Orbital and physical parameters of eclipsing binaries from the All-Sky Automated Survey catalogue — VII. V1200 Centauri: a bright triple in the Hyades moving group.*

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ABSTRACT

We present the orbital and physical parameters of the detached eclipsing binary V1200 Centauri (ASAS J135218-3837.3) from the analysis of spectroscopic observations and light curves from the All Sky Automated Survey (ASAS) and SuperWASP database. The radial velocities were computed from the high-resolution spectra obtained with the OUC 50-cm telescope and PUCHEROS spectrograph and with 1.2m Euler telescope and CORALIE spectrograph using the cross-correlation technique TODCOR. We found that the absolute parameters of the system are $M_1 = 1.394 \pm 0.030 \, M_\odot$, $M_2 = 0.866 \pm 0.015 \, M_\odot$, $R_1 = 1.39 \pm 0.15 \, R_\odot$, $R_2 = 1.10 \pm 0.25 \, R_\odot$. We investigated the evolutionary status and kinematics of the binary and our results indicate that V1200 Centauri is likely a member of the Hyades moving group, but the largely inflated secondary’s radius may suggest that the system may be even younger, around 30 Myr. We also found that the eclipsing pair is orbited by another, stellar-mass object on a 351-day orbit, which is unusually short for hierarchical triples. This makes V1200 Cen a potentially interesting target for testing the formation models of multiple stars.

Key words: binaries: eclipsing - binaries: spectroscopic - binaries: pre-main sequence - stars: fundamental parameters - stars: individual: V1200 Cen

1 INTRODUCTION

Detached, double-lined spectroscopic binaries that are also eclipsing provide an accurate determination of stellar mass, radius and temperature for each of their individual components, and hence constitute a strong test of single star stellar evolution theory (Lastennet & Valls-Gabaud 2002). Eclipsing binary (EB) stars are very important for the study of stellar astrophysics. Their particular geometrical layout, their dynamics and radiative physics enable a detailed and accurate modelling and analysis of the acquired data, and allow to measure many basic physical parameters of the components (Helminiak et al. 2009). Studies of binary stars by all of the techniques available in modern astrophysics allow to measure a wide range of parameters for each of the component stars, with some of them determined with very high accuracy (e.g., uncertainties of less than 1%).

This also refers to the pre-main-sequence (PMS) stars. Through a complete analysis of spectroscopy and photometry of these systems orbital and physical parameters of the two stars can be accurately derived. However, until recently there were only seven known low-mass pre-main sequence EBs with $M < 1.5 \, M_\odot$: RXJ 0529.4+0041A (Covino et al. 2000, 2004), V1174 Ori (Stassun et al. 2004), 2MJ0535-05 (Stassun et al. 2006, 2007), JW380 (Irwin et al. 2007), Par 1802 (Cargile et al. 2008), ASAS J0528+03 (Stempels et al. 2008), and MML53 (Hebb et al. 2010).

Multiple systems of two or more bodies seem to be the norm at all stellar evolutionary stages, according to observations, and it has been accepted for some time now that binarity and multiplicity is established as the principal channel of star formation (Reipurth et al. 2014). For this reason, knowledge of the formation of multiple stars becomes necessary to understand star formation in general (Delgado-Donate et al. 2004). Moreover, observations of
young multiple systems allow to test evolutionary models in early stages of stellar evolution.

On the other hand, it is important to increase the sample of young stars (especially PMS) because main-sequence, solar-type stars are well described by stellar evolution models (observations agree well with theoretical isochrones), but recent measurements of the stellar properties of low-mass dwarfs and young PMS stars remain problematic for the existing models (Morales-Calderón et al. 2012).

In this paper we present the orbital and physical analysis of an eclipsing binary V1200 Centauri (HD 120778, HIP 67712, ASAS J135218−3837.3; \( \alpha = 13\text{h}52\text{.m}17\text{.s}51, \delta = -38\text{°}37\text{‘}16\text{.82} \)). It is a well detached system with a circular orbit, a short orbital period (\( \sim 2.5 \) days), and observed parameters consistent with the pre-main-sequence evolutionary stage. We also announce the discovery that it is a triple hierarchical system.

