Δm) for subcomponents in binary and multiple systems (Balega et al. 2002; Tokovinin et al. 2010). Many analytic methods have used results of this technique to estimate orbital and physical parameters, such as Kowalsky's method (Smart 1930), the Fourier transform method (Monet 1979), Tokovinin's dynamical method (Tokovinin 1992), the Koval'skij method (Olević & Cvetković 2004), Docobo's analytic method (Docobo 1985, 2012; Docobo et al. 2018) and Al-Wardat's complex method (Al-Wardat 2007; Al-Wardat et al. 2014b, 2017).

In our analysis, we apply Tokovinin's dynamical method to estimate orbital parameters (Tokovinin 1992) using a modern version of Tokovinin's ORBITX program. The method requires knowledge of θ, ρ and the epoch of the orbit (Tokovinin 2017, 2018).

On the other hand, the physical parameters are of fundamental value in terms of testing the formation and evolution models of a binary system in addition to the orbital solution. As a result, we follow Al-Wardat's complex method (Al-Wardat 2007) which combines the results of spectrophotometry with the results of speckle interferometry to obtain the physical parameters (Al-Wardat 2012; Al-Wardat et al. 2014b, 2016; Masda et al. 2016, 2018). This method makes use of the entire spectral energy distributions (SEDs) of the binary systems, which are constructed with `ATLAS9` atmospheric modeling (Kurucz 1994).

In addition, synthetic photometry is employed to estimate the physical parameters more accurately through the color indices without needing the observed spectra of binary systems (Straizys 1996; Castelli 1999; Bessell & Murphy 2012; Linnell et al. 2013). It is a quantitative analysis of the synthetic SED of a binary system, and is about modifying stellar parameters so that the synthetic magnitudes fit the observed ones (Al-Wardat et al. 2014b,a; Masda et al. 2016; Al-Wardat et al. 2017). The method, which will be followed to evaluate the stellar parameters of the binary system applying synthetic photometry throughout the analysis of the system, was described in detail in a previous paper (Masda et al. 2018).

Two methods have been successfully applied to estimate the physical and geometrical parameters of several solar-type stars and sub-giant binary stars whether the observed spectra were available or not, such as HD 25811, HD 375, Gliese 762.1, FIN 350, COU 1511, HIP 105947 and two systems HIP 14075 and HIP 14230 (Al-Wardat et al. 2014a,c, 2016, 2017; Gumaan Masda et al. 2018; Masda et al. 2018).

The system GJ 9830 (HIP 116259) is a well-known close binary system in the solar neighborhood. This system is located at the *Gaia* parallax of 29.178±0.186 mas (Gaia Collaboration 2018) which has a precise kinematic distance of 34.27±0.0002 pc. Balega et al. (2007) estimated a close binary system orbital solution for GJ 9830 by implementing the Monet (1977) method. Their estimated total mass was $1.56 \pm 0.18\,\mathcal{M}_\odot$ under the old *Hipparcos* parallax of 30.24 mas (ESA 1997a). The last observed relative position measurement acquired by Balega et al. (2007) was at epoch 2006.946. As a result, 18 new interferometric measurements from epoch 2002 to epoch 2011 are included in our orbit (Table 2). Due to the changes in residuals, especially in ρ, it was necessary to compute a new orbit.

Our main aim is to estimate the orbital and physical parameters of the close binary system GJ 9830 by using Tokovinin's dynamical method and Al-Wardat's complex method, respectively. Moreover, we employ the new parallax of the system from the *Gaia* space mission.

2 OBSERVATIONAL DATA

Our study depends on observational photometric data which are taken from different reliable sources such as the *Hipparcos* catalog ESA (1997a), compiled Strömgren photometry (Hauck & Mermilliod 1998) and the *Tycho* catalog (Høg et al. 2000). These data are used as reference and compared with synthetic photometric results to get the best stellar parameters of the system. In addition to that, we have obtained new data from interferometric measurements of the system for the sake of reconstructing the system's orbit (Table 2).

Table 1 contains the fundamental and observed photometric data for GJ 9830 from the SIMBAD database, NASA/IPAC and Strömgren databases, and the *Hipparcos* and *Tycho* catalogs.

