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Studying the Physical Parameters of the Stellar Binary System Hip 42455 (HD 73900)

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ABSTRACT

We present the results of the combined spectrophotometric and dynamic analysis for the close visual binary star Hip 42455 (HD 73900, I 314). A model binary that consists of two main sequence stars with a clear magnitude difference, but completely different estimations of their spectral types, and different parallax measurements given by the four catalogs of the two main precise astrometric missions, Hipparcos and Gaia. The analysis follows Al-Wardat's method for analyzing binary and multiple stellar systems. It investigates the system's physical parameters using the parallax measurements given by the catalogs of Hip 1997, Hip 2007, Gaia DR2, and EDR3. The results were as follows: $T_{\rm eff}^{A} = 6880 \pm 70$ K, $T_{\rm eff}^{B} = 5630 \pm 70$ K ,$R_A = 1.554$ R$_\odot$, $R_B = 0.929$ R$_\odot$, $M_A = 1.44 \pm 0.15$ M$_\odot$, $M_B = 0.98 \pm 0.13$ M$_\odot$, while the spectral type for the primary and secondary components are G7V and F2V, respectively. As a result, the new parallax for this system was given as $\pi_{\rm Dyn} = 25.82 \pm 0.85$, based on the best fit between the dynamical mass sum and the individual masses. This value lies between the old (1997) and new (2007) Hipparcos measurements, and is a bit far from those given by Gaia DR2 and Gaia EDR3.

Key words: *binaries: visual – Techniques: photometric – Stars: individual: Hip 42455, HD 73900, I 314.*

1. Introduction

The study of close binary stars is essential in determining the stellar parameters and, of course, provides important information on their final evolution (Hilditch 2001, Taani and Khasawneh 2017). However, stellar masses play a crucial role in understanding the formation and evolution theories of these stars (Bouvier and Wadhwa 2010, Cai *et al.* 2011, Dai *et al.* 2017, Taani *et al.* 2019, Taani *et al.* 2022). The determination of an accurate fundamental parameters of individual components in binary systems, with well-established parallaxes, represents a direct way to find the masses of Close Visual Binary Systems (CVBSs). This would provide a useful constraint on binary star formation and evolution mechanisms, and hence the formation and evolution of the Milky Way Galaxy. This would be a beneficial constraint on the mechanisms governing the formation and evolution of binary stars, and consequently the formation and evolution of the Milky Way Galaxy (Wei *et al.* 2010, Postnov and Yungelson 2014, Taani 2016). The total mass of a CVBS can be calculated directly from the orbital solutions, while the estimation of the individual masses needs an indirect method like Al-Wardat's method for analyzing binary and multiple stellar systems (Al-Wardat 2002, Al-Wardat *et al.* 2021a).

Table 1

Parameters of system Hip 42455 as given by different catalog

Property	Hip 42455	Source of data
α_{2000}	$08^{h}39^{m}22\overset{s}{.}10$	SIMBAD*
δ_{2000}	$-36^{h}36^{m}24\overset{s}{.}10$	–
m_V [mag]	6.21 ± 2.16	ESA (1997)
$(B-V)$ [mag]	0.426 ± 0.006	–
B_T [mag]	6.61 ± 0.004	Hog *et al.* (2000)
V_T [mag]	6.16 ± 0.003	–
$\pi_{Hip1997}$ [mas]	24.86 ± 0.55	ESA (1997)
$\pi_{Hip2007}$ [mas]	26.42 ± 0.67	Van Leeuwen (2007)
$\pi_{Gaia2018}$ [mas]	24.1552 ± 0.1818	Gaia Collaboration *et al.* (2018)
$\pi_{Gaia2020}$ [mas]	24.4092 ± 0.0446	Gaia Collaboration *et al.* (2022)

