The visually close binary system HD375; Is it a sub-giant binary?

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Atmospheric modeling is used to build synthetic spectral energy distributions (SEDs) for the individual components of the speckle interferometric binary system HD375. These synthetic SEDs are combined together for the entire system and compared with its observational SED in an iterated procedure to achieve the best fit. Kurucz blanketed models with the measurements of magnitude differences were used to build these SED’s. The input physical elements for building these best fitted synthetic SEDs represent adequately enough the elements of the system. These elements are: $T_{\text{eff}}^{a} = 6100 \pm 50$ K, $T_{\text{eff}}^{b} = 5940 \pm 50$ K, log $g_{a} = 4.01 \pm 0.10$, log $g_{b} = 3.98 \pm 0.10$, $R_{a} = 1.93 \pm 0.20 R_{\odot}$, $R_{b} = 1.83 \pm 0.20 R_{\odot}$, $M_{a}^{*} = 3^{m} 26^{s} 40^{m} .40$, $M_{b}^{*} = 3^{m} 51^{s} 50^{m} .50$, $L_{a} = 4.63 \pm 0.80 L_{\odot}$ and $L_{b} = 3.74 \pm 0.70 L_{\odot}$ depending on new estimated parallax $\pi = 12.02 \pm 0.60$ mas. A modified orbit of the system is built and compared with earlier orbits and the masses of the two components are calculated as $M_{a} = 1.35 M_{\odot}$ and $M_{b} = 1.25 M_{\odot}$. Depending on the estimated physical and geometrical elements of the system, which are assured by synthetic photometry, we suggest that the two components are evolved subgiant (F8.5 IV & G0 IV) stars with age of 3.5 Gy formed by fragmentation.

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I. INTRODUCTION

Hipparcos mission revealed that many previously known single stars are actually binary or multiple systems [18]. Most of these resolved systems are nearby stars that appear as a single star even with the largest ground-based telescopes except when observed using high resolution techniques like speckle interferometry (SI) [10, 43] and adaptive optics (AO) [39, 40]. That is why these binaries took their names (Speckle Interferometric Binaries SIBs), and are also known as visually close binary systems (VCBSs).

In general, the study of binary stars is the most powerful direct method to correlate stellar theoretical models with the actual observational elements, which is more complicated in the case of VCBSs. It connects mass determinations with other important elements such as radius, luminosity, and effective temperature and gives a basic check of stellar structure and evolution theory [27]. It also gives a unique way for a thorough investigation of the spectral types and luminosity classes [17]. Hundreds of such systems with periods in the order of 10 years or less, are routinely observed and analyzed by the aforementioned high resolution techniques. But, in spite of that, there is still a paucity in the individual physical elements of the systems’ components. The only way to estimate these elements is by indirect analysis of the binaries. A method that makes use of Kurucz blanketed models [20] to build a synthetic spectral energy distribution (SED) for each component separately, and hence for the entire system. Then, by comparing this entire synthetic SED with the observational one in an iterated repetition to achieve the best fit between them, one may be able to determine the physical and geometrical elements of the individual components.

The method at first used earlier versions of line-blanketed plane-parallel theoretical model atmospheres for F, G, and K-type stars [14], where it counted only for the hydrogen lines opacities in building the SEDs [2]. After that, it employed ATLAS9 with its new opacity distribution functions (ODFs) [15] to build the individual synthetic SEDs, and it was successfully applied to some binary systems like Cou1289, Cou1291, Hip11352, Hip11253, Hip70973 and Hip72479 [1, 4, 6, 7].

The VCBS HD375 was firstly analyzed using the earlier version of this method by [2]. The modified physical and geometrical elements for the system using the modified version of the aforementioned method, and the modified orbit of the system depending on latest SI ob-

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II. ATMOSPHERIC MODELING

Table I contains basic data of the system from SIMBAD, NASA/IPAC and Table II contains data from Hipparcos and Tycho Catalogues [18].

