Physical Properties of the Local Stellar System HIP 23824

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Abstract. In this paper, we present the analysis of the stellar system HIP 23824 to determine its nature and physical properties. We used a complex spectrophotometric technique that combined atmospheric modelling with synthetic photometry to obtain the physical parameters of each component in the system and to investigate its multiplicity. Based on our analysis, we found that HIP 23824 is more consistent with being a triple rather than a binary or a quadruple system. It consists of three main sequence stars, A_a, A_b and B, with the following physical parameters: T_{eff}^{Aa} = 6300±50K, T_{eff}^{Ab} = 6150±50K and T_{eff}^{B}=5500±50K; $R^{Aa} = 1.30 \pm 0.02R_\odot$ $R^{Ab} = 1.16 \pm 0.02R_\odot$ and $R^B = 0.85 \pm 0.02;$ the $\text{Log g}_{Aa} = 4.3 \pm 0.30$, $\text{Log g}_{Ab} = 4.30 \pm 0.30$and $\text{Log g}_B = 4.40 \pm 0.30;$ and $L_{Aa} = 2.39 \pm 0.03L_\odot$, $L_{Ab} = 1.78 \pm 0.03L_\odot$ and $L_B = 0.59 \pm 0.02L_\odot$, respectively. Based on the position of each stellar component on the evolutionary and isochrone tracks, we estimated their masses as: $M_{Aa} = 1.20 \pm 0.2M_\odot$, $M_{Ab} = 1.16 \pm 0.2M_\odot$ and $M_B = 0.9 \pm 0.2M_\odot$. The finding is consistent with a previous study that used the dynamical analysis method to estimate the total mass of the system. The consistency between the three components in parameters and ages proves that the system was formed by fragmentation.

Keywords: binary stars, multiple stars, atmosphere modelling, HIP 23824.

I. INTRODUCTION

The majority of the stars in our universe are part of multiple stellar systems. A fraction of the binary and multiple stars are in excess of 50% among the nearby solar-type main-sequence stars (1), which heightens their importance in understanding the formation and evolution of stellar systems. They also play an important role in determining crucial stellar parameters, such as masses, with high precision.

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In 2002, Al-Wardat (2) introduced a spectrophotometric method for analysing binary and multiple stellar systems (BMSSs). This method combined the observational measurements with theoretical stellar models from atmospheres modelling (ATLAS9) to study the nature of binary and multiple stellar systems and determine their stellar parameters (2). The method has been used to analyse BMSSs and to estimate their physical parameters in many earlier studies [3-5].

We recently started a project that utilised the spectrophotometrical method by Al-Wardat (2002) (2) to study the closest (d < 100 pc) and brightest (m_v < 10) triple stellar system candidates in our local universe. The project aimed to investigate the multiplicity of these systems, i.e., whether they are binary, triple, or quadruple systems, and to estimate their physical parameters. These are important to enhance our understanding of multiple stellar systems in general, including their formation and evolution theories.

In this paper, we present the analysis of one of the systems in our stellar sample, HIP 23824. We aim to determine its multiplicity and the physical parameters of each of its components, i.e., the effective temperatures (T_{eff}), radii (R), gravitational accelerations (Logg), luminosities (L), and spectral types (S_p), as well as to investigate its metallicity and age. The basic properties of this system are presented in TABLE 1. Based on the Catalogue of Components of Double & Multiple Stars by Dommanget and Nys (2002) (3), the system is suggested to be a binary system consisting of stars *A* and *B*. On the other hand, the study by Nordström et al. (2004) (4) detected double lines radial velocity measurements for component *A*, suggesting that this component is a binary star.

TABLE 1. Basic properties of the stellar system HIP 23824.

Properties	Parameters	Value	Reference
Magnitude [mag.]	Visual Magnitude (m_v)	6.800	(5)
	Visual extinction (A_v)	0.471	(6)
	B (Tycho)	7.456	(5)
	V (Tycho)	6.869	(5)
Parallax (**π**) [mas]	Hip 2007	20.81	(7)
	Gaia DR3E	21.16	(8)

Tokovinin (2016) (9) analysed the orbit of the system, where it was assumed that it is a triple stellar system in *A*, consisting of a sub-binary star *A* (A_a and A_b) and a single star *B*. The orbit was modelled according to the most recent data using the dynamical analytical method. Based on the dynamical analysis, the paper found the following orbital parameters for the outer binary *AB*: period P = 26.99 yr, semi-major axis a = 0.2742 arcsec, inclination i = 61.6 deg, and eccentricity e = 0.654. The study was also able to estimate the individual masses of the stellar components, i.e.,1.15$M_\odot$, 1.02$M_\odot$, and 0.83$M_\odot$ for stars A_a, A_b, and *B*, respectively. The orbit is classified as grade 3, which means that there is a lack of data coverage. However, the orbital elements derived can still be considered reliable.