This system was first studied in 1954 in the Cape Photographic Catalog 1950 (Jackson & Stov\( \_\)1954), but only the magnitudes and epoch. Then in 1984 the spectral type of F5V was defined (Houk\( \_\)1984). The system is described as an Eclipsing Algol (EA) by Otero & Claus\( \_\)2004 and has a \( V \) magnitude of 8.551 (Anderson & Francis\( \_\)2012). As a bright star, it was a subject of spectroscopic studies of the Geneva-Copenhagen survey (Nordström et al.\( \_\)2004; Holmberg et al.\( \_\)2009), where was treated as a single star, however due to large brightness ratio in the visual we can consider some of their results reliable. The parallax and proper motion are also known: \( \pi = 8.43(94) \) mas, \( \mu_\alpha = -72.49(87), \mu_\delta = -44.20(78) \) mas yr\( ^{-1} \) (van Leeuwen\( \_\)2007).

In Section 2 we describe the observations used to identify V1200 Cen as an eclipsing and spectroscopic binary with a circumbinary companion, in Section 3 we determine the orbital parameters of the system and physical properties of the component stars of and compare them with theoretical isochrones. Finally, in Section 4 we discuss the future observations needed to fully analyse the system.

2 OBSERVATIONS

2.1 Echelle spectroscopy

Observations with PUCHEROS instrument were carried out between January and May 2012 at the 50-cm telescope of the Observatory UC Santa Martina located near Santiago, Chile. The telescope is the European Southern Observatory (ESO) instrument, formerly located at La Silla. PUCHEROS is the Pontificia Universidad Católica High Echelle Resolution Optical Spectrograph developed at the Center of Astro-Engeneering of Pontificia Universidad Católica de Chile (Infante et al.\( \_\)2014; Vanzi et al.\( \_\)2012). The spectrograph is based on a classic echelle design, fed by the telescope through an optical fibre and it covers the visible range (380 to 690 nm) with a spectral resolution of 50,000. Observations were made in a simultaneous wavelength calibration mode, where the light of the object is collected by one fibre, and of the ThAr lamp by the other. The spectra were taken between June 2012 and July 2013. CORALIE data were reduced with a dedicated, Python-based pipeline (Jordán et al.\( \_\)2014).

2.2 Photometry

Photometric data were obtained from the All-Sky Automated Survey (ASAS) (Pojmański\( \_\)2002; Paczyński et al.\( \_\)2006) and from the SuperWASP transiting planet survey (Pollacco et al.\( \_\)2006). ASAS has produced an extensive catalogue of variable stars (ACVS) of the southern hemisphere\( ^1 \). In this work, we use 495 data points from the third stage of the survey, obtained in the \( V \) filter between 2000 and 2009. SuperWASP is a wide-field photometric variability survey designed to detect transiting gas-giant planets around bright main sequence stars. The survey cameras observe bright stars \( (V \sim 9-13) \) at high precision (1%) using a broad \( V + R \) band filter. 3234 data points have been extracted from the SuperWASP public archive\( ^2 \).

3 ANALYSIS

3.1 Radial velocities and orbital solution

Radial velocities (RVs) were measured with an implementation of the two-dimensional cross-correlation technique TODCOR (Zucker & Mazeh\( \_\)1994 with synthetic spectra used as templates. The formal RV measurement errors were computed from the bootstrap analysis of TODCOR maps created by adding randomly selected single-order TODCOR maps. The peaks of the cross-correlation function (CCF) coming from both components were significantly different in height, due to the large brightness ratio of the two stars. The PUCHEROS spectra usually had lower signal-to-noise (S/N) ratio (5-30) and the CCF peak from the secondary was not always recognized. The S/N of the CORALIE data was normally higher (25-60) and the secondary’s CCF peak was more prominent, still very low though. With TODCOR we also tried to estimate the intensity ratio of the two components, but due to low S/N of the cool secondary the results were very uncertain and we find them unreliable.

