Analysis of the multiple-star V1200 Centauri

F. Marcadon on behalf of the Solaris team

Nicolaus Copernicus Astronomical Center, Polish Academy of Sciences, ul. Rabiańka 8, PL-87-100 Toruń, Poland

Abstract

We present a new analysis of the multiple-star V1200 Centauri based on the most recent observations for this system [1]. We used the photometric observations from the Solaris network and the *Transiting Exoplanet Survey Satellite (TESS)*, combined with the new radial velocities from the CHIRON spectrograph and those published in the literature.

We confirmed that V1200 Cen consists of a 2.5-d eclipsing binary orbited by a third body. Regarding the third body, we obtained significantly different results than those previously published. Indeed, we argue that V1200 Cen is a quadruple system with a secondary pair composed of two low-mass stars.

Radial velocities

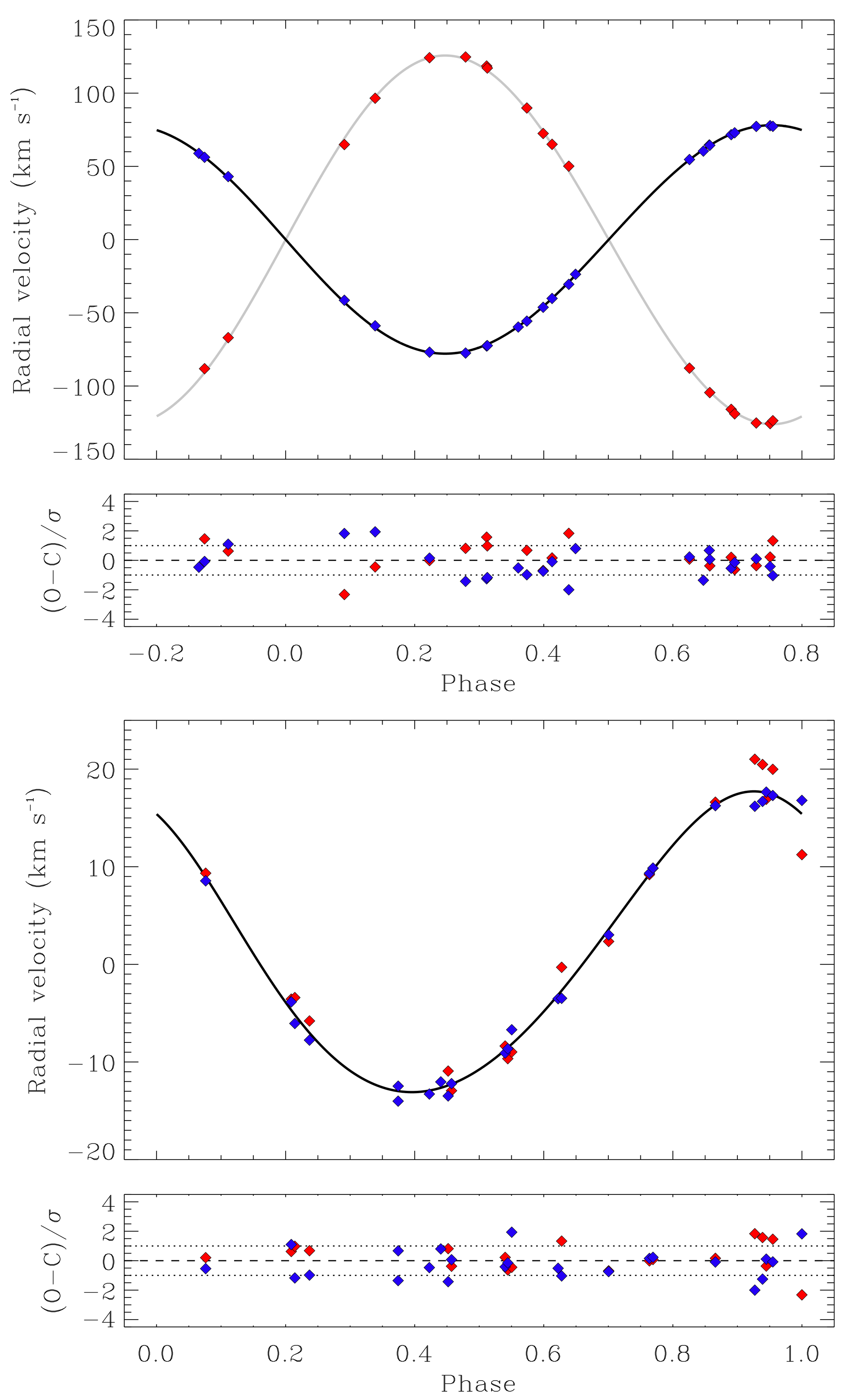

Figure 2: Radial-velocity (RV) observations of V1200 Cen

The upper panel shows the best-fitting solutions for stars Aa (black) and Ab (grey) after having removed the 180-d modulation induced by the third body. The curve is phase-folded at the orbital period $P_A \simeq 2.5$ d. The lower panel shows the best-fitting solution for the centre of mass of the eclipsing pair after having removed the orbital motion of stars Aa and Ab. The curve is phase-folded at the orbital period $P_{AB} \simeq 180$ d.

Thanks to the new RV measurements from CHIRON, we obtained a more precise and robust solution than that of [4]. We found that the AB system has a 180-d orbital period and is almost circular with an eccentricity of 0.088. The new orbit implies a more massive third body than in the previous study, namely $M_B = 0.871\,M_\odot$ instead of $0.662\,M_\odot$ (minimum mass for the third body, corresponding to $i_{AB} = 90°$).