The magnitude difference between the two components $\Delta m = 0\text{"}27 \pm 0.01$ is adopted as the average of all $\Delta m$ measurements under the speckle filters $545nm/30$ (see Table III) as the closest filters to the visual. This value was used as an input to the equations:

$$m_v^0 = m_v + 2.5 \log(1 + 10^{-0.4\Delta m}) \quad (1)$$

and

$$m_v^b = m_v^0 + \Delta m \quad (2)$$

Using the entire visual magnitude of the system $m_v = 7\text{"}41$ (see Table II), the preliminary individual visual magnitude $m_v$ for each component is: $m_v^0 = 8\text{"}04$ and $m_v^b = 8\text{"}31$.

Preliminary individual absolute magnitudes were calculated using equation [3] assuming that both components are main sequence stars. These were used to calculate the preliminary input elements ($T_{\text{eff}}^0 = 6750K, T_{\text{eff}}^b = 6500K, \log g_a = 4.19$ and $\log g_b = 4.21$) to construct model atmospheres for each component using grids of Kurucz’s 1994 blanketed models (ATLAS9). Once needed, Equations 4 & 5 are used, interstellar reddening is taken from Table II $T_{\odot} = 5777K$ is used and bolometric corrections are taken from [31] and [22]. Hence a spectral energy distribution for each component is built.

$$M_v = m_v + 5 - 5 \log(d) - A_v \quad (3)$$

$$\log(R/R_{\odot}) = 0.5 \log(L/L_{\odot}) - 2 \log(T/T_{\odot}) \quad (4)$$

$$\log g = \log(M/M_{\odot}) - 2 \log(R/R_{\odot}) + 4.43 \quad (5)$$

The total energy flux from a binary star is created from the net luminosity of the components $a$ and $b$ located at a distance $d$ from the Earth. One can write [4]:

$$F_\lambda \cdot d^2 = H_\lambda^a \cdot R_a^2 + H_\lambda^b \cdot R_b^2$$

TABLE I: Data from SIMBAD and NASA/IPAC.

|      | Hip689 | ref. |
|------|--------|-----|
|      | HD375  |     |
|      | HD517  |     |
| $\alpha_{2000}$ | $00^h08^m28.46^s$ | 1 |
| $\delta_{2000}$ | $+34^\circ 56' 04.73^"$ | 1 |
| TyC  | 2267-721-1 | 1 |
| SAO  | 53674  | 1 |
| Sp. Typ. | F8   | 1 |
| E(B-V) | 0.057 | 1 |
| $A_v$ | $0^m180$ | 2 |

1SIMBAD, 2NASA/IPAC [http://irsa.ipac.caltech.edu]

TABLE II: Data from Hipparcos and Tycho Catalogues.

|      | Hip689 |        |
|------|--------|--------|
|      | HD375  |        |
| $V_j(Hip)$ | 7.41  |        |
| $(B-V)_j(Hip)$ | $0^m660 \pm 0.015$ |        |
| $B_T$ | $8^m113 \pm 0.009$ |        |
| $V_T$ | $7^m470 \pm 0.007$ |        |
| $(B-V)_j(Tyc)$ | $0^m584 \pm 0.009$ |        |
| $\pi_{Hip \text{ (}}\text{ (mas)}$ | 12.72 $\pm$ 0.86 |        |
| $\pi_{Hip \text{ (}}\text{ new)}$ | 11.69 $\pm$ 0.67 |        |
| $\pi_{TyC \text{ (}}\text{ (mas)}$ | 4.10 $\pm$ 5.20 |        |

TABLE III: Magnitude difference between the components of the system along with filters used to obtain the observations.