The orbital solution was done simultaneously on all RV measurements with our simple procedure, which fits a double-Keplerian orbit using the Levenberg-Marquardt algorithm (for a more detailed description, see Helminiak et al.\( \_\)2003), and allows for Monte-Carlo and bootstrap analysis to obtain reliable estimations of uncertainties. We used the photometric data first to find the orbital period, and check for eventual eccentricity (see next Section). The eccentricity was found to be indistinguishable from zero so it was held fixed to 0.0 in the further steps. In the orbital analysis also the period and \( T_0 \) were held fixed. In the final orbital analysis we have also kept fixed the period and \( T_0 \). We used the values

\footnote{1 \url{http://www.astrouw.edu.pl/asas/?page=acvs}}

\footnote{2 \url{http://exoplanetarchive.ipac.caltech.edu/applications/ExoTables/search.html?dataset=superwasptimeseries}}

\( ^1 \) http://www.astrouw.edu.pl/asas/?page=acvs

\( ^2 \) http://exoplanetarchive.ipac.caltech.edu/applications/ExoTables/search.html?dataset=superwasptimeseries

\( \alpha \)
modified version of our procedure to look for a third, circumbinary body in the system. We fitted for the outer orbit’s period i.e. differing from the model by a similar value. We then used a for both components, and residuals of both components correlated, the magnitude of the inner pair velocity variations being explained by a mismatch between the spectrum and the template, with high reduced 2χrms for the primary and secondary, respectively and much lower 2χrms for the PUCHEROS data and in the case of CORALIE data the correction is implemented in the reduction pipeline. Therefore, the scale of the perturbation and the outer orbit’s eccentricity can’t be explained by the improper correction for the barycentre. Hereafter, following the usual convention, we will refer to the eclipsing pair as AB, and to the third body as C.

We started with a purely double-Keplerian solution with no perturbations, but the solutions we were getting were not satisfactory, with high reduced χ2 ≃ 1600, rms of the fit about 10 km/s for both components, and residuals of both components correlated, i.e. differing from the model by a similar value. We then used a modified version of our procedure to look for a third, circumbinary body in the system. We fitted for the outer orbit’s period P3, amplitude of the inner pair orbit variations K12, and the base epoch T3, eccentricity e3 and the argument of pericentre ω3. We ran the fitting procedure again on the whole data set, and found a satisfactory solution, characterised by a much lower rms = 0.98 and 1.50 km/s for the primary and secondary, respectively and much lower reduced χ2 = 1.29. All of our spectra have barycentric correction, we used IRAF’s bcvcor for the PUCHEROS data and in the case of CORALIE data the correction is implemented in the reduction pipeline. Therefore, the scale of the perturbation and the outer orbit’s eccentricity can’t be explained by the improper correction for the barycentre. Hereafter, following the usual convention, we will refer to the eclipsing pair as AB, and to the third body as C.

We present all the measurements, together with the errors and residuals, in Table 1. In Table 2 we present our results of the full orbital analysis. The parameters of the circumbinary orbit should be treated as preliminary, but the binary pair’s orbital elements are well constrained. The RV measurement errors were initially scaled in such way that the final reduced χ2 was close to 1, and the fit itself was not affected (weights not changed). The errors were found by a bootstrap analysis (10000 iterations). In such a way we take care of the possible systematics and obtain reliable uncertainties of the final parameters. Our model, separated into the Keplerian and perturbation components, is presented in Figure 1.

It is worth noting that the mass function f(M3) was calculated from the full formula:

\[ f(M_3) = \frac{M_3 \sin^3 i_3}{(M_1 + M_2 + M_3)^2} \]

and is quite large. The minimum mass of the third body (for i3 = 90°) is a substantial fraction of the total mass of the eclipsing pair.