II. METHOD

To estimate the physical parameters of multiple and binary stellar systems utilising the spectrophotometric method by Al-Wardat (2002) (2), we built a synthetic spectral energy distribution (SED) for each component using the suggested model atmosphere. Hence, the entire

SED for the whole system was to be used for comparison with the available observations, in an iteration mode, until the best fit between the synthetic and the observational photometry and colour indices was reached.

Atmospheric Modelling (SED Modelling)

Atmospheric modelling is a process in which the grids of blanketed models (ATLAS9) (10) are used to construct the synthetic SED for the system as a whole and for its components individually. In this study, we determined the SED modelling firstly by assuming that the system is a binary, and then by considering both triple system cases (i.e., triple in *A* and triple in *B*), and finally by assuming it as a quadruple system. We did not analyse the system as having more than four components as the analysis would be very complex and these systems are also extremely rare.

The preliminary calculations included computing the average value for the magnitude differences (Δm) between the components *A* and *B* in the V-band. The measurements were retrieved from the Fourth Catalogue of Interferometric Measurements of Binary Stars (11), and the resultant average value was then calculated from these data, i.e., $\Delta m_{avg} = 2.25$. Next, we utilised the value of Δm_{avg} along with the total visual magnitude (m_v) in the Johnson V-band filter (TABLE 1), i.e., $m_v = 6.8$ (5), to obtain the apparent magnitudes for components *A* and *B*. We then used the computed apparent individual magnitudes, together with $T_{\rm eff}$, mass, spectral type, and the parallaxes listed in TABLE 1**,** as well as the bolometric correction values from Gray and David (2005) (12) and Lang (1992) (13), to calculate the preliminary bolometric magnitude (M_{bol}), *R*, Logg and the *L* for components *A* and *B* using the well-known equations for main-sequence star (see (14)).

Next, we used these estimated parameters as initial input for the software ATLAS9 to build the individual preliminary synthetic SED for the binary components *A* and *B*. These individual synthetic SEDs were then combined to get the total preliminary synthetic SED of the entire system according to the total flux equation from Al-Wardat (2002) (2),

$$F_\lambda \,.\, d^2 = \sum_{i=1}^{N} H_\lambda^i \,.\, R_i^2$$

where F_λ is the flux of the combined synthetic SED of the entire system at the Earth`s surface, R_i is the radius of the component in units of $R_\odot$, and H_λ^i is the flux of the component in $erg\ cm^{-2}\ s^{-1} Å^{-1}$.

The above steps were repeated iteratively with different initial input values. This was performed to obtain the best fitting synthetic SED that would give the most precise physical parameters for the system. Synthetic photometry values were determined for each component and for the entire system using another subroutine in the method and the zero points of Apellaniz et al. (2007) (15). The best-fitting SEDs correspond to those with synthetic photometrical parameters consistent with that obtained from the observations ((5), (8)).

III. RESULTS AND DISCUSSION

The nature of HIP 23824

We have analysed HIP 23824 as a binary, triple, and quadruple stellar system. The study of Nordström et al. (2004) (4) detected double lines radial velocity measurements for the star *A*, suggesting that component *A* is not a single star. Hence, we rejected the cases in which star *A* is single. Consequently, our system is either a triple in *A* as mentioned by Tokovinin (2016) (9), or a quadruple stellar system, as these are the two cases in which the star *A* is not a single star.

To decide which case is more likely for HIP 23824, we proceeded with our analysis by assuming that HIP 23824 is a triple in *A*, consisting of a sub-binary star *A* (A_a and A_b) and a single star *B*. We obtained good fitting results for both the main and sub-binary systems. The reliability of our results is shown through the synthetic photometry results (TABLE 2). Based on the adopted physical parameters (TABLE 3), we positioned the components on the stellar evolutionary tracks and stellar isochrone derived by Girardi et al. (2002) (16). These are illustrated in Figure 1. We investigated different metallicities for the system, and we found that it fits solar metallicity the best, which is consistent with the measured value given by Netopil (2017) (17).

TABLE 2. Comparison between synthetic photometry determined from the best fit synthetic SED and those obtained from observations ((5)).

