New Stellar Companion To Exoplanet Host Binary Star WASP 3 AB

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Abstract: This work reports the discovery of a new wide (ρ = 18.33”) stellar companion, with common proper motion and common parallax to WASP-3 AB exoplanet host binary star (WSP 3 AB = WDS 18345+3540). This system is located at about 235-240 pc. The new companion is a weak star (mag. V = 14.1) of spectral type K5V separated about 4330 AU of AB. VOSA, a Virtual Observatory tool for spectral energy distribution fitting was used to characterize the astrophysics of the new component. From Gaia DR2 astrometric data, the relative and projected velocity of the new companion with respect to WSP 3 AB was calculated. This relative velocity is greater than the escape velocity but the hypothesis of background and no-moving object can be rejected with extremely high significance. Gaia DR2 don’t list B component and likely the astrometry for the main stellar component be affected by binarity.

1 Introduction

At the moment of writing this work more than 4296 exoplanets have been discovered in 3175 planetary systems. Some of them are composed of more than one star, that is, are binary or multiple systems. One of the exoplanet host binary system is WASP 3 (see Figure 1) listed in WDS catalog as WSP 3 AB (= WDS 18345+3540 AB) and composed of stars with K magnitude of 9.36 and 15.93 separated by only 1.2”.

In this work, I report the discovery of a third wide (ρ = 18.33”) stellar companion of K5V spectral type with common proper motion and common parallax. To characterize this new component, I used Virtual Observatory (VO) techniques. The VO is “an international initiative designed to provide the astronomical community with the data access and the research tools necessary to enable the exploration of the digital, multi-wavelength universe that is resident in the astronomical data archives.”

I took advantage of the accurate proper motions of the European Space Agency’s Gaia mission Second Data Release (DR2) archive (Lindegren et al. 2018; Arenou et al. 2018).

This new companion was briefly reported in the Double Star Information Circular num. 198 (June 2019) of Commission G1 of International Astronomical Union (IAU). But here I publish for the first time many astrophysical and dynamical data.

In Section §2, I present the close pair WSP 3 AB and estimate for the first time the spectral type of the B component and the minimum orbital period. In Section §3, I detail the astrophysical characterization of WASP 3 C using VOSA and other procedures. New astrometric measures are detailed in Section §4. In Section §5, I describe the dynamical study of C with respect to AB.

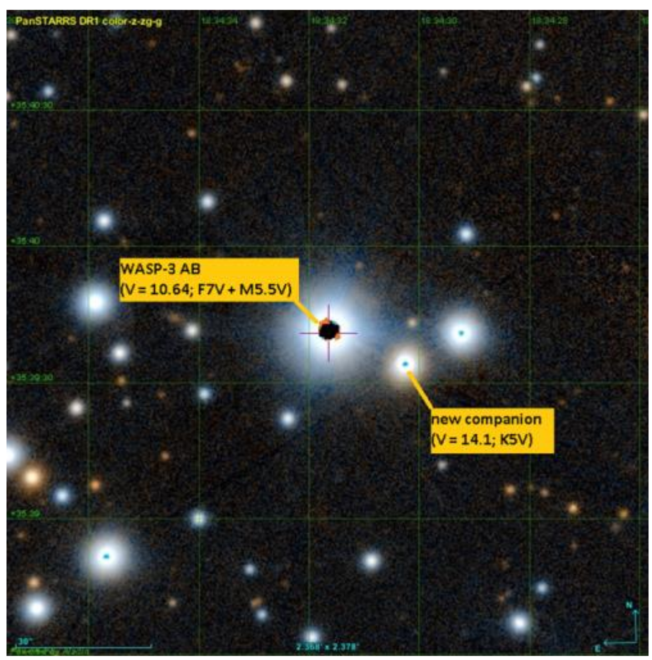

Figure 1: WASP-3 and the new weak companion (PanSTARRS DR1 image). Image obtained using Aladin Sky Atlas.