Table 1. Radial velocity (RV) measurements of V1200 Cen, together with the final measurement errors (σ) and residuals from the final three-body fit (O − C), All values in km s\(^{-1}\). In the last column, 5/P denotes OUC-50cm/PUCHEROS and E/C Euler 1.2m/CORALIE observations.

| JD-2450000 | v1    | σ1 | O − C1 | v2    | σ2 | O − C2 | Tel./Sp. |
|------------|-------|----|--------|-------|----|--------|---------|
| 5714.615861| 45.958| 0.646| -0.340 | —     | —  | —      | 5/P     |
| 5736.539995| 64.395| 0.494| 0.222  | -127.519| 2.640| -0.757 | 5/P     |
| 5737.639889| -67.029| 0.523| 0.394  | 88.377 | 4.198| -1.718 | 5/P     |
| 5750.604835| -62.826| 2.446| 1.482  | —     | —  | —      | 5/P     |
| 5751.584224| 74.651| 0.536| -0.788 | -126.370| 4.324| 3.856  | 5/P     |
| 6066.642808| 47.460| 1.498| -0.858 | —     | —  | —      | 5/P     |
| 6066.665643| 51.655| 0.841| 0.658  | —     | —  | —      | 5/P     |
| 6078.656477| -36.335| 2.129| 1.846  | —     | —  | —      | 5/P     |
| 6080.625298| -89.867| 0.163| -0.009 | 112.325| 1.503| 0.657  | E/C     |
| 6081.564728| 52.113| 0.228| -0.021 | -116.745| 1.075| -0.456 | E/C     |
| 6179.474281| -26.024| 0.167| 0.035  | 80.336 | 0.885| -1.105 | 5/P     |
| 6346.690592| -12.831| 0.169| -0.321 | 67.855 | 0.876| 0.573  | E/C     |
| 6348.857536| -55.020| 0.165| 0.255  | 136.192| 1.064| 1.044  | E/C     |
| 6349.894755| 94.865| 0.194| 0.023  | -107.687| 1.017| -0.499 | E/C     |
| 6397.509298| 38.353| 0.112| -0.034 | -71.655| 0.772| 1.072  | E/C     |
| 6398.517694| -77.575| 0.116| 0.017  | 112.000| 0.951| -0.331 | E/C     |
| 6497.610599| -67.667| 0.157| -0.152 | 133.439| 0.797| 0.229  | E/C     |
| 6498.610654| 64.361| 0.113| 0.082  | -78.099| 0.942| 0.453  | E/C     |

Table 2. Results of the RV analysis and the orbital parameters of V1200 Cen.

| Parameter | Value ± |
|-----------|---------|
| K1 [km s\(^{-1}\)] | 78.23 0.37 |
| K2 [km s\(^{-1}\)] | 126.0 1.1 |
| v1 [km s\(^{-1}\)] | 10.92 0.94 |
| σ1 [R\(_{\odot}\)] | 10.026 0.058 |
| e12 | 0.0 (fixed) |
| q | 0.6208 0.0062 |
| M1 sin3 i [M\(_{\odot}\)] | 1.352 0.027 |
| M2 sin3 i [M\(_{\odot}\)] | 0.839 0.012 |
| P3 [d] | 351.5 3.4 |
| T3 [JD-2540000] | 5358.2 8.0 |
| K12 [km s\(^{-1}\)] | 18.37 0.11 |
| e3 | 0.42 0.09 |
| ω3 | 156 7 |
| a3 sin i3 [AU] | 0.538 0.033 |
| f [M\(_{\odot}\)] | 0.099 0.025 |
| M3(i3 = 90°) [M\(_{\odot}\)] | 0.662 0.066 |
| E/C−5/P1 [km s\(^{-1}\)] | 0.98 0.31 |
| E/C−5/P2 [km s\(^{-1}\)] | 5.32 2.00 |
| DoF | 20 |
| rms1 [km s\(^{-1}\)] | 0.68 |
| rms2 [km s\(^{-1}\)] | 1.40 |