System	Filter	Hipparcos and Tycho Catalogues (5)	This work
Johnson-Cousins	B_J	7.37	7.37
	V_J	6.80	6.80
	$(B\text{-}V)_J$	0.57	0.57
Tycho	B_T	7.46	7.51
	V_T	6.87	6.84

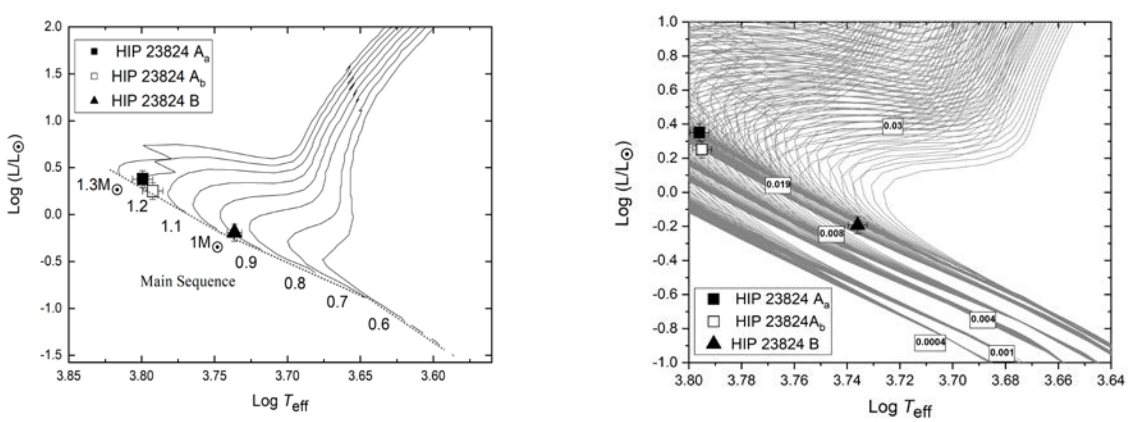

FIGURE 1. The position of each star in HIP 23824 system on the evolution tracks (left) and isochrone tracks (right) derived by *(16)* assuming that it is a triple in *A* i.e., star *A* is a sub-binary system while star *B* is a single star.

The system was then reanalysed by assuming that it is a quadruple system with four components, A_a, A_b, B_a and B_b. The achieved components were positioned on the stellar evolutionary tracks and stellar isochrone tracks derived by Girardi et al. (2002) (16). The positions of the components of the sub-binary system *B* lie outside of the isochrone tracks. Therefore, we rejected the possibility that HIP 23824 is a quadruple system, which in turn affirms that the system is more consistent with being a triple system in *A*, i.e., consisting of the sub-binary system *A* and the single star *B* as suggested by Tokovinin (2016) (9).

The physical properties of HIP 23824

The adopted physical properties of HIP 23824 are presented in Table 3. These were obtained based on the analysis of the system as a triple in *A*. The parameters T_{eff}, *R* and Logg was directly obtained from the best-fit SED, and the luminosities were calculated utilising the Stefan-Boltzmann's law. Meanwhile, the masses of the individual components were determined from their positions on the evolutionary tracks derived by Girardi et al. (2002) (16). Based on our analysis, we found that there is a good consistency within the error values between the masses estimated in this work and those obtained by Tokovinin (2019) (9) using dynamical analysis (i.e., $1.15M_{\odot}$, $1.02M_{\odot}$, and $0.83M_{\odot}$ for star A_a, A_b, and *B*, respectively). Since the orbit of the system solved by Tokovinin (2019) (9) is categorised as grade 3, we propose that the masses we obtained are more accurate. Therefore, we recommend for a modification of the orbit in the future. In addition, we also estimated the age of the stars from the isochrone tracks. Based on this, we found that the age of each star in HIP 23824 is 2 ± 0.5Gyr. The similarity in parameters and age between the three components suggests that the fragmentation process is the most likely formation scenario for the system.

TABLE 3. Physical parameters for each star in HIP 23824 system when assuming it is a triple in A.

Parameters	**Component A_a**	**Component A_b**	**Component *B***
T_{eff} (K)	6300 ± 50	6150 ± 50	5500 ± 50
R ($R_{\odot}$)	1.30 ± 0.02	1.16 ± 0.02	0.85 ± 0.02
Log g	4.30 ± 0.3	4.30 ± 0.3	4.40 ± 0.3
L ($L_{\odot}$)	2.39 ± 0.15	1.78 ± 0.15	0.59 ± 0.15
Mass ($M_{\odot}$)	1.20 ± 0.2	1.17 ± 0.2	0.90 ± 0.2
Stellar type	F5	F6	G8

IV. CONCLUSION

In this study, we analysed the stellar system HIP 23824 to investigate its multiplicity, i.e., to estimate the number of stars in the system, and determine their physical parameters. We used the newly released data from catalogues and the spectrophotometric technique developed by Al-Wardat (2002) (2) to determine the physical parameters with better accuracy than those of past studies. Based on our results, we affirmed that HIP 23824 is a triple system in *A*. The system consists of three solar-type main-sequence stars of A_a, A_b and *B*, with the age of about 2 Gyr. The masses calculated for each stellar component in the system are consistent with a past study which used the dynamical modelling method, providing support for our results. We proposed for more speckle interferometric observations in the future to modify the system's orbit due to the relatively low-level solution of current orbital analysis.

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