Light-curve modelling

We collected photometric data for V1200 Cen during three main campaigns of observation between 2017 February and August (∼75 nights), between 2018 March and August (∼55 nights), and between 2019 February and April (∼25 nights) with Solaris, a network of four autonomous observatories in the Southern hemisphere [2].

In this work, we analysed the high-precision photometric data collected by *TESS* for V1200 Cen (TIC 166624433), in addition to the Solaris light curves. V1200 Cen was observed by *TESS* in 2-min cadence mode for 27.1 d during sector 11, that is between 2019 April 23 and 2019 May 20. For the light-curve analysis of the *TESS* and Solaris data, we used the latest version (v34) of the JKTEBOP code [3]. In order to derive reliable uncertainties, we performed Monte Carlo simulations on the *TESS* and Solaris light curves, with 10 000 runs each, as implemented in JKTEBOP.

In Fig. 1, we presented the observed *TESS* and Solaris light curves associated with their best-fitting models derived from our analysis. The *I*-band light curve was detrended before fitting in order to remove the long-term variability of the comparison star and the short-term atmospheric fluctuations. The root mean squares (rms) of the residuals are 0.6 and 12.0 mmag, respectively. We obtained very consistent results between the different surveys (see [4] for more details), based on various approaches . Thanks to the high precision of the *TESS* photometry, we also significantly improved the precision on the fractional radii (∼1 per cent).