* *http://simbad.u-strasbg.fr/simbad/sim-fid*

This method uses the available data (parallax, magnitudes, and magnitude differences) which can be obtained from the speckle interferometry measurements and the color indices of a binary or multiple system. Then, one can build the synthetic Spectral Energy Distribution (SED) to determine the complete physical properties including the effective temperatures, gravity acceleration, radii, masses, absolute magnitudes, spectral types, and luminosity classes of the components of the CVBSs. However, these SEDs are constructed by using grids of Kurucz's line-blanketed planar parallel atmospheres. The advantage of this method is that it can still be valid even in the absence of orbital and spectroscopic data for the systems. Several CVBSs were analyzed using this method (*e.g.,* Al-Wardat *et al.* 2014abc), Masda *et al.* 2019, Al-Tawalbeh *et al.* 2021, Yousef *et al.* 2021, Al-Wardat *et al.* 2021b, Hussein *et al.* 2022).

In this work, we are focusing on one of the interesting systems, Hip 42455. A model binary consists of two main sequence stars, with a clear magnitude difference with different estimations in their spectral types. What makes it more interesting is the different parallax measurements given by the four catalogs of the two main precise astrometric missions, Hipparcos and Gaia (see Table 1). However, we aim to deduce which is the true measurement by the complete analysis of the system – building a precise mass-luminosity relation, and getting a better understanding of the formation and evolution of such stellar system.

2. Method

2.1. The Spectrophotometric Method

In this work, we follow the procedures of Al-Wardat's method to analyze the system, which employs grids of plane-parallel line-blanketed model atmospheres of single stars and computed using the ATLAS 9 (Kurucz 1993, Kurucz 1995, Cannon and Pickering 1993), to build the synthetic SEDs for the components A and B. These SEDs of individual components are combined per the second step of Al-Wardat's method to build the entire synthetic SED of the system using the following equation (Al-Wardat 2002):

$$F_\lambda \cdot d^2 = H_\lambda^A \cdot R_A^2 + H_\lambda^B \cdot R_B^2, \tag{1}$$

where R_A and R_B are the radii of the primary and secondary components in solar units, d is the distance of the system in pc. H_λ^A and H_λ^B are the fluxes of the primary and secondary components, and F_λ denotes to the flux for the entire synthetic SED of the entire binary system measured at the Earth's surface.

Synthetic photometry, which includes magnitudes and color indices, is then used as a test tool to ensure the best fit between the observational and synthetic SEDs. This step of the method is applied to both, the individual and total synthetic magnitudes. Magnitudes are calculated by integrating the total fluxes over each passband of a particular photometric system, divided by that of the reference star (Vega), using the following equation (Al-Wardat 2012):

$$m_p[F_{\lambda,s}(\lambda)] = -2.5 \log \frac{\int P_p(\lambda) F_{\lambda,s}(\lambda) \lambda \mathrm{d}\lambda}{\int P_p(\lambda) F_{\lambda,r}(\lambda) \lambda \mathrm{d}\lambda} + \mathrm{ZP}_p, \tag{2}$$

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 the reference star (Vega). The Zero points (ZP_p) from Apellániz (2007) are used.

$$m_v^A = m_v + 2.5 \log\left(1 + 10^{-0.4\Delta m}\right) \tag{3}$$

$$m_v^B = m_v^A + \Delta m \tag{4}$$

The observational value of the magnitude difference was taken as the average value of all Δm under the V-band filters (541-551 nm). The counted observational values were as follows: $\Delta m_V = 2.1$ mag from Lindegren *et al.* (1997), $\Delta m_V = 2.2$ mag from Tokovinin *et al.* (2010), and $\Delta m_V = 2.2$ mag from Tokovinin *et al.* (2015). The other calibration observational values are the entire visual magnitude $m_V = 6.21$ mag, and the entire color index $B-V = 0.426 \pm 0.006$ mag (ESA 1997).

Hence, preliminary values of the absolute magnitudes of the two components of the system, which are needed to figure out the preliminary effective temperatures, were calculated using the following equation:

$$M_V = m_v + 5 - 5\log d - A_V. \tag{5}$$

A note should be made concerning the extinction interstellar coefficient (A_V). We adopt the accurate estimate of this value, which is 1.3768, due to the absorption of the star light in the space (Schlafly and Finkbeiner 2011)[*].