| $\Delta m$ | filter $(\lambda/\Delta\lambda)$ | ref. |
|-----------|---------------------------------|-----|
| $0^m04 \pm 0.39$ | $V_{Hip} : 550nm/40$ |        |
| $0^m28 \pm 0.05$ | $545nm/30$ |        |
| $0^m31 \pm 0.05$ | $545nm/30$ |        |
| $0^m03 \pm 0.15$ | $624nm/41$ |        |
| $0^m22 \pm 0.24$ | $2151nm/214$ |        |
| $0^m02 \pm 0.15$ | $503nm/40$ |        |
| $0^m00 \pm 0.15$ | $701nm/12$ |        |
| $0^m20 \pm 0.15$ | $648nm/11$ |        |
| $0^m20 \pm 0.15$ | $600nm/30$ |        |
| $0^m81$ | $698nm/39$ |        |
| $0^m23 \pm 0.06$ | $545nm/30$ |        |
| $0^m22 \pm 0.03$ | $600nm/30$ |        |
| $0^m01$ | $745nm/44$ |        |
| $0^m15$ | $541nm/88$ |        |
| $0^m55$ | $698nm/39$ |        |
| $0^m47$ | $650nm/38$ |        |
| $0^m41$ | $650nm/38$ |        |
| $0^m49$ | $698nm/39$ |        |
| $0^m54$ | $745nm/44$ |        |
| $0^m29$ | $550nm/40$ |        |
| $0^m20 \pm 0.04$ | $600nm/30$ |        |
| $0^m01$ | $550nm/40$ |        |
| $0^m07$ | $745nm/44$ |        |
| $0^m00$ | $745nm/44$ |        |
| $0^m04$ | $550nm/40$ |        |
| $0^m88$ | $550nm/39$ |        |
| $0^m71$ | $698nm/39$ |        |
| $0^m00$ | $745nm/44$ |        |
| $0^m48$ | $550nm/40$ |        |
| $0^m43$ | $692nm/40$ |        |
| $0^m52$ | $562nm/40$ |        |
| $0^m38$ | $692nm/40$ |        |
| $0^m48$ | $447nm/60$ |        |

observations are presented. These information will enhance our knowledge about stellar parameters in general and consequently will help in understanding the formation and evolution mechanisms of stellar binary systems.
from which

\[ F_\lambda = (R_a/d)^2 (H_\lambda^a + H_\lambda^b - (R_b/R_a)^2), \]

where \( H_\lambda^a \) and \( H_\lambda^b \) are the fluxes from a unit surface of the corresponding component. \( F_\lambda \) here represents the entire SED of the system.

The resulting entire synthetic SED which is built using the preliminary input elements does not coincide with the observational one. It shows a lower color \((B-V)\) index, which means that the temperatures of the stars should be lower.

Many attempts were made to achieve the best fit between the synthetic SEDs and the observed one. The preliminary calculated set is taken as starting values and an iteration method for the different sets of elements is used. The best fit is evaluated using to the following criteria:

- The maximum values of the absolute flux (represent by the apparent magnitudes and calculated using synthetic photometry).
- The inclination of the spectrum (represents by the color indices \((U-B), (B-V)\) and \((v-b)\)).
- The magnitude difference between the components (\(\Delta m\)).
- The profiles of the absorption lines.

While the last three criteria depend mainly on \(T_{\text{eff}}\) and \(\log g\), which were fulfilled using:

\[ T_{\text{eff}}^a = 6100 \pm 50K, T_{\text{eff}}^b = 5940 \pm 50K \]

\[ \log g_a = 4.00 \pm 0.10, \log g_b = 3.99 \pm 0.10, \]

the first criterion depends on the parallax of the system and the radii of the components (see equation 7). The estimated entire synthetic visual magnitudes according to the parallax of Hipparcos and the radii of [22] (assuming that both components are main sequence stars) are higher (i.e. the absolute flux is lower) than the observed ones. This means that either the parallax of the system is incorrect and the system is closer to earth or the system’s components are no longer main sequence stars but evolved and have higher radii.

Now, in order to get the exact fit with the observational absolute flux (Fig. 1), the parallax is chosen according to the following two approaches:

1. Fixing the parallax as given by Hipparcos modified data \(\pi = 11.69 \pm 0.67\) mas [44], and changing the radii till the best absolute flux reached. Note that while changing the radii, only slight changes in the value of \(\Delta m\) are allowed.