Table 1 Fundamental and Observed Photometric Data for the System GJ 9830

Property	GJ 9830	Reference
α_{2000} [a]	$23^{\mathrm{h}}33^{\mathrm{m}}24.06^{\mathrm{s}}$	SIMBAD
δ_{2000} [b]	$+42^\circ50'47.86''$	–
Sp. Typ.	G0	–
$E(B-V)$	0.099 ± 0.01	c
A_v (mag)	0.30	c
π_{Hip} (mas)	30.24 ± 1.12	d
π_{Hip} (mas)	25.04 ± 0.74	e
π_{Gaia} (mas)	29.178 ± 0.186	f
V_J (mag)	7.14	d
B_J (mag)	7.72	g
$(V-I)_J$ (mag)	0.79 ± 0.01	d
$(B-V)_J$ (mag)	0.585 ± 0.008	–
$(b-y)_S$ (mag)	0.40 ± 0.002	h
$(v-b)_S$ (mag)	0.58 ± 0.002	–
$(u-v)_S$ (mag)	0.86 ± 0.007	–
B_T (mag)	7.86 ± 0.007	g
V_T (mag)	7.23 ± 0.006	–

Notes: [a] Right ascension; [b] Declination; [c] Schlafly & Finkbeiner (2011), [d] Old *Hipparcos* (ESA 1997a), [e] New *Hipparcos* (van Leeuwen 2007); [f] Gaia Collaboration (2018); [g] Høg et al. (2000); [h] Hauck & Mermilliod (1998).

Table 2 Relative position measurements, and residuals $\Delta\theta$ and $\Delta\rho$ (our work) of the system, which are used to construct the orbit of the system.

Data Epoch	θ (°)	ρ ($''$)	$\Delta\theta$ (°)	$\Delta\rho$ ($''$)	Reference
1991.25	341.0	0.195	15.3	0.013	ESA (1997b)
1998.7764	83.0	0.105	–2.2	–0.000	Balega et al. (2002)
2000.6171	119.6	0.153	6.0	–0.001	Horch et al. (2002)
2000.7590	114.7	0.154	–0.3	–0.004	Horch et al. (2002)
2000.8646	115.6	0.157	–0.5	–0.003	Balega et al. (2006)
2000.8727	115.6	0.157	–0.5	–0.004	Balega et al. (2006)
2001.7607	123.8	0.174	0.2	–0.007	Balega et al. (2006)
2001.7607	123.5	0.177	–0.1	–0.004	Balega et al. (2006)
2002.8820*	132.28	0.173	0.9	–0.019	Metchev & Hillenbrand (2009)
2003.5304*	137.90	0.180	2.1	–0.005	Horch et al. (2008)
2003.5304*	135.0	0.182	–0.8	–0.003	Horch et al. (2008)
2003.5386*	136.4	0.176	0.6	–0.009	Horch et al. (2008)
2003.5386*	135.8	0.179	–0.0	–0.006	Horch et al. (2008)
2003.5386*	135.9	0.178	0.1	–0.007	Horch et al. (2008)
2003.6343*	137.0	0.176	0.5	–0.007	Horch et al. (2008)
2003.6343*	137.7	0.175	1.2	–0.008	Horch et al. (2008)
2004.8240	152.1	0.099	3.1	–0.017	Balega et al. (2007)
2006.5174*	315.3	0.134	1.3	0.018	Horch et al. (2008)
2006.5202*	316.9	0.129	2.9	0.012	Horch et al. (2008)
2006.5256*	315.7	0.129	1.6	0.012	Horch et al. (2008)
2006.6870*	320.4	0.146	3.7	0.014	Balega et al. (2013)
2007.817*	328.9	0.190	1.8	0.003	Horch et al. (2010)
2007.8201*	328.5	0.193	1.4	0.006	Horch et al. (2010)
2007.8253*	329.0	0.195	1.8	0.008	Horch et al. (2010)
2011.6837*	0.00	0.1344	0.0	0.004	Horch et al. (2017)
2011.9402*	3.20	0.1245	–0.7	0.001	Horch et al. (2017)
2011.9402*	3.00	0.1301	–0.9	0.007	Horch et al. (2017)

Notes: * New data from interferometric measurements of the GJ 9830 binary system.

3 METHOD AND ANALYSIS

3.1 Orbital Parameters

Understanding the relative motion of the secondary star around the primary star of a binary system is essentially a matter of determining the orbital parameters. As a result, we follow Tokovinin's dynamical method to do so and use the ORBITX code of Tokovinin (1992) to compute the best orbit. The angular separations (ρ) and position angles (θ) are obtained in Table 2 from the Fourth Catalog of Interferometric Measurements of Binary Stars (INT4). The program performs a least-squares adjustment to all available relative position observations, with weights inversely proportional to the square of their standard errors. The orbit solution involves: the orbital period, P; the eccentricity, e; the semi-major axis, a; the inclination, i; the argument of periastron, ω; the position angle of nodes, Ω; and the time of primary minimum, T_0. Hence, the modified orbit is shown in Figure 1 and the orbital parameters are listed in Table 4.