Regarding the parallax, we start the analysis using the available parallax measurements, which are given by the catalogs of Gaia (DR2 and DR3), and Hipparcos (1997, 2007). We note here that we corrected the Gaia parallax as a function of magnitude, color and celestial positions (Lindegren *et al.* 2021). We obtained a -0.01525 mas parallax-zero-point correction. The overall Gaia parallax correlation can be seen in Fig. 1 in Mardini *et al.* (2022a). Also, more details about the parallax-zero-point correction are presented in Mardini *et al.* (2022ab). Our system is ≈ 40 pc away from the Sun, inferring the low correction value (see Section 6 in Mardini *et al.* (2020) and Fig. 2 in Chiti *et al.* (2021).

These parallaxes are as follows: $\pi_{\text{Hip1997}} = 24.86 \pm 0.55$ mas from ESA (1997), $\pi_{\text{Hip2007}} = 26.42 \pm 0.67$ mas from Van Leeuwen (2007), $\pi_{\text{Gaia2018}} = 24.1552 \pm 0.1818$ mas from Gaia Collaboration *et al.* (2018), and $\pi_{\text{Gaia2020}} = 24.4092 \pm 0.0446$ mas from Gaia Collaboration *et al.* (2022).

The values of the bolometric magnitudes (M_{bol}), luminosities (L), radii (R), and gravity accelerations (log g) for the two components of the system are calculated using the following well-known equations for main sequence star:

$$\begin{aligned} M_{\text{bol}} &= M_V + B.C. & (6)\\ \log \frac{L}{\mathrm{L}_\odot} &= \frac{M_{bol_\odot} - M_{\text{bol}}}{2.5} & (7)\\ \log\left(\frac{R}{\mathrm{R}_\odot}\right) &= 0.5\left(\frac{L}{\mathrm{L}_\odot}\right) - 2\log\left(\frac{T_{\text{eff}}}{T_{\text{eff}_\odot}}\right) & (8)\\ \log g &= \log\left(\frac{M}{\mathrm{M}_\odot}\right) - 2\log\left(\frac{R}{\mathrm{R}_\odot}\right) + 4.43 & (9) \end{aligned}$$

where $T_\odot = 5777$ K, $\mathrm{R}_\odot = 6.69 \times 10^8$ m and $M_{bol_\odot} = 4.^{\mathrm{m}}75$.

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[*] *https://irsa.ipac.caltech.edu/applications/DUST/*

Table 2

Orbital elements of the system Hip 42455 as given by Tokovinin (2019)

Orbital Element	Tokovinin (2019)
P [yr]	65.79
T [yr]	1990.84
e	0.824
a [$''$]	0.565
Ω [°]	339.7
ω [°]	57.5
i [°]	99.0

Table 3

Magnitudes and color indices of the synthetic SEDs for the entire system and the individual components (A and B)

Sys.	Filter	Entire Synth. $\sigma = \pm 0.03$	Hip 42455 A	Hip 42455 B
Joh-Cou.	U	6.65	6.69	9.48
	B	6.61	6.68	9.20
	V	6.20	6.30	8.46
	R	5.95	6.07	8.06
	$U-B$	0.03	0.01	0.28
	$B-V$	0.42	0.38	0.74
	$V-R$	0.24	0.22	0.39
Ström.	u	7.83	7.91	10.63
	v	6.85	6.94	9.60
	b	6.40	6.52	8.87
	y	6.13	6.27	8.43
	$u-v$	0.97	0.97	1.03
	$v-b$	0.44	0.41	0.73
	$b-y$	0.27	0.24	0.43
Tycho	B_T	6.68	6.77	9.39
	V_T	6.21	6.34	8.54
	B_T-V_T	0.47	0.42	0.85

Magnitudes and color indices are given under Johnson-Cousins, Strömgren and TYCHO filters

We tested different solutions depending on different parallax measurements. The results are plotted in Figs. 2 and 3 based on the isochrones of low mass star. The isochrones were taken from Girardi *et al.* (2000). Note that placing their positions on the stellar evolutionary of HR diagram is not affected by the parallax measurements, which is an advantage of using this method. As a result, depending on their positions and the results that we obtained, one can deduce the masses of the primary and secondary components, which are 1.45 $M_\odot$ and 1.0 $M_\odot$ respectively (Table 4).