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2 The Close Binary WASP 3 AB

Ngo et al. (2015) using the 9.8 m Keck II telescope, discovered in 2012.42 a low mass (0.108 ± 0.006 $M_\odot$) and weak companion to WASP 3 A at 1.19 arcsec (285.4 ± 0.7 AU) of separation. They performed high quality measurements (errors of about 1.5 mas) in 2012.57 and 2013.41. Nog et al. determined that WASP 3 AB is a common proper motion system and estimated the apparent magnitude in JHKs bands of B component.

Gaia satellite does not list the B component in Data Release 2 (DR2). This is not unusual. Arenou et al. (2018) determined that only a small fraction of sub-arcsecond pairs were resolved. And the angular separation of AB, 1.19", is near this limit. Maybe in the final release of the Gaia catalog, B may be listed.

From Gaia DR2 parallax of the A component, the JHKs absolute magnitudes for B was calculated matching with a M5.5V star. This is the first time the spectral type of B component is published in the literature. Assuming a face-on (i = 0 deg) and circular (e = 0) orbit, an orbital period of 4,169 years was calculated which correspond to a change in positional angle of 0.09 deg yr^{-1} approximately. For an edge-on orbit, the separation will change up to 1.8 mas yr^{-1}. No significant relative motion detected.

If the relative astrometry is corrected by atmospheric refraction, only angular distance will be affected and it must be increased by 1 mas.

3 Characterizing the New Stellar Companion WASP 3 C

The exoplanet host binary star WASP-3 AB (F7V + M5.5V, mag. V = 10.64) has a new weak companion (V = 14.1) located at 18.33 arcsec (4330 AU at the distance of the system). Figure 1 shows the position of this new companion. The system is located at about 237 pc. The reddening in the line of sight was estimated using the maps of Schlafly and Finkbeiner (2011). The resulting values were scaled to the initial distance using the formula published by Anthony-Twarog, and Twarog (1994). In this work, a reddening of Av = 0.08 was calculated

The VO Spectral energy distribution Analyzer (VOSA[2]; Bayo et al. 2008) tool was used to derive astrophysical properties of WASP 3 C from fits of the observed spectral energy distributions to theoretical models. Apart from the CMC14 (band *r*) and 2MASS (bands J, H and K_s; Skrutskie et al. (2006)) photometric data, I also used those of the Wide-field Infrared Survey Explorer (bands W1–4; WISE, Wright et al. (2010)), Gaia DR2 (bands G, G_{Bp} and G_{Rp}) and Pan-Starrs PS1 (bands *g, r, z, i, z, y*; Flewelling et al. (2016), Chambers et al. (2016)). In total 15 photometric points which 14 were used in the fits (*W4* band is an upper bound value and was rejected).

In VOSA, we used the BT-Settl theoretical models (Allard 2012) in the fitting procedure (using minimization χ^2) between 4200 and 4700 K in T_{eff} and between 4.0 and 5.0 in log g for solar metallicity. The uncertainty in the best fit was the size of the grid, which was of 50 K in T_{eff} and 0.25 in log g. Anyway, the VOSA log g values have to be taken with caution and refined using other indicators. The results of the fits was T_{eff} = 4400 ± 50 K, log g = 4.5 ± 0.25 and R = 0.82 ± 0.02 $R_\odot$. T_{eff} and stellar radius is in very good agreement with Gaia DR2 (Teff = 4441^{+380}_{-173} and R = $0.76^{+0.07}_{-0.10}$ $R_\odot$).

Figure 2 plots the spectral energy distribution (SED) for WASP 3 C obtained with VOSA. Figure 3 plots the result of the BT-Settl fit over plotting a theoretical spectrum.

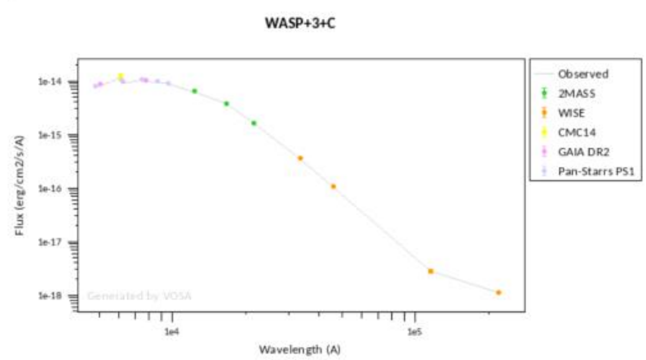

Figure 2: SED for WASP 3 C obtained with VOSA.