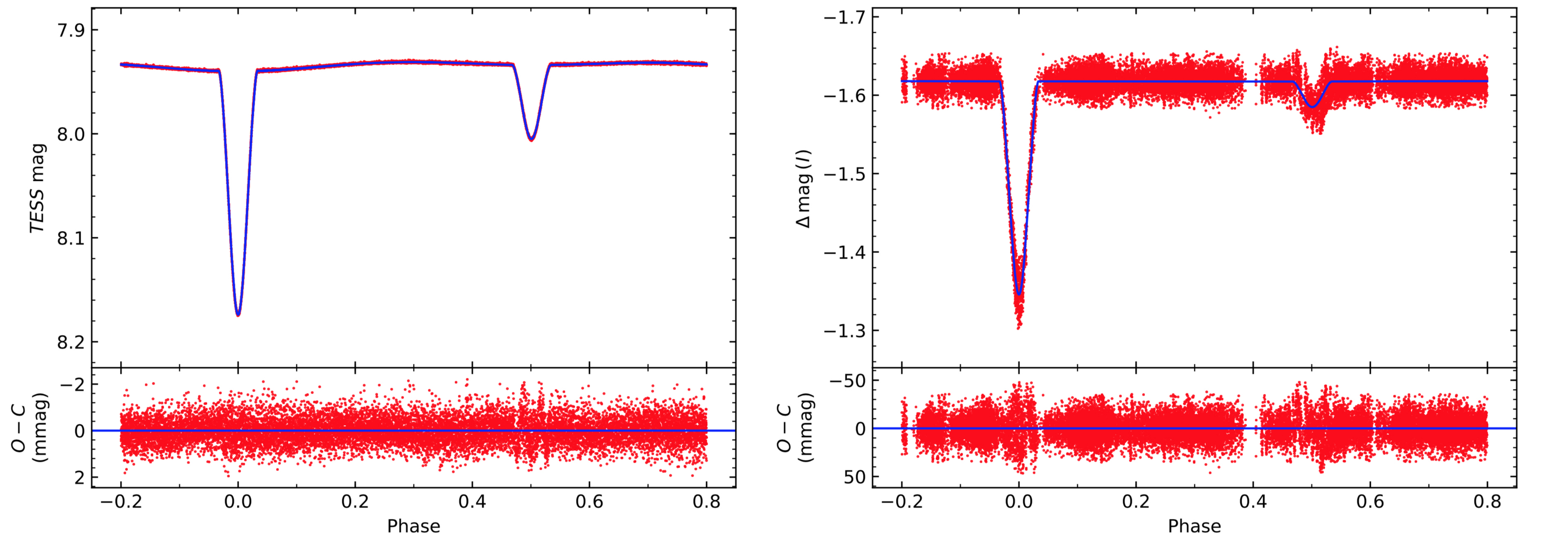

Figure 1: Phase-folded light curves of V1200 Cen from *TESS* (left) and Solaris in the *I* band (right)

Comparison with stellar models

In order to determine the age of the two stars Aa and Ab, we generated a set of isochrones using a dedicated web interface based on the Modules for Experiments in Stellar Astrophysics (MESA; see [5]). We considered in this work only the case of non-rotating stars ($v/v_{\rm crit} = 0$). For both stars, we first adopted the solar mixture from [6], which corresponds to $Y_{\odot,\rm ini} = 0.2703$ and $Z_{\odot,\rm ini} = 0.0142$. We then searched for the isochrone that best matches the observed parameters (R, M, $T_{\rm eff}$) of each star. Following the previous study of [4], we selected isochrones with ages lower than 30 Myr.

The comparison between the observed parameters from our analysis of V1200 Cen and the predictions from MESA isochrones is shown in Fig. 3. For star Aa, we found that the parameters R, M and $T_{\rm eff}$ match well the 18.5-Myr isochrone within their 1σ error bars, assuming a solar metallicity. For star Ab, we did not find an isochrone that simultaneously matches these parameters when assuming a solar metallicity. In particular, the predicted $T_{\rm eff}$ value is underestimated by about 400 K for the best-matching isochrone. The effect of changing the metallicity was then investigated. Finally, we found an isochrone that matches the different parameters for an age of 7 Myr and a metallicity of $[{\rm Fe/H}]_{\rm ini} = -0.45$ (i.e. $Y_{\rm ini} = 0.2568$ and $Z_{\rm ini} = 0.0052$), as shown in Fig. 3. Furthermore, the precision on the derived parameters allowed us to distinguish between isochrones with an age difference of 1 Myr.

We have also fitted the two stars using the CESTAM stellar evolution code [7]. We obtained a good agreement between MESA and CESTAM models. In particular, individual ages are found to be 16–18.5 Myr and 5.5–7 Myr for stars Aa and Ab, respectively.