2.2. The Dynamical Method

In order to obtain the best fit between the masses estimated using Al-Wardat's method and the dynamical mass sum, we used Kepler's third law in its following form:

$$M_{\text{Tot}} = M_A + M_B = \left(\frac{a^3}{\pi^3 P^2}\right) \mathrm{M}_\odot, \tag{9}$$

where $\mathrm{M_A}$ is the mass of the primary component, $\mathrm{M_B}$ is the mass is the secondary component, a is the semi-major axis in arcseconds, π is the parallax in arcseconds and P is the period in years.

The error of the calculated mass sum using the former equation is given by:

$$\frac{\sigma_M}{M} = \sqrt{9\left(\frac{\sigma_\pi}{\pi}\right)^2 + 9\left(\frac{\sigma_a}{a}\right)^2 + 4\left(\frac{\sigma_P}{P}\right)^2}. \tag{10}$$

The Sixth Catalog of Orbits of Visual Binary Stars shows that this system has a good orbit of grade 3. The orbital solution was given by Tokovinin (2020), and by using the latest observational relative position measurement by Tokovinin (2019). As a result, we calculated the mass sums associated with the different parallax measurements. The results are listed in Table 4.

3. Results and Discussion

Table 3, lists the results of the synthetic magnitudes and color indices of the entire system and individual components under three photometric filters: Johnson: *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, $B_T - V_T$.

Fig. 1, shows the synthetic SEDs for the entire system and the individual components, as given by Al-Wardat's method. These SEDs were used to calculate the synthetic photometry and color indices.

The positions of the individual components of the system on the H-R diagram and evolutionary tracks for the five solutions are shown in Figs. 2 and 3. Four of these solutions used the parallax measurements, while the fifth used a new parallax value given in this work. Table 5 lists the final physical parameters of the system using the new dynamical parallax.

However, Evans *et al.* (1961) and Eggen (1962) suggested that the spectral type for this system to be F3 IV, while Malaroda (1975) classified it as a F1 sub giant and

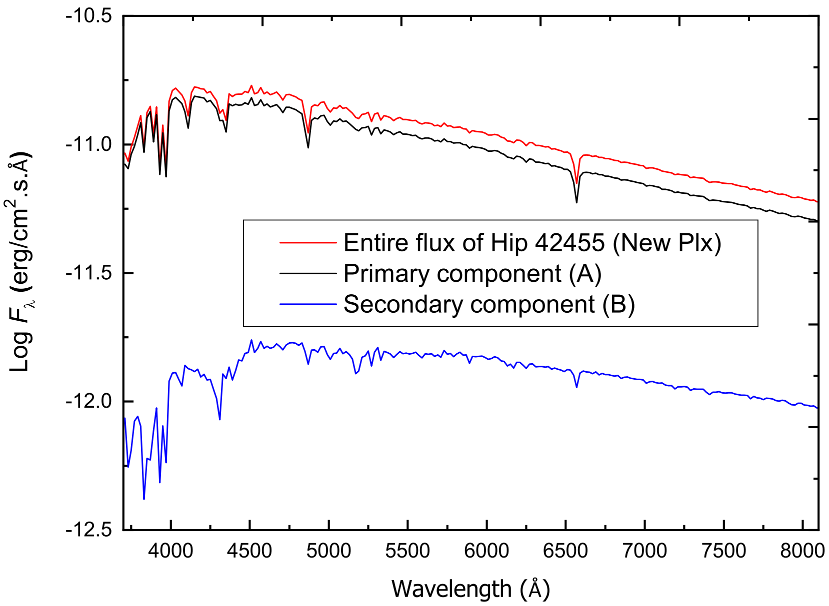


Fig. 1. The synthetic SED of entire system and for the individual components of the system as given by Al-Wardat's method.