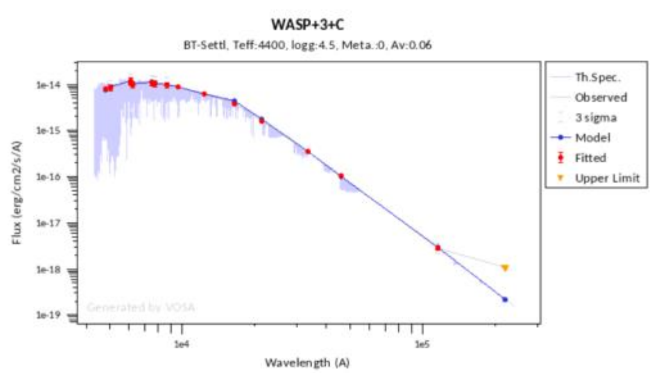

Figure 3: BT-Settl fit of WASP 3 C over plotting a theoretical spectrum.

[1]Combined V magnitude obtained from Tycho-2 catalog and converted to standard system.
[2]http://svo2.cab.inta-csic.es/theory/vosa/

VOSA allows performing a template fit to obtain the spectral type. In this work, I use the empirical template library of stellar spectra of Kesseli et al. (2017). In this case the fit used only fits five observational points toward the bluest part of the SED. The spectral type resulting is K5V.

Table 1 lists all the astrophysical data for AB and C components obtained in the astronomical literature or in this work. For the Gaia parallax and distance I took into account the systematic offset of -0.03 mas (Lindegren et al. 2018). This value is the mean offset but the exact offset for a combination of magnitude, colour, and position may be different by several tens of µas. For this reason I add quadratically the mean offset to the parallax listed by Gaia.

I also estimated the spectral type using other procedures. The Pan-STARRS colors (transformed to *B, V, I* standard photometry using the transformation of Kostov & Bonev (2017)) and 2MASS photometry (see Table 1) were also used to obtain a spectral type K5V. The procedure used consisted in compare the *V* magnitude and the *B* - *V, V* - *I, J* - *H* and *H* - *K* colors (taken into account their errors) for WASP 3 C component with those listed in the Mamajeck table (Version 2019.3.22)[3]. The entry of the table with a minimum χ^2 was chosen. An excel tool designed by the author was used.

Other nearly independent method use V magnitude for WASP 3 C and Gaia DR2 parallax to obtain a V absolute magnitude of +7.12 ± 0.05 which matches with a K4V spectral type. In addition to this, using the effective temperature listed in Gaia DR2, a spectral type of K5V is also estimated. In both methods, Mamajeck table is used. In this work a spectral type K5V was adopted for WASP 3 C.

Again using the Mamajeck table, a stellar mass of 0.76 solar mass was estimated. This is the first time in the literature that astrophysical parameters for WSP 3 C are published.

4 New Astrometric Measurements

Since the new C component was reported for the first time (Rica 2019) USNO catalogued this new companion and add a few astrometric points. Table 2 list WDS astrometric points and detail the observational epoch, the position angle and distance, the magnitudes, the observed number of nights (column "n"), the reference of the publication, the aperture of the telescope (in meter) and finally the source. The first astrometric point listed in WDS was obtained using the POSSI-O photographic plate taken in 1950. With the objective to improve the quality of this measure I used the REDUC software, programmed by the French astronomer Florent Losse. This software is widely used by the nonprofessional double star community and in the normal mode REDUC obtains very good centroid calculation even for bad shaped and overexposed stars, like those relatively bright stars on POSS photographic plates. My measurement (246.0 deg and 17.90") is significantly closer to modern measures than the measure reported by Damm (2019) in a private communication to USNO using the old POSS-O plate. The last astrometric point was obtained by the author using the coordinates of Gaia DR2 catalog.