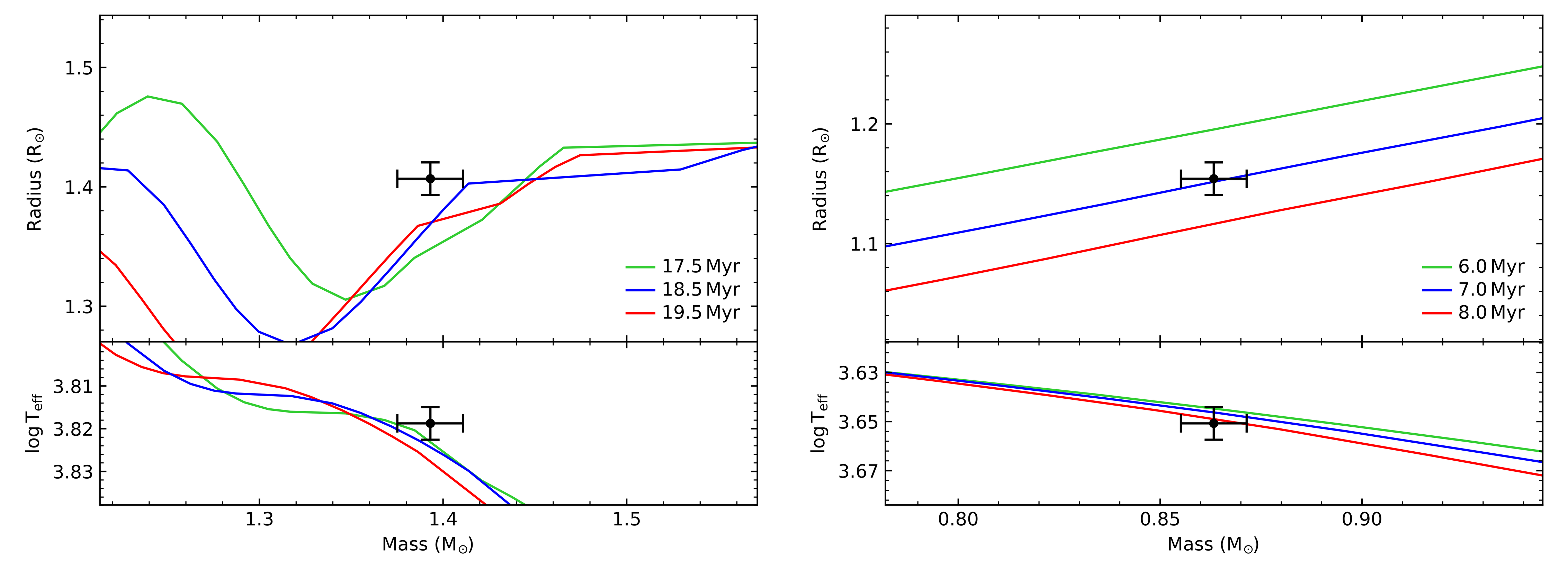

Figure 3: Comparison between the observed parameters of V1200 Cen and the predictions from MESA isochrones

Third body in the spectra

During the RV calculations, we have not noticed any prominent third peak in the cross-correlation functions, nor in the TODCOR maps. In order to verify this, we used the formalism of Broadening Function (BF; see [8]), and applied it to five CHIRON spectra that have the highest S/N. As a template, we used a spectrum of $T_{\rm eff} = 5200$ K, $v_{\rm rot} = 20\,{\rm km\,s^{-1}}$ generated with ATLAS9. A single BF was generated for each of the Echelle orders, and all the single-order BFs were then added in velocity domain, forming the final BF for a given observation. Additionally, we have calculated the expected RVs of the third star, if it had a mass of $0.871\,M_\odot$ (lower limit of mass, corresponding to the lowest flux contribution). Finally, to check if our approach would recover a small third-light flux, we took one of the spectra (from 2019 August 22) and injected artificial signals at the level of 1 and 3 per cent of the combined brightness of the inner binary.