Edwards (1976) classified the system as a F3 sub giant. We find that the catalogs of two-dimensional spectral types for the HD stars classified the system as a F3/5 V. And Cańnon and Pickering (1993) classified the system as a F0.

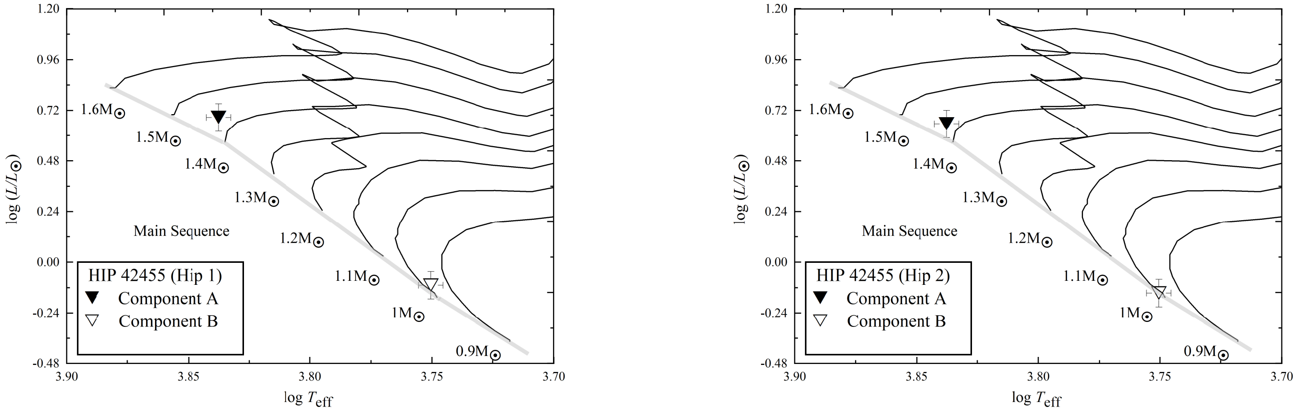
Our results show that the system consists of F2V primary *A* component, and G7V *B* secondary component.

As shown in Table 4, the comparison between the total mass from Al-Wardat's method with the dynamical mass using (Tokovinin 2019) orbital parameters, shows a good agreement within the error values using Hipparcos 2007 parallax.

Table 4

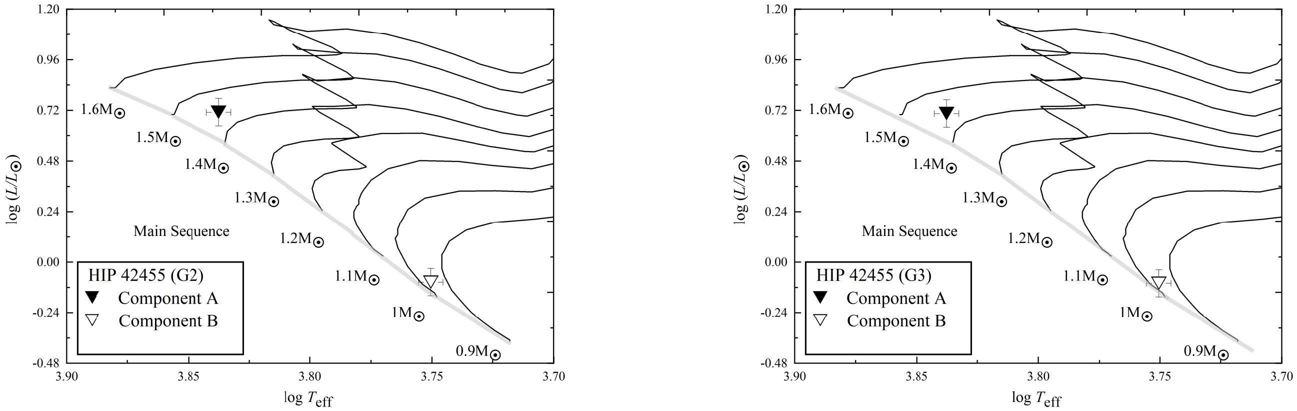
The adopted final results for the physical parameters of the individual components of the system Hip 42455 using the new parallax given by this study as ($\pi_{\rm Dyn} = 25.82 \pm 0.85$) mas