We calculate the total mass and the corresponding error of the binary system by using Kepler's third law and employing the estimated orbital parameters, semi-major axis in arcseconds, orbital period in years (see Table 4) and the new parallax from Gaia Collaboration (2018) in arcseconds, as follows

$$\mathcal{M}_T = \left(\frac{a^3}{\pi^3 P^2}\right) \mathcal{M}_\odot \,, \tag{1}$$

$$\frac{\sigma_\mathcal{M}}{\mathcal{M}} = \sqrt{\left(3\frac{\sigma_\pi}{\pi}\right)^2 + \left(3\frac{\sigma_a}{a}\right)^2 + \left(2\frac{\sigma_p}{p}\right)^2} \,. \tag{2}$$

This equation gives the total mass and corresponding error of the binary system as $1.75 \pm 0.06\,\mathcal{M}_\odot$. This result will subsequently be compared with the estimated theoretical individual masses of the binary system from Al-Wardat's complex method.

3.2 Physical Parameters

Estimating the physical parameters of the binary system GJ 9830 using Al-Wardat's complex method for analyz-

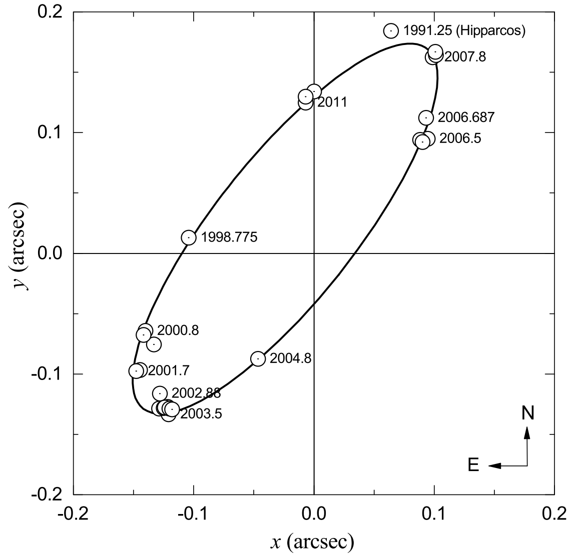

Fig. 1 The modified apparent orbit of the binary system GJ 9830 calculated using the interferometric measurements from the INT4 (with 18 new measurements). The origin point represents the position of the primary component.

Table 3 Speckle interferometric magnitude differences and *Hipparcos* $\Delta H_{\rm Hip}$ measurements of the system, along with filters used to obtain the observations from INT4.

HIP	Δm (mag)	$\sigma_{\Delta m}$	Filter ($\lambda/\Delta\lambda$) (nm)/	Ref.
GJ 9830	2.61	0.58	$V_{\rm Hip}$: 545/30	[1]
	2.48	0.04	545/30	[2]
	2.53	0.07	545/30	[3]
	2.40	0.12	648/41	[4]
	2.21	0.12	648/41	[4]
	2.16	0.03	600/30	[5]
	2.18	0.10	600/30	[5]
	2.60	*	550/40	[6]
	2.47	*	541/88	[6]
	2.45	0.03	545/30	[7]
	2.28	*	550/40	[6]
	2.34	*	550/40	[6]
	2.52	*	550/40	[8]
	2.64	*	550/40	[8]
	2.26	*	562/40	[9]

Notes: * Indicates that these measurements have no errors in INT4. [1] ESA (1997a); [2] Pluzhnik (2005); [3] Balega et al. (2002); [4] Horch et al. (2004); [5] Balega et al. (2006); [6] Horch et al. (2008); [7] Balega et al. (2007); [8] Horch et al. (2010); [9] Horch et al. (2017).

ing close visual binary systems requires proper determination of the magnitude difference between the components of the system. So, we estimate the visual magnitude difference of the system as $\Delta m = 2.47 \pm 0.07$ mag between the two components as the average for all Δm measurements given in Table 3 under the 541–562 nm V-band filters. Combining that value with the entire visual magnitude of the system, we obtain the apparent visual magnitudes

Table 4 Orbits, total mass and quality controls published for the GJ 9830 system, compared with the orbital solution calculated in this work.