2. Fixing the radii as given by [22] tables or the standard R-L-T equation [41] for the main sequence stars of \(T_{\text{eff}}^a = (6100 \pm 50)K, T_{\text{eff}}^b = (5940 \pm 50)K\) and changing the parallax till the best absolute flux reached.

Doubts in Hipparcos parallax measurements were introduced by [41]. They noted that, in some cases, Hipparcos parallax measurements are distorted by the orbital motion of the components of binary systems. Therefore, one has to be careful when using these measurements.

The first approach resulted in the following radii:

\[ R_a = 2.00 \pm 0.15R_\odot, R_b = 1.89 \pm 0.15R_\odot, \]

which refer to subgiant stars.

While the second approach resulted in the following radii and parallax:

\[ R_a = 1.18 \pm 0.15R_\odot, R_b = 1.12 \pm 0.15R_\odot \]

and \(\pi = 19.818\) mas \((d = 50.46 \pm 0.02)pc\), which disagrees with Hipparcos trigonometric parallax.

The estimated parallax obtained by the second approach does not coincide with orbital elements and mass sum calculated hereafter in this work (see Table V), while that given by Hipparcos was acceptable somehow. Hence, the elements obtained by the first approach represent the system better than those obtained by the second approach, but not the best (see section IV).

III. ORBITAL ELEMENTS

The orbit of the system is built using the positional measurements listed in Table IV which are taken from
the Fourth Interferometric Catalog and from [27]. There are seven new points used to modify the orbit of [27]. Fig. 2(a) shows the orbit of the system, which represents the relative positions of the secondary star with respect to the primary, and the ascending motion of the secondary according to the positional measurements. Fig. 2(b) shows a comparison between the new orbit (solid line) and that of [27] (doted line). The preliminary orbit of [10], and that of [3] are shown in Fig. 3. The modified orbital elements of the system along with the previous ones are listed in Table V. It shows a good consistency between our estimated period, periastron epoch, semi-major axis and eccentricity and those estimated by [27], while there are some differences in the inclination, position angle of nodes and the argument of periastron.

IV. MASSES

Using the estimated orbital elements, we calculated the total mass of the system (in solar masses) and the corresponding error are calculated using the following equations:

\[
\sigma_M = \sqrt{\left(3\sigma_a^2 + \sigma_a^2\right)^2 + \left(2\sigma_p^2\right)^2}. \tag{8}
\]

The preliminary result using Hipparcos new trigonometric parallax \(\pi\) (mas) = 11.69 ± 0.67 is \((M_a + M_b)/M_\odot = 2.80 ± 0.49\), while it is 2.19 ± 0.45 when using Hipparcos old trigonometric parallax \(\pi\) (mas) = 12.72 ± 0.86 (Table IV).

The calculated mass sum using Hipparcos new parallax gives higher value than what would be expected for two stars with the previously estimated physical elements, which is well enhanced by the positions of the two components on the evolutionary tracks. Another loop of iterated calculations is performed to reach the best fit between the estimated physical parameters and the orbital elements, especially the mass sum, which affected highly by the parallax value.

The best fit (Fig. 4) between the synthetic SED and the observational one, along with the best consistency between the physical and geometrical elements of both components, dynamical parallax and dynamical mass sum are achieved using a modified dynamical parallax \(\pi\) (mas) = 12.02 ± 0.60), which gives a mass sum of 2.60 ± 0.16. The final physical and geometrical elements of the system are listed in Table IV which adequately enough represent the elements of the system within the error values of the measured quantities.

V. SYNTHETIC PHOTOMETRY

The following relation is used in the calculations of the entire and individual synthetic magnitudes of the system

\[ m_p[F_{\lambda,s}(\lambda)] = -2.5\log\left[\frac{F_p(\lambda)F_{\lambda,s}(\lambda)d\lambda}{\int F_p(\lambda)F_{\lambda,s}(\lambda)d\lambda} + ZP_p\right], \tag{10} \]

where \(m_p\) is the synthetic magnitude of the passband \(p\), \(F_p(\lambda)\) is the dimensionless sensitivity function of the passband \(p\), \(F_{\lambda,s}(\lambda)\) is the synthetic SED of the object and \(F_{\lambda,s}(\lambda)\) is the SED of the reference star (Vega). Zero points (ZP) from [32] (and references there in) are adopted.