\(^{a}\) E/C−5/P is the difference in spectrograph zero points measured for each component separately.
so the popular approximation \((M_1 + M_2 + M_3)^2 \approx (M_1 + M_2)^2\) is not valid. We checked for tertiary eclipses in the residuals of the light curve models (see next Section) and we found no obvious evidence for them, which means that the outer orbit’s inclination is different from \(\sim 90^\circ\). We have also failed to identify a tertiary peak in the CCF, which means that the tertiary component is significantly dimmer than the secondary. All this is consistent with for example a 0.7 \(M_{\odot}\) star on a \(70 - 75^\circ\) orbit. It is also not excluded that the system may itself be a binary composed of two similar, lower-mass stars, which together exceed the mass of B. This would be in agreement with Tokovinin (2014), who found no hierarchical triples with outer orbits shorter than \(\sim 1000\) days. The mechanism leading to a formation of such double-double system, with short inner orbital periods and outer period shorter than \(1000\) d, assumes non-aligned outer and inner orbits (Whitworth 2001; Tokovinin 2014). It is thus possible that in V1200 Cen the mutual inclination between the outer and inner orbit is large, making the Kozai mechanism possible (Kozai 1962).

### 3.2 Light curve modelling

Both ASAS and SuperWASP light curves were fitted using the JKT EOB code (Southworth et al. 2004a,b), which is based on the Eclipsing Binaries Orbit Program (EBOP; Popper & Etzel 1981), and PHOEBE (Prša & Zwitter 2005) – an implementation of the WD code (Wilson & Devinney 1971). JKT EOB determines the optimal model light curve that matches the observed photometry and reports the parameters obtained for the model. The parameters derived include the period \(P\), time of minimum light \(T_0\), surface brightness ratio, relative sum of the radii \((R_1 + R_2)/a\), ratio of the radii \(R_2/R_1\), inclination \(i\), eccentricity \(e\), and argument of periastron \(\omega\). The routine also takes into account the effects of limb darkening, gravity darkening and reflection effects. We adopted the logarithmic limb darkening law from Claret et al. (2000). To obtain the limb darkening coefficients we considered the ASAS light curve to be in Johnson’s \(V\) passband. For the SuperWASP filter we interpolated the coefficients from Pollacco et al. (2006). We also checked the ASAS data for O-C timing variations, and we did not find any significant ones. Thus we did not correct the light curves for the light time effect induced by the third body. We used PHOEBE to obtain the temperature of the secondary star, using the temperature of the primary star known previously from Holmberg et al. (2009). We did not use the latest Geneva-Copenhagen survey results, as they rely on infrared data, which in the case of V1200 Cen
can be affected by the secondary and tertiary star. The value of the mass ratio was found in the previous orbital analysis. Figure 2 shows the observed ASAS and SWASP light curves together with their models.

Reliable uncertainties in case of ASAS data were calculated with the Monte-Carlo method (10000 runs) and with residual-shifts (Southworth 2008) in case of SWASP data. Figure 3 shows the distribution of \( r_1 + r_2 \) and \( k \) as the function of the inclination angle. The usual correlation is clearly visible. The results of the LC analysis with JKTEBOP are presented in Table 3. We found that the ratios of radii (\( k \)) and effective temperatures are the most uncertain values, vastly contributing to errors of such physical parameters as absolute radii or luminosities. This is due to large scatter of the photometric data and low contribution of the star B (12% in \( V \)). One way to constrain \( k \) would be to use intensity ratios from TODCOR, but as we mentioned the S/N of the spectra was too low. Data of a much higher S/N are needed, optimally taken in IR (both photometry and spectroscopy), where the secondary’s contribution is larger.

### 3.3 Kinematics

Using the known parallax and proper motion (van Leeuwen 2007) and our value of the systemic velocity \( v_\gamma \), we have calculated the galactic velocities: \( U = -36.7 \pm 3.3 \), \( V = -21.8 \pm 3.6 \) and \( W = -1.8 \pm 0.6 \) km s\(^{-1}\) (no correction for the solar movement has been done). These values put V1200 Cen in the Hyades moving group (Seabroke & Gilmore 2007; Zhao et al. 2009), which suggests the age of \( \sim 625 \) Myr. However, Famaey et al. (2008) have shown that about half of the stars that reside in the same area in the velocity space as the Hyades group, actually does not belong to it. Nevertheless, V1200 Cen seems to be a young system belonging to the thin galactic disk.