		System GJ 9830	
Parameter	Unit	Balega et al. (2007)	This work
P	(yr)	15.70 ± 0.23	16.368 ± 0.032
T_0	(yr)	2005.49 ± 0.01	2005.662 ± 0.021
e	–	0.536 ± 0.007	0.537 ± 0.006
a	(arcsec)	0.220 ± 0.002	0.225 ± 0.002
i	(°)	75.1 ± 0.4	74.94 ± 0.220
Ω	(°)	141.5 ± 0.3	141.50 ± 0.18
ω	(°)	89.5 ± 0.8	89.50 ± 0.180
$\mathcal{M}_T$	($\mathcal{M}_\odot$)	1.56 ± 0.18	1.75 ± 0.06
rms (θ)	(°)	3.25	0.85
rms (ρ)	(arcsec)	0.003	0.006
$\pi_{\rm Hip}$	(mas)	30.24 ± 1.12 [a]	29.178 ± 0.186 [b]

Notes: [a] The old parallax (ESA 1997a); [b] The *Gaia* parallax (Gaia Collaboration 2018).

of individual components as: $m_v^A = 7.25 \pm 0.08$ mag and $m_v^B = 9.72 \pm 0.21$ mag for the primary and secondary components of the system, respectively.

The results of the apparent visual magnitudes, combined with the parallax from *Gaia* (Gaia Collaboration 2018) of 29.178 ± 0.186 mas, lead to the absolute visual magnitudes for components of the system as $M_V^A = 4.58 \pm 0.21$ mag and $M_V^B = 7.05 \pm 0.28$ mag for the primary and secondary components of the system, respectively using the following equation (Heintz 1978) (see p.28)

$$M_V = m_v + 5 - 5\log(d) - A_v \ . \tag{3}$$

Here, the interstellar extinction can be neglected because the binary system being studied is a nearby star.

Errors in the absolute visual magnitudes of the components of the system in Equation (3) are calculated with the following relation

$$\sigma_{M_V^*} = \pm\sqrt{\sigma^2_{m_v^*} + \left(\frac{5\log e}{\pi_{\rm Hip}}\right)^2 \sigma^2_{\pi_{\rm Hip}}} \quad * = A, B. \quad (4)$$

Here, $\sigma_{m_v^*}$ represents the errors of the apparent visual magnitudes.

Based on the above estimated absolute magnitudes (M_V) of the individual components in the system and their relations with effective temperatures ($T_{\rm eff}$) in addition to tables in Lang (1992); Gray (2005) and the below Equations (5) and (6), we obtain preliminary input parameters of the system as: $T_{\rm eff}$ =5878 K, $\log g = 4.36$, $R = 1.10 R_\odot$ for the primary component and $T_{\rm eff}$ =4798 K, $\log g$ =4.54, $R = 0.74 R_\odot$ for the secondary component.

$$\log(R/R_\odot) = 0.5\log(L/L_\odot) - 2\log(T_{\rm eff}/T_\odot), \quad (5)$$
$$\log g = \log(M/M_\odot) - 2\log(R/R_\odot) + 4.43\ . \quad (6)$$

Here $T_\odot$ is taken as 5777 K.

In order to test the results of the synthetic photometry of the system for the sake of obtaining the best stellar parameters, we need to construct the synthetic SED of the system based on the input parameters and on grids of blanketed models (`ATLAS9`) (Kurucz 1994). Hence, the entire synthetic SED of the binary system as observed from Earth, which is connected to the individual synthetic SEDs of the binary system, is computed using the following equation

$$F_\lambda = (R_A/d)^2(H_\lambda^A + H_\lambda^B \cdot (R_B/R_A)^2), \quad (7)$$

where R_A and R_B are the radii of the primary and secondary components of the system in solar units respectively, H_λ^A and H_λ^B are the corresponding fluxes at the surfaces of the stars, and F_λ is the flux for the entire SED of the system above the Earth's atmosphere which is located at a revised distance d (pc) from the system.

As a result of a lack of knowledge about the observed spectrum of the binary system, we will depend on the results of the synthetic SED by utilizing synthetic photometry for the sake of the reliability of accurate physical parameters. This technique is essentially dependent on the results of Al-Wardat's complex method. Our aim is to obtain the best agreement between the observed color indices and magnitudes of the entire system with the entire synthetic SED of the system and consequently obtain the best physical parameters of this binary system.