The results of the calculated magnitudes and color indices (Johnson-Cousins: \(U, B, V, R, U - B, B - V, V - \)
TABLE V: Orbital elements of the system (10, 3, 27 and this work)

| Parameter       | Balega et al. (2002) | [3] | [27] | (this work) |
|-----------------|-----------------------|-----|------|-------------|
| $P$ (yr)        | 19.3                  | 10.74 ± 0.24 | 12.9 | 12.79 ± 0.11 |
| $T_o$ (yr)      | 2005.6                | 1988.265 ± 0.177 | 2006.12 | 2006.36 ± 0.02 |
| $e$             | 0.38                  | 0.52 ± 0.02 | 0.6  | 0.5237 ± 0.0051 |
| $a$ (arcsec)    | 0.124                 | 0.127 ± 0.003 | 0.091 | 0.0904 ± 0.0005 |
| $i$ (deg)       | 125                   | 124 ± 2.0 | 159  | 149.03 ± 1.13  |
| $\Omega$ (deg)  | 42                    | 32 ± 3.0 | 315  | 62.99 ± 3.03   |
| $\omega$ (deg)  | 107                   | 105 ± 1.0 | 72   | 183.42 ± 3.22  |
| $(M_a + M_b)/M_\odot$ | 2.3$^*$ | 3.55$^*$ | 2.835$^{**}$ | 2.19 ± 0.45$^\dagger$ |

* Depending on the estimated individual absolute magnitudes supposing that both components are main sequence stars.
** Using Hipparcos new trigonometric parallax $\pi$ (mas) = 11.69 ± 0.67.
† Using Hipparcos old trigonometric parallax $\pi$ (mas) = 12.72 ± 0.86.
‡ Using the estimated parallax in this work $\pi$ (mas) = 12.02 ± 0.60.

FIG. 2: Relative visual orbit of the system HD375; The origin represents the position of the primary component. The filled circles are the new points used to modify the orbit (see Table IV) and Hipparcos point is denoted by a star. (a) Shows the epoch of the positional measurements; Bracts mean that there is more than a point in that year. (b) Comparison between the modified orbit of this work (solid line) and that of [27] (dotted line).

FIG. 3: (a) The preliminary orbit of the system by [10]. (b) The orbit of [3].
TABLE VI: Physical and geometrical elements of the components of the system.

| Component  | a                   | b            |
|------------|---------------------|--------------|
| $T_{\text{eff}}$ (K) | 6100 ± 50           | 5940 ± 50    |
| Radius ($R_\odot$) | 1.93 ± 0.20         | 1.83 ± 0.20  |
| log $g$    | 4.01 ± 0.10         | 3.98 ± 0.10  |
| $L(\odot)$ | 4.63 ± 0.80         | 3.74 ± 0.70  |
| $M_V$      | $3^{m}26^{s}0.40$   | $3^{m}51^{s}0.50$ |
| Mass, ($M_\odot$) | 1.35 ± 0.16         | 1.25 ± 0.15  |
| $\rho(\odot)$ | 0.188 ± 0.015      | 0.204 ± 0.015|
| Sp. Type*  | F8.5 IV             | G0 IV        |
| Parallax (mas) | 12.02 ± 0.60       |              |
| $(M_a + M_b)/M_\odot$ | 2.60 ± 0.16        |              |
| Age* (Gy)  | 3.5 ± 0.5           |              |

*Depending on the positions of the components on the evolutionary tracks of [22].

FIG. 4: Doted line: the entire observational SED in the continuous spectrum of the system. Solid lines: the entire synthetic SED of the two components using a modified dynamical parallax ($\pi$ (mas) = 12.02 ± 0.60); the synthetic flux of the primary component with $T_{\text{eff}} = 6100 ± 50$ K, log $g = 4.01 ± 0.10$, $R = 1.93 ± 0.15 R_\odot$, and the synthetic flux of the secondary component with $T_{\text{eff}} = 5940 ± 50$ K, log $g = 3.98 ± 0.10$, $R = 1.83 ± 0.15 R_\odot$.