Two strong peaks, coming from the primary and secondary components, are clearly visible at positions corresponding to their RVs measured with TODCOR. However, no prominent third peak can be seen at positions expected for a $0.871\,M_\odot$ single star. One can also see that the 3 per cent additional signal is easily detectable, and the 1 per cent signal produces a distinctive peak as well. We therefore conclude that in our CHIRON spectra we would be able to detect the third light of at least 1 per cent level, and that a single star as massive as the secondary is not visible.

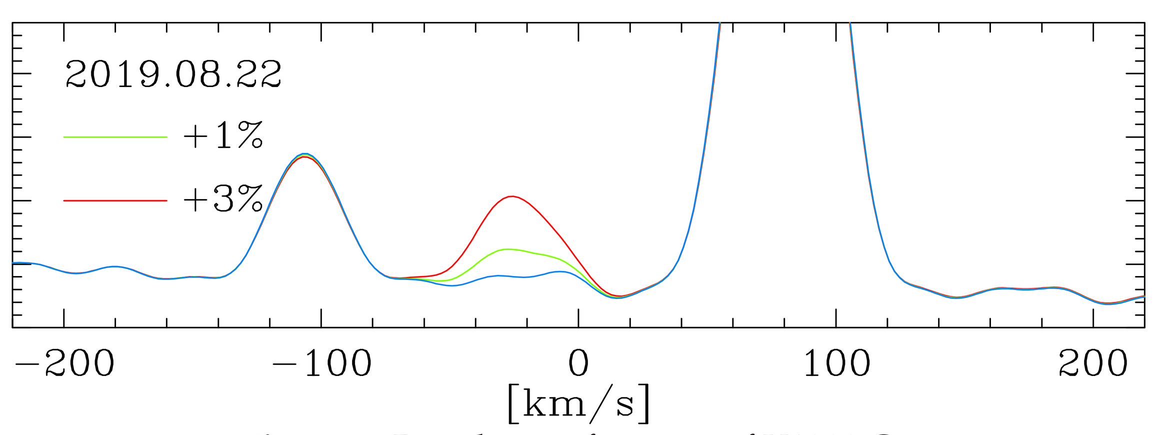

Figure 4: Broadening function of V1200 Cen

Summary

The aim of this work was to perform a new analysis of V1200 Centauri, a multiple-star system that contains a close eclipsing binary. Thanks to the additional measurements from CHIRON, we derived a new orbital solution assuming an outer period of 180.4 d, instead of 351.5 d, and a minimum mass for the third body of $0.871 \pm 0.020\,M_\odot$. A consequence of this result is that the third body is actually a binary system with two low-mass stars that are not detectable from our observations. V1200 Centauri is thus a quadruple-star system consisting of two close pairs orbiting each other with a 180-d period.

We also determined the ages of each eclipsing component using two evolution codes, namely MESA and CESTAM. We obtained ages of 16–18.5 Myr and 5.5–7 Myr for the primary and the secondary, respectively. In particular, the secondary appears larger and hotter than that predicted at the age of the primary. Finally, we concluded that dynamical and tidal interactions occurring in multiples may alter the stellar properties and explain the apparent non-coevality of V1200 Centauri.

References

[1] F. Marcadon et al. *MNRAS*, 499:3019–3033, 2020.

[2] S. K. Kozłowski et al. *PASP*, 129:105001, 2017.

[3] J. Southworth et al. *MNRAS*, 351:1277–1289, 2004.

[4] J. Coronado et al. *MNRAS*, 448:1937–1944, 2015.

[5] B. Paxton et al. *ApJS*, 234:34, 2018.

[6] M. Asplund et al. *ARA&A*, 47:481–522, 2009.

[7] J. P. Marques et al. *A&A*, 549:A74, 2013.

[8] S. M. Rucinski. *AJ*, 124:1746–1756, 2002.

Contact Information

Web www.camk.edu.pl/en/staff/fmarcadon/
Email fmarcadon@ncac.torun.pl
Phone +33 (0)6 07 63 18 40