	Dynamical mass sum	Al-Wardat's method mass sum
$\pi_{\rm Hip1997}$ (24.86 ± 0.55 mas)	2.7122	2.42 ± 0.28
$\pi_{\rm Hip2007}$ (26.42 ± 0.67 mas)	2.25958	2.43 ± 0.28
$\pi_{\rm Gaia2018}$ (24.1552 ± 0.1818 mas)	2.95661	2.42 ± 0.28
$\pi_{\rm Gaia2020}$ (24.4092 ± 0.0446 mas)	2.86527	2.42 ± 0.28
$\pi_{\rm Thiswork}$(25.82 ± 0.85 mas)	2.42	2.42 ± 0.28



Using Hipparcos 1997 parallax

Using Hipparcos 2007 parallax



Using Gaia 2018 parallax

Using Gaia 2020 parallax

Fig. 2. Positions of the two components on the HR diagram, their evolutionary tracks and isochrone diagrams of Girardi *et al.* (2000). The four figures represent the fours solutions given by Al-Wardat's method using the four parallax measurements. The adopted fifth solution, using the new parallax estimated in this work, is shown separately in Fig. 3.

Table 4, lists the dynamical mass sum of the system using different parallaxes. The results show that none of the calculated dynamical masses fits those given by the previous solution as 2.42 ± 0.28, which lies between the dynamical mass sums given by the old and new Hipparcos values. Hence, to achieve the best consistency between the dynamical mass sum and that of Al-Wardat's method, we propose a new dynamical parallax for the system as 25.82 ± 0.85 mas

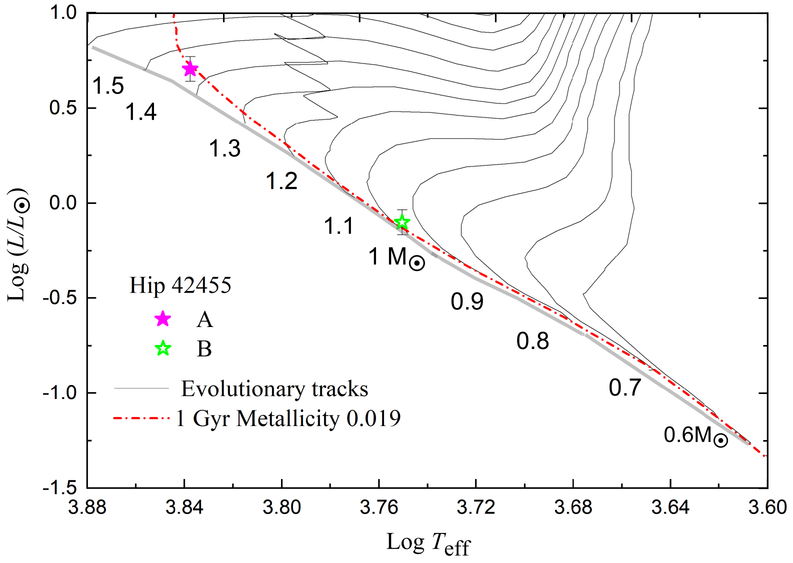


Fig. 3. Position of components of the system on the HR diagram, evolutionary tracks, and age line as given by Al-Wardat's method using the new parallax given by this study as ($\pi_{Dyn} = 25.82 \pm 0.85$) mas. The age line represents 1 Gyr for stars with solar metalicity. Evolutionary tracks and age lines were taken from (Girardi *et al.* 2000).

4. Conclusion

Using Al-Wardat's method for analyzing binary and multiple stellar systems, which is a computational spectrophotometric method, we presented a complete analysis of the stellar binary system Hip 42455.

The method employs grids of Kurucz's line-blanketed plane-parallel model atmospheres (ATLAS 9) to build the synthetic SED for each component. From which, it builds a synthetic SED for the entire system according to some observational parameters (*i.e.*, magnitudes, color indices, and magnitude differences).