3.2.1 *Synthetic photometry*

The stellar parameters are mainly dependent on the best fit between the observed color indices and magnitudes of the entire system with the entire synthetic SED of the system, whether the observed spectrum is available or not. Therefore, the entire and individual synthetic magnitudes and color indices of the binary system are calculated by integrating the model fluxes over each bandpass of the system calibrated to the reference star (Vega) by applying the following equation (Maíz Apellániz 2007; Al-Wardat 2012)

$$m_p[F_{\lambda,s}(\lambda)] = -2.5\log\frac{\int P_p(\lambda)F_{\lambda,s}(\lambda)\lambda{\rm d}\lambda}{\int P_p(\lambda)F_{\lambda,r}(\lambda)\lambda{\rm d}\lambda} + {\rm ZP}_p, \quad (8)$$

where m_p is the synthetic magnitude of the passband p, $P_p(\lambda)$ is the dimensionless sensitivity function of the passband p, $F_{\lambda,s}(\lambda)$ is the synthetic SED of the object and $F_{\lambda,r}(\lambda)$ is the SED of Vega. Zero points (ZP$_p$) from Maíz Apellániz (2007) (and references therein) were adopted.

In order to obtain accurate physical parameters, it is necessary to have accurate knowledge of the following criteria:

(1) The color indices and magnitudes of the synthetic photometry should be computed for the studied binary system with Equation (8).
(2) The color indices and magnitudes, $B-V$, $b-y$, V_J, etc. of the entire SED should be completely consistent with the observed ones from the binary system.
(3) The magnitude difference between the components ($\Delta m = V_J^b - V_J^a$) of the synthetic photometry should be consistent with the observed one.

The color indices of a binary system are strongly related to deriving the best stellar parameters. So, under the preceding criteria, the final results of the calculated magnitudes and color indices from three different photometrical systems, Johnson-Cousins: U, B, V, R, $U-B$, $B-V$, $V-R$; Strömgren: u, v, b, y, $u-v$, $v-b$, $b-y$ and *Tycho*: B_T, V_T, B_T-V_T for the entire GJ 9830 synthetic system and individual components therein, are shown in Table 5.

The best agreement between observed and synthetic photometry is achieved for a set of stellar parameters describing the individual components of the system ($T_{\rm eff}$, $\log g$, R and d). This result is depicted in Figure 2 and listed in Table 7.

The errors associated with the individual radii of the components have been double-checked using the following

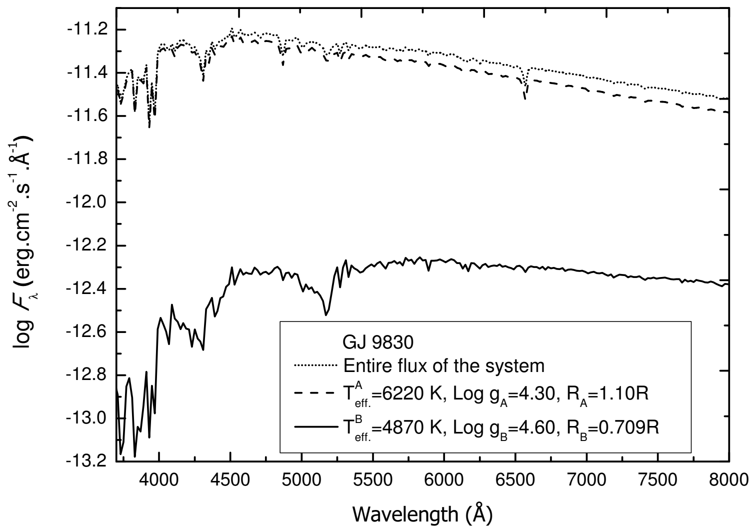

Fig. 2 The entire and individual synthetic SEDs of the system by applying Al-Wardat's method and relying on Kurucz line blanketed models, if these were measured from outside the Earth's atmosphere at a distance of 34.27 pc from the star.