### 3.4 Absolute parameters

The absolute dimensions and distance were calculated using JKTEBOP with the results obtained from the radial velocity and light curve analysis. The parameters with their respective uncertainties used for the input were the velocity semi amplitudes (km s\(^{-1}\)), period (days), orbital inclination (degrees), fractional stellar radii \( r \) and effective temperatures, and apparent magnitudes in the \( B \) and \( V \) filters. We did not use the available \( JHK \) photometry as it could have been affected by the third star. For the interstellar reddening we considered E(B-V)=0, and we observed no major differences for the distances obtained in the two filters, both in agreement with the value of the parallax 8.43±0.94 mas (119±13 pc; van Leeuwen 2007). We present the absolute parameters of V1200 Cen in Table 4.

### 3.5 Evolutionary status

In Figure 4 we present our results from Table 4 plotted over theoretical stellar evolution models of Siess (2000) and from Yonsei-Yale...
The basis of spectroscopic values of the Y object, so it is either evolved, as the 3 Gyr isochrone suggests, or at an age is fully consistent with the data, and the resulting distance is in good agreement with the Hipparcos distance. We report the discovery that the eclipsing binary V1200 Centauri is a triple, likely a member of the Hyades moving group, but the largely inflated secondary’s radius may suggest that the system may be PMS around 30 Myr. There are few such objects known so far, however they are very important for calibrating stellar evolution models at young ages, where stars are changing rapidly as they evolve onto the main sequence. Analysis of ASAS and SuperWASP light curves combined with radial velocity measurements allowed to obtain absolute parameters of the system. Through our analysis of radial velocities and orbital solution we determined the presence of a third companion, in a wide orbit. We reached a good precision in mass determination (2.2 and 1.7%), but other parameters (radii, temperatures, luminosities) are not that well established. Further analysis of the system allowed us to compare our results with stellar evolution models, obtaining an approximate age of 30 Myr. Despite its brightness, data of higher S/N are required to better constrain physical parameters of the system, especially temperatures and ratio of the radii. Possible solution would be to obtain photometry and spectroscopy in the IR, where components B and C contribute more than in visual. The secondary eclipse would be deeper, and the influence of the third light should be detectable. Also, if RVs of the star C were measured, a full dynamical solution of the system could be obtained, including mass of the third star and the inclination of its orbit. This would also allow for comparing the isochrones with three stars, thus constrain the age and evolutionary status even better. With its probable age, V1200 Cen is an important object to study the tidal and third-body interactions young binaries.

### Table 4. Physical parameters of V1200 Cen obtained with JKTABSDIM on the basis of spectroscopic values of $T_{\text{eff},1}$ and $[Fe/H]$.

| Parameter | Value | ± |
|-----------|-------|---|
| $a$ [R$_\odot$] | 10.13 | +0.07 | -0.06 |
| $M_1$ [M$_\odot$] | 1.394 | 0.030 |
| $M_2$ [M$_\odot$] | 0.866 | 0.015 |
| $R_1$ [R$_\odot$] | 1.39 | +0.14 | -0.13 |
| $R_2$ [R$_\odot$] | 1.10 | +0.22 | -0.25 |
| $\log g_1$ | 4.30 | -0.69 | +0.19 |
| $\log g_2$ | 4.29 | +0.20 |
| $[Fe/H]$ | -0.18$^a$ |
| $T_{\text{eff},1}$ [K] | 6266$^a$ | 94 |
| $T_{\text{eff},2}$ [K] | 4650$^b$ | 900 |
| $L_1$ [log(L/L$_\odot$)] | 0.42 | +0.09 | -0.19 |
| $L_2$ [log(L/L$_\odot$)] | -0.29 | +0.38 | -0.40 |
| $d$ [pc] | 98 | 11 |

$^a$ From Holmberg et al. (2009). $^b$ From temperature ratio obtained with PHOEBE.

(Y$^2$: Yi et al. 2001) set for ages of 6, 10, 15, 20 and 625 Myr. For the Y$^2$ we also include the 3 Gyr isochrone.