The analysis revealed that binary system Hip 42455 consists of (1.44 ± 0.15 $M_\odot$) F2V and (0.98 ± 0.13 $M_\odot$) G7V main-sequence, solar-type stars.

We used two methods to determine the system's total mass. Al-Wardat's method yields a mass sum of ($2.42 \pm 0.28 M_\odot$). The second method yields four distinct re-

Table 5

The adopted final results for the physical parameters of the individual components of the system Hip 42455 using the new parallax given by this study as ($\pi_{\text{Dyn}} = 25.82 \pm 0.85$) mas.

		Hip 42455	
Parameters	Units	A	B
$T_{\text{eff}} \pm \sigma_{T_{\text{eff}}}$	[K]	6880 ± 70	5630 ± 70
$R \pm \sigma_R$	[$R_\odot$]	1.493 ± 0.09	0.893 ± 0.08
$\log g \pm \sigma_{\log g}$	[cm/s^2]	4.20 ± 0.11	4.50 ± 0.13
$L \pm \sigma_L$	[$L_\odot$]	4.48 ± 0.20	0.72 ± 0.10
$M_{\text{bol}} \pm \sigma_{M_{\text{bol}}}$	[mag]	3.12 ± 0.08	5.11 ± 0.08
$M_V \pm \sigma_{M_V}$	[mag]	3.14 ± 0.13	5.24 ± 0.14
M	[$M_\odot$]	1.44 ± 0.15	0.98 ± 0.13
Sp. Type		F2V	G7V
Age	[Gyr]	**1.0**	

sults depending on how the dynamical total mass is computed using the orbital components. The given masses are: 2.71 $M_\odot$ for Hip 1997 ($\pi = 24.86 \pm 0.55$ mas), 2.26 $M_\odot$ for Hip 2007 ($\pi = 26.42 \pm 0.67$ mas), 2.96 $M_\odot$ for Gaia DR2 ($\pi = 24.16 \pm 0.1818$ mas), and 2.87 $M_\odot$ for Gaia DR3 ($\pi = 24.41 \pm 0.0446$ mas).

According to Al-Wardat's method (which is barely affected by the change in the parallax value) as it is clear in Table 4 and Fig. 2, the mass sum should be (2.42 ± 0.28 $M_\odot$). This leads us to adopt a new parallax value as $\pi_{\text{Thiswork}}(\pi = 25.82 \pm 0.85$ mas). This, of course, does not underestimate the values given by Hipparcos and Gaia catalogs, but it is a well-known problem of measuring the parallax of binary and multiple stellar systems known as the photo-center effect, which appears more clearly in Gaia as it has a higher resolution than Hipparcos.

Finally, this system demonstrates that both components have a 1 Gyr age due to their position on the evolutionary tracks and HR diagram. This, along with metallicity confirmation of 0.019, indicates that fragmentation is the most likely formation process for this system.

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REFERENCES

Al-Tawalbeh Y.M., Hussein, A.M., Taani, A.A., *et al.* 2021, *Astrophysical Bulletin*, **76**, 71.

Al-Wardat, M.A 2002, *Bulletin of the Special Astrophysical Observatory*, **53**, 51.

Al-Wardat M. 2012, *Publications of the Astronomical Society of Australia*, **29**, 523.

Al-Wardat M., Balega, Yu.Yu., Leushin, V.V., *et al.* 2014a, *Astrophysical Bulletin*, **69**, 58.

Al-Wardat M.A., Widyan, H.S., and Al-Thyabat, A. 2014b, *Publications of the Astronomical Society of Australia*, **31**, 5.

Al-Wardat, M.A.,Hussein, A.M., Al-Naimiy, H.M., and Barstow, M.A. 2021a, *Publications of the Astronomical Society of Australia*, **38**, e002.

Al-Wardat, M.A., Abu-Alrob, E., Hussein, A.M., *et al.* 2021b, *Research in Astronomy and Astrophysics*, **21**, 161.

Apellaniz, J.M. 2007, *ASP Conf Ser.*, **364**, 227.

Bouvier, A., and Wadhwa, M. 2010, *Nature Geoscience*, **3**, 637.