R; Strömgren: $u$, $v$, $b$, $y$, $u - v$, $v - b$, $b - y$ and Tycho: $B_T$, $V_T$, $B_T - V_T$ of the entire system and individual components, in different photometrical systems, are shown in Tables VII.

A comparison between the synthetic visible magnitudes and their color indices with the observational ones of the system (Tables VII) shows a good consistency within the three photometrical systems Johnson-Cousins, Strömgren and Tycho (see Table VIII).

Depending on the tables of [22] or using [31] $Sp - T_{\text{eff}}$ empirical relation, the spectral types of the system’s components can be estimated as F8.5 and G0 for the components a and b respectively.

TABLE VIII: Magnitudes and color indices of the synthetic spectra of the system.

| System    | Filter | Entire synth. | Comp. a | Comp. b |
|-----------|--------|---------------|---------|---------|
| Johnson   | $U$    | 8.14          | 8.73    | 9.08    |
| Cousins   | $B$    | 8.02          | 8.63    | 8.93    |
| Strömgren | $u$    | 9.29          | 9.88    | 10.23   |
|           | $v$    | 8.35          | 8.96    | 9.28    |
|           | $b$    | 7.75          | 8.37    | 8.65    |
|           | $y$    | 7.38          | 8.01    | 8.26    |
|           | $u - v$| 0.94          | 0.93    | 0.95    |
|           | $v - b$| 0.60          | 0.58    | 0.63    |
|           | $b - y$| 0.37          | 0.36    | 0.39    |
| Tycho     | $B_T$  | 8.17          | 8.77    | 8.09    |
|           | $V_T$  | 7.47          | 8.11    | 8.36    |
|           | $B_T - V_T$ | 0.69          | 0.67    | 0.73    |

TABLE VIII: Comparison between entire synthetic visible magnitudes and color indices of the system with the entire ones calculated from the observational SED [3].

| System          | Fil. | entire synth. | entire obs. |
|-----------------|------|---------------|--------------|
| Johnson- Cousins| $B$  | 8.02          | 8.03         |
|                 | $V$  | 7.41          | 7.43         |
|                 | $B - V$ | 0.61        | 0.60         |
| Strömgren       | $v$  | 8.35          | 8.35         |
|                 | $b$  | 7.75          | 7.80         |
|                 | $v - b$ | 0.60       | 0.55         |
| Tycho           | $B_T$ | 8.17          | 8.18         |
|                 | $V_T$ | 7.47          | 7.50         |
|                 | $B_T - V_T$ | 0.69       | 0.67         |

VI. RESULTS AND DISCUSSION

Atmospheric modeling and visual magnitude difference between the two components along with the entire observational SED are used to build synthetic individual and entire SED’s for the components of the VCBS HD375. The least-square fitting with weights inversely proportional to the squares of the positional measurements observational errors is used to modify the orbit of the system. Hence, the physical and geometrical elements of the VCBS HD375 are estimated, and the parallax of the system is modified.

Fig. 4 shows the achieved best fit between the entire synthetic SED’s and the observational one. Where we can see a good consistency of the maximum values of the absolute flux and the inclination of the spectrum.
TABLE IX: Comparison between the observational and synthetic magnitudes, colors and magnitude differences of the system.

| HD375 | Obs.\textsuperscript{†} | Synthetic (This work) |
|-------|-----------------|-----------------------|
| V\textsubscript{J} | 7\textsuperscript{m}.41 | 7\textsuperscript{m}.41 |
| B\textsubscript{T} | 8\textsuperscript{m}.17 ± 0.02 | 8\textsuperscript{m}.11 ± 0.01 |
| V\textsubscript{T} | 7\textsuperscript{m}.47 ± 0.02 | 7\textsuperscript{m}.47 ± 0.01 |
| (B − V)\textsubscript{J} | 0\textsuperscript{m}.61 ± 0.03 | 0\textsuperscript{m}.61 ± 0.02 |
| Δm | 0\textsuperscript{m}.25 ± 0.02 | 0\textsuperscript{m}.27 ± 0.01 |