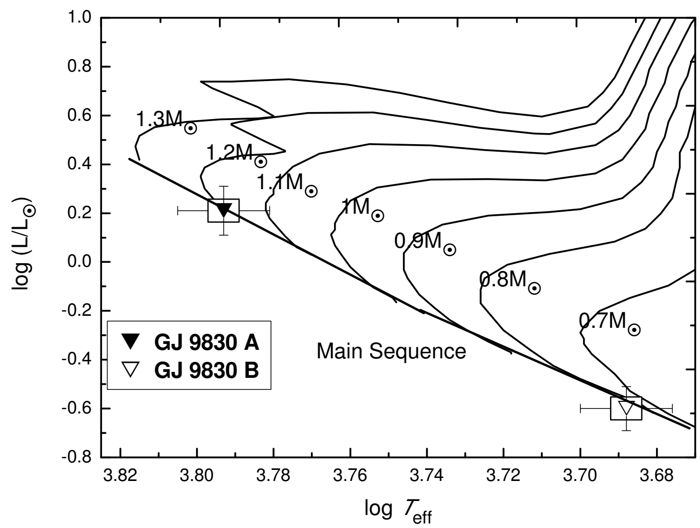

Fig. 3 The evolutionary tracks of both components of GJ 9830 on the H-R diagram with masses (0.7, 0.8, ..., 1.3 $M_{\odot}$). The evolutionary tracks were adopted from Girardi et al. (2000b).

equation

$$\sigma_R \approx \pm R \sqrt{\left(\frac{\sigma_{M_{\rm bol}}}{5 \log e}\right)^2 + 4\left(\frac{\sigma_{T_{\rm eff}}}{T_{\rm eff}}\right)^2} \,. \qquad (9)$$

Here $M_{\rm bol}$ is the bolometric magnitude for each system's component.

Based on the final derived radii and effective temperatures of the system, the stellar luminosities and bolometric magnitudes along with their errors are listed in Table 7. The spectral type of GJ 9830 A is found to be F7.5V and that of GJ 9830 B to be K3.5V.

To place the individual components of the system on the theoretical Hertzsprung-Russell (H-R) diagram and estimate the age and total mass of the system, we use the values of $\log L/L_{\odot}$ and $\log T_{\rm eff}$ based on the evolutionary tracks of Girardi et al. (2000b) (see Fig.3) and isochrones of Girardi et al. (2000a) (see Fig.4). The positions of the components stars in these diagrams lead to theoretical estimates of their masses and ages. As a result, the individual masses of the system are $\mathcal{M}^A = 1.18 \pm 0.10\,\mathcal{M}_{\odot}$ and $\mathcal{M}^B = 0.75 \pm 0.08\,\mathcal{M}_{\odot}$ for the primary and secondary components, respectively, with a system age of $1.40 \pm 0.50\,$Gyr.

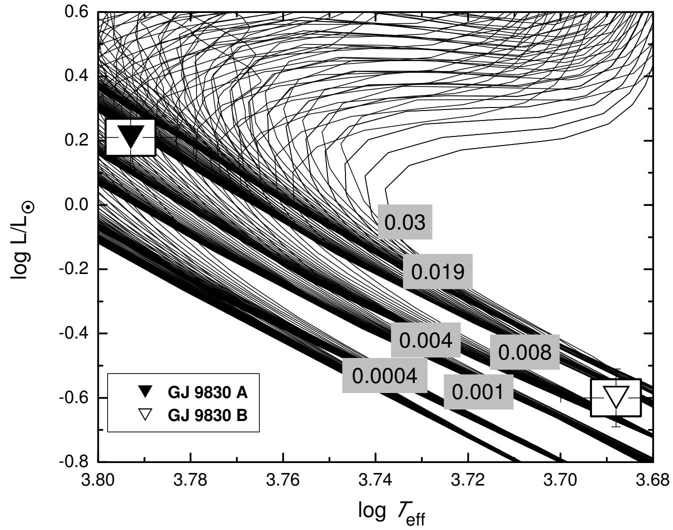

Fig. 4 The isochrones for both components of GJ 9830 on the H-R diagram for low and intermediate mass: from 0.15 to 7.0 $M_\odot$ stars with different metallicities. The isochrones were adopted from Girardi et al. (2000a).

4 RESULTS AND DISCUSSION

Table 4 shows the results of the accurate orbital parameters for the close binary system GJ 9830, which are also displayed in Figure 1. Values for the root mean square (rms) of the binary system are $0.85°$ and $0.006''$. Balega et al. (2007) estimated the orbital parameters by following the method in Monet (1977), which are in good agreement with our study for a certain range of parameters, despite the availability of more relative position measurements in our case. At the same time, the best agreement is between results of Tokovinin's dynamical and Al-Wardat's method in terms of the total mass of the binary system. The residuals, $\Delta\theta$ and $\Delta\rho$, of the binary system are provided in Table 2.

Table 5 features the results of the calculated magnitudes and color indices for the entire synthetic system and individual components in the system GJ 9830. Table 6 depicts the best agreement between the entire synthetic magnitudes and color indices with the observed ones within three photometric systems: Johnson-Cousins, Strömgren and *Tycho*. This led to the most important indication for the reliability of the calculated physical parameters of the close binary system, GJ 9830, as listed in Table 7.