The values from Table 4 are marked as black points. The two most precise values we have are the mass and temperature of the primary. One can see that it is too cool for a main sequence object, so it is either evolved, as the 3 Gyr isochrone suggests, or at its pre-main-sequence (PMS) stage. However, both Y$^2$ and Siess’ models predict a drastic change in temperature and radius between 10 and 20 Myr. The primary’s radius is much too small for an evolved star and agrees with the late PMS, meanwhile the temperature clearly suggests younger age, inconsistent with the radius. We also note that secondary’s parameters are much better reproduced by PMS models, especially its radius, which is much larger than main-sequence objects of the same mass, as expected for stars that are still evolving onto the main sequence.

The comparison of our results with the model predictions indicates that V1200 Cen is a pre-main-sequence system, but no age is fully consistent with the data, and the resulting distance is only in a fair agreement with results from the Hipparcos. Unfortunately, the uncertainties are very large, especially for the secondary component, so our conclusions cannot be treated as final. The strongest constrain we have comes from the primary’s temperature, which was derived spectroscopically by Holmberg et al. (2009). We find almost exactly the same temperature ~ 6263 K – using the observed $B - V$ colour (0.475 mag) and calibrations by Sekiguchi & Fujimoto (2000). One has to remember that the Holmberg’s temperature was derived under the assumption that the star is single. Thus, it is still possible that the true $T_{\text{eff}}$ is higher. We run a series of tests to find the temperatures that give the best agreement with the Hipparcos parallax, assuming their ratio to be the same as found by us with PHOEBE. We found the best match to the observed distance for much higher temperatures of 6900 and 5120 K for the primary and secondary respectively. The resulting effective temperatures and related luminosities are summarised in Table 5. We plot them on the Figure 4 with red symbols.

One can see that the new higher values of radiative parameters fit the main sequence or even 20 Myr models, and both radii still agree with the 30 Myr isochrone. The age of 30 Myr also happens to be the time scale of circularisation of the system’s orbit. All in all, we get a self-consistent model of a 30-625 Myr old, young multiple. As an attempt to distinguish between high and low temperature scale we also run a simplified spectral analysis with the Spectroscopy Made Easy package (SME: Valenti & Piskunov 1996). We took the CORALIE spectra, shifted by the measured velocity of the primary and stacked them together. We run the SME on a portion of spectrum spanning 6190-6260Å, and keeping the $[Fe/H]$, $\log(g)$ and $v_{\text{rot}}$ on values from or expected from Tab 4. The secondary’s contribution was treated as a contribution to the continuum, constant across the wavelength range. We obtained $T_{\text{eff},1} \sim 6000$ K, favouring the lower temperature scale, and younger ages (Fig 4).

We are aware of the fact that such analysis is affected by the secondary, and we do not treat it as a proof for the correctness of Holmberg’s temperature, but we find it unlikely to be off by almost 1000 K, between spectral types F0 and F8.

### Table 5. Radiative parameters of V1200 Cen obtained with JKTABSDIM by fitting the temperature scale to match the Hipparcos distance.

| Parameter | Value | ± |
|-----------|-------|---|
| $T_{\text{eff},1}$ [K] | 6900 | 100$^a$ |
| $T_{\text{eff},2}$ [K] | 5120$^b$ | 900$^b$ |
| $L_1$ [log(L/L$_\odot$)] | 0.59 | +0.09 | -0.10 |
| $L_2$ [log(L/L$_\odot$)] | 0.13 | +0.36 | -0.37 |

$^a$ Uncertainty assumed. $^b$ From temperature ratio obtained with PHOEBE.
**Figure 4.** Mass vs. radius, $\log(L)$ and $\log(T_{\text{eff}})$. The left column shows our results and the isochrones from Y$^2$ for ages of 6, 10, 15, 20, 625 Myr and 3 Gyr. The right column shows the same but using the Siess (2000) isochrones (without 3 Gyr). Black symbols are for our results from Table 4 and red symbols for the results from Table 5.
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