\textsuperscript{†} See Table III

There is also a good consistency between the synthetic magnitudes and colors and the observational ones within the three photometrical systems Johnson-Cousins, Strömgren and Tycho (Tables VIII & IX). This consistency gives a good indication about the reliability of the estimated elements of the individual components of the system, which are listed in Table VI.

The estimated masses and radii can only be explained by assuming that the system is a subgiant binary system. Earlier calculations of the mass sum are listed in Table VI, and they calculated it in three different ways; using Kepler’s law (called the dynamical mass), using the mass-luminosity relation along with the observed photometry (photometric mass \(M_{\text{ph}}\)), and using the mass-spectrum relation along with the spectral classification (spectral mass \(M_{\text{sp}}\)). They found \(M_d(M_\odot) = 2.78 \pm 0.89\), \(M_{\text{ph}}(M_\odot) = 2.67\) and \(M_{\text{sp}}(M_\odot) = 1.10\). The discrepancy between the dynamical and spectral mass estimations is possibly due to their assumption that both components are main-sequence stars, where they used Table VI of \[42\], and that the spectral mass represents the minimum mass of the system.

A deep look at the estimated physical and geometrical elements of the system (Table VI) shows that the secondary component is very similar to the star \(\beta\) Hydri (HIP 2021), which is a G2IV evolved subgiant with an age of about 6.5 - 7.0 Gyr \[16, 19\]. \[12\] used high precision astroseismology to measure the mean stellar density of \(\beta\) Hydri as \(\rho(\odot) = 0.1803 \pm 0.0011\) and \[36\] used interferometry to measure its angular diameter, where they estimated its physical elements as: \(T_{\text{eff}}(K) = 5872 \pm 44\), \(R(R_\odot = 1.814 \pm 0.017), \log g = 3.952 \pm 0.005\) \(L(L_\odot) = 3.51 \pm 0.09\) and mass \(M(M_\odot) = 1.07 \pm 0.03\).

The primary component is also similar to the secondary component of the binary system Beta Leonis Minoris (\(\beta\) LMi B) which is known as an F8 subgiant with mass \(M(M_\odot) = 1.7 \pm 0.4\) and absolute magnitude \(M_\odot = 2\textsuperscript{m}.3\) \[21\].

That leads us to suggest that both components are evolved subgiant stars with age around 3.5 Gy. Fig. 5 shows the positions of the components on the evolutionary tracks of \[20\].

Based on the similarity of both components, fragmentation is proposed as the most likely formation process for the system. Where \[13\] concludes that fragmentation of a rotating disk around an incipient central protostar is possible, as long as there is continuing infall. \[43\] pointed out that hierarchical fragmentation during rotational collapse has been invoked to produce binaries and multiple systems.

VII. CONCLUSIONS

The VCBS HD375 was analyzed using atmospheric modeling and dynamical analysis. The elements of the systems’ components were estimated depending on the best fit between the entire observational SED and synthetic ones built using the atmospheric modeling of the individual components. The total and individual \(UBV\) Johnson-Cousins, \(uvby\) Strömgren and \(BV\) Tycho synthetic magnitudes and colors of the system were calculated.

A modified orbit and geometrical elements of the system were calculated and compared with earlier ones. Based on the estimated elements, especially radii and masses, we suggest that the two components are F8.5 & G0 in their early subgiant stage, lying a bit upper the main-sequence on the H-R diagram. The estimated physical and geometrical elements of the two components coincide (within the error values) with those given by the Tables of \[12\] for subgiants.

Finally, fragmentation is proposed as the most likely process for the formation and evolution of both systems. Moreover, the system can be used to test the stellar evolution theory and constraints on the physical description of the stellar interiors.
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