The results of the apparent magnitudes m_v from synthetic photometry are found to be completely the same as those from the observed photometry of the binary system. At the same time, the difference between synthetic and observed values of the magnitudes and color indices in the different photometrical systems of the binary system is less than 0.04σ. The agreement between these values demonstrates accuracy of the method and is an indication for the reliability of the calculated stellar parameters in the system.

Table 5 Magnitudes and color indices of the composed synthetic spectrum and individual components of GJ 9830.

Sys.	Filter	Entire synth. $\sigma = \pm 0.03$	GJ 9830 A	GJ 9830 B
Joh-Cou.	U	7.84	7.88	11.51
	B	7.73	7.81	10.72
	V	7.14	7.25	9.72
	R	6.81	6.95	9.14
	$U-B$	0.10	0.07	0.78
	$B-V$	0.59	0.56	1.00
	$V-R$	0.33	0.31	0.58
Ström.	u	9.01	9.05	12.73
	v	8.06	8.12	11.31
	b	7.48	7.57	10.24
	y	7.11	7.22	9.66
	$u-v$	0.95	0.93	1.42
	$v-b$	0.58	0.55	1.08
	$b-y$	0.36	0.34	0.58
Tycho	B_T	7.87	7.94	11.0
	V_T	7.21	7.32	9.83
	B_T-V_T	0.66	0.62	1.17

Figure 2 shows the entire and individual synthetic SEDs of the close binary system, GJ 9830, based on the calculated stellar parameters and on the revised distance of the system from the *Gaia* astrometric mission (Gaia Collaboration 2018).

To estimate the stellar masses and ages of the system, we referenced the theoretical H-R diagram from Girardi et al. (2000b) with evolution tracks, and the isochrones given by Girardi et al. (2000a), respectively. GJ 9830's components on the evolutionary tracks of Girardi et al.

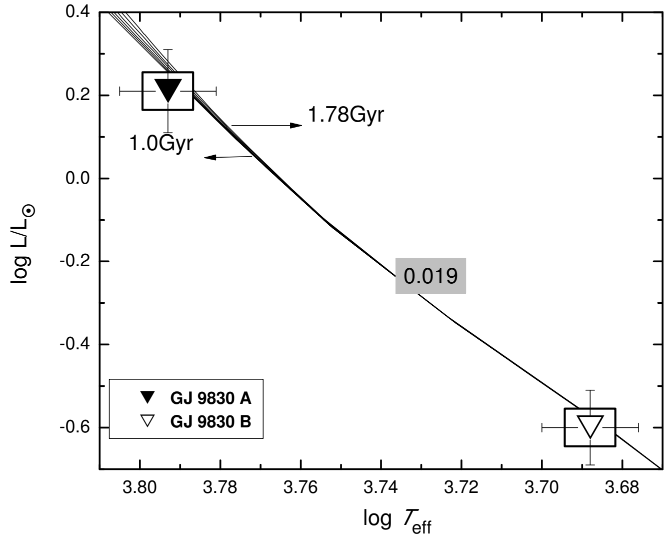

Fig. 5 The isochrones for both components of HIP 9830 on the H-R diagram for low and intermediate mass: from 0.15 to 0.99 $M_{\odot}$, and for the compositions [$Z = 0.019$, $Y = 0.273$] of stars with different metallicities. The isochrones were adopted from Girardi et al. (2000a).

Table 6 Comparison between the entire synthetic and entire observational magnitudes, colors and magnitude differences for the system.

Filter	GJ 9830	
	Entire obs. [a]	Entire synth.[b] (this work)
V_J (mag)	7.14	7.14 ± 0.03
B_J (mag)	7.72	7.73 ± 0.03
$(B-V)_J$ (mag)	0.59 ± 0.008	0.59 ± 0.04
$(b-y)_S$ (mag)	0.40 ± 0.002	0.36 ± 0.04
$(v-b)_S$ (mag)	0.58 ± 0.002	0.58 ± 0.04
$(u-v)_S$ (mag)	0.86 ± 0.007	0.95 ± 0.04
B_T (mag)	7.86 ± 0.007	7.87 ± 0.03
V_T (mag)	7.23 ± 0.006	7.21 ± 0.03
Δm (mag)	$2.47^c \pm 0.07$	2.47^d

Notes: [a] The real observations (Table 1), [b] Entire synthetic work of GJ 9830 (Table 5); [c] Average magnitude differences for all Δm under the 541–562 nm V-band filter (Table 3); [d] $\Delta m = V_J^B - V_J^A$ for the system (Table 5).