Cai, Y., Ali, T., Zhao, Y.H., and Zhang, C.M. 2011, *Acta Astronomica Sinica*, **52**, 449.

Cannon, A.J., and Pickering, E.C. 1993, *VizieR Online Data Catalog*, **III**, 135A.

Chiti, A., Mardini, M.K., Frebel, A., and Daniel, T. 2021, *ApJ*, **911**, L23.

Dai, Z., Szkody, P., Taani, A., Garnavich, P.M., and Kennedy, M. 2017, *A&A*, **606**, A45.

Edwards, T.W. 1976, *AJ*, **81**, 245.

Eggen, O.J. 1962, *Royal Greenwich Observatory Bulletins*, **51**, 79.

ESA 1997, “The Hipparcos and TYCHO Catalogues”, *ESA SP Series*, vol. 1200.

Evans, D.S., Menzies, A., Stoy, R.H., and Wayman, P.A. 1961, *Royal Greenwich Observatory Bulletins*, **48**, 389.

Gaia Collaboration, Brown, A.G.A., Vallenari, A., *et al.* 2018, *A&A*, **616**, A1.

Girardi, L., Bressan, A., Bertelli, G., and Chiosi, C. 2000, *VizieR Online Data Catalog*, **414**, 10371.

Hilditch, R.W. 2001, “An introduction to close binary stars”.

Hog, E., Fabricius, C., Makarov, V.V., *et al.* 2000, *ApJ*, **51**, 79.

Hussein, A.M., Al-Wardat, M.A. Abushattal, *et al.* 2022, *AJ*, **163**, 182.

Kurucz, R.-L. 1993, *Kurucz CD-Rom*, 13.

Kurucz, R.L. 1995, *ApJ*, **452**, 102.

Lindegren, L., Mignard, F., Söderhjelm, S., *et al.* 1997, *A&A*, **323**, 53.

Lindegren, L., Bastian, U., Biermann, M., *et al.* A&A, *2021*, **649**, 4.

Malaroda, S. 1975, *AJ*, **80**, 637.

Mardini, M.K., Placco, V.M., Meiron, Y., *et al.* 2020, *ApJ*, **903**, 88.

Mardini, M.K., Frebel, A., Chiti, A., *et al.* 2022a, *ApJ*, **936**, 78.

Mardini, M.K., Frebel, A., Ezzeddine, R., *et al.* 2022b, *MNRAS*, **517**, 3993.

Masda, S., Docobo, J., Hussein, A., *et al.* 2019, *Astrophysical Bulletin*, **74**, 464.

Postnov, K.A., and Yungelson, L.R. 2014, *Living Reviews in Relativity*, **17**, 3.

Schlafly, E.F., and Finkbeiner, D.P. 2011, *ApJ*, **737**, 103.

Taani, A. 2016, *Research in Astronomy and Astrophysics*, **16**, 101.

Taani, A., Abushattal, A., and Mardini, M.K. 2019, *Astron. Nachr.*, **340**, 847.

Taani, A., and Khasawneh, A. 2017, *Journal of Physics Conference Series*, **869**, 012090.

Taani, A., Vallejo, J.C., and Abu-Saleem, M. 2022, *Journal of High Energy Astrophysics*, **35**, 83.

Tokovinin, A., Mason, B.D., and Hartkopf, W.I. 2010, *ApJ*, **139**, 743.

Tokovinin, A., Mason, B.D., Hartkopf, W.I., Mendez, R.A., and Horch, E.P. 2015, *AJ*, **150**, 50.

Tokovinin, A. 2019, *VizieR Online Data Catalog*, J/AJ/158/222.

Tokovinin, A. 2020, *IAUDS, Inf. Circ.*, 201.

Van Leeuwen, F. 2007, *A&A*, **474**, 653.

Wei, Y.-C., Taani, A., Pan, Y.-Y., *et al.* 2010, *Chinese Physics Letters*, **27**, 119801.

Yousef, Z.T., Annuar, A., Hussein, A.M., *et al.* 2021, *Research in Astronomy and Astrophysics*, **21**, 114.