Table 7 The final stellar parameters for components of the system GJ 9830.

Parameter	Units	GJ 9830	
		GJ 9830 A	GJ 9830 B
$T_{\rm eff}$	K	6220 ± 100	4870 ± 100
R	$R_{\odot}$	1.10 ± 0.08	0.709 ± 0.07
$\log g$	cgs	4.30 ± 0.12	4.60 ± 0.11
L	$L_{\odot}$	1.63 ± 0.05	0.25 ± 0.04
$M_{\rm bol}$	mag	4.22 ± 0.21	6.26 ± 0.20
$\mathcal{M}_{\odot}$ [1]	$\mathcal{M}_{\odot}$	1.18 ± 0.10	0.75 ± 0.08
Sp. Type[2]		F7.5V	K3.5V
Parallax [3]	mas	29.178 ± 0.186	
Age [4]	Gyr	1.40 ± 0.50	

Notes: [1] Depending on the evolutionary tracks of Girardi et al. (2000b) (Fig. 3); [2] Using the tables of Lang (1992); Gray (2005); [3] Gaia Collaboration (2018); [4] Depending on the isochrones for different metallicities of Girardi et al. (2000a) (Fig. 5).

(2000b) (Fig. 3) are characteristic of main sequence stars. Accordingly, the stellar masses of the binary system were computed using two different methods, Al-Wardat's and Tokovinin's methods, based on the *Gaia* parallax (Gaia Collaboration 2018). The former gave $\mathcal{M}^A = 1.18 \pm 0.10\,\mathcal{M}_{\odot}$ and $\mathcal{M}^B = 0.75 \pm 0.08\,\mathcal{M}_{\odot}$ for the primary and secondary components, respectively, while the latter gave $1.75 \pm 0.06\,\mathcal{M}_{\odot}$. The total mass using Al-Wardat's complex method was found to be similar to that from Tokovinin's method. This indicated the accuracy of the methods applied to this binary system.

Figure 4 displays the initial chemical compositions [$Z = 0.0004$, $Y = 0.23$], [$Z = 0.001$, $Y = 0.23$], [$Z = 0.004$, $Y = 0.24$], [$Z = 0.008$, $Y = 0.25$], [$Z = 0.019$, $Y = 0.273$] (solar composition) and [$Z = 0.03$, $Y = 0.30$]. According to the positions of components in a binary system on the tracks, the helium and metal mass fractions, Y and Z, respectively, are [$Z = 0.019$, $Y = 0.273$] (solar composition).

Figure 5 shows the components of the GJ 9830 system on isochrones. It is clear from the parameters of the system's components and their positions on the evolutionary tracks that both components are characteristic of young solar type main sequence stars, with an age of around 1.40 ± 0.50 Gyr.

Depending on the formation theories, fragmentation is suggested as the most likely process for the formation of the system. Bonnell (1994) concludes that fragmentation of a rotating disk around an incipient central protostar is possible, as long as there is continuing infall. In addition, Zinnecker & Mathieu (2001) pointed out that hierarchical fragmentation during rotational collapse has been invoked to produce binaries and multiple systems.

5 CONCLUSIONS

By using Al-Wardat's method for analyzing close visual binary systems, which employs Kurucz `ATLAS9` line-blanketed plane-parallel model atmospheres in constructing the synthetic SED and applying synthetic photometry on the synthetic SED, we were able to evaluate the physical parameters of the main sequence system GJ 9830. The present analysis shows that the binary GJ 9830 belongs to a class of main sequence systems. The results from synthetic photometry are found to be similar to those from the observed ones, which demonstrates the accuracy of the method we implemented and leads to an estimation of the best stellar parameters for the binary system.

The orbital parameters of the system were calculated properly using Tokovinin's dynamical method. These parameters gave an accurate total mass of the binary system of $1.75 \pm 0.06\,\mathcal{M}_\odot$ based on the new parallax from *Gaia* and on revised orbits of the binary system.

The positions of the components in the system have been examined in a broad way based on the evolutionary tracks and isochrones. The spectral types of the components of GJ 9830 are cataloged as F7.5V and K3.5V for the primary and secondary components of the system, respectively, with an age of 1.40 ± 0.50 Gyr. The evolutionary tracks and isochrones of the system's components are discussed, and the fragmentation process is suggested as the most likely process for the formation of this system.

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