5 Dynamical Study of the New Component C

From the astrometric data of Gaia DR2 a relative motion of 2.07 ± 0.07 mas yr^{-1} (2.32 ± 0.08 km s^{-1}) of the new companion with respect to WASP-3 AB was determined. This is 9% of the total proper motion suggesting a common proper motion nature. From spectral types and stellar masses, an escape velocity (assuming face-on and circular orbit) of 0.80 km s^{-1} was calculated. As the relative motion is clearly greater than escape velocity I cannot conclude a gravitational relation between AB and C. But we have to take into account that Gaia did not detect component B and therefore the satellite measured the astrometric solution of the AB photo-center. This photo-center will orbit around the AB center of mass of several thousand years. The quality astrometric parameters of Gaia (ASTROMETRIC_EXCESS_NOISE and RUWE) show no problem in the astrometric fit for AB while for the new component, the RUWE = 1.74 (higher than the limit of 1.4 propose by Lindegren) indicating a possible problem in the Gaia astrometric reduction. Although the ASTROMETRIC_EXCESS_NOISE = 0.17 mas indicates no problem in Gaia astrometry solution.

From historical astrometric points the separation (ρ) seems to increase in 2.4 ± 0.6 mas yr^{-1} while no significant change was observed for position angle. The relative motion is of 2.8 mas yr^{-1} (in agreement with that obtained using Gaia data) with a significance less than 2σ.

From the stellar masses and the differential magnitude of A and B stellar components, I calculated that the center of mass is located at 0.10" from A while the photo-center is at 0.001-0.003" (depending if J, H, Ks band is used) from A. Therefore the distance between center of mass and photo-center is about 0.097". In summary, the astrometric solution of AB listed in Gaia DR2 could be significantly altered.

[3] http://www.pas.rochester.edu/~emamajek/EEM_dwarf_UBVIJHK_colors_Teff.dat. Most of the content of this table was incorporated into Table 5 of Pecaut & Mamajek (2013).

	AB	C	Reference
Designations	WASP 3 BD+35 3293	UCAC4 629-058739	
α_{2000}	18h 34m 31.618s	18h 34m 30.246s	Gaia DR2
δ_{2000}	+35° 39′ 41.15″	+35° 39′ 33.64″	Gaia DR2
V	+10.64 ± 0.06 [a)]	+14.07 ± 0.04 [d)]	
B – V	+0.41 ± 0.07 [a)]	+1.12 ± 0.06 [d)]	
V – I	…	+1.40 ± 0.06 [d)]	
G	+10.453	+13.604	Gaia DR2
J	+9.60 ± 0.02	+11.76 ± 0.02	2MASS
H	+6.41 ± 0.01	+11.20 ± 0.02	2MASS
K	+6.36 ± 0.02	+11.06 ± 0.02	2MASS
$\mu(\alpha)$ [mas yr $^{-1}$]	-6.07 ± 0.04	-7.39 ± 0.04	Gaia DR2
$\mu(\delta)$ [mas yr $^{-1}$]	-21.75 ± 0.05	-23.34 ± 0.06	Gaia DR2
Spectral type	F7V + M5.5V [c)]	K5V [c)]	
Parallax [mas]	4.30 ± 0.04	4.17 ± 0.04	Gaia DR2
Distance [pc]	232.7 ± 2.3	239.8 ± 2.4	
Radial Velocity [km s^{-1}]	-4.40 ± 0.36	…	Gaia DR2
[Fe/H]	-0.06 ± 0.08	…	Torres et al. (2012)
Mass [M☉]	1.20 ± 0.01 [e)] 1.26 ± 0.10 [b)]	0.76 [c)]	
Radius [R☉]	1.30 ± 0.07 [e)]	0.82 ± 0.02 [c)]	
Teff [K]	6486 ± 50 [f)]	4441^{+380}_{-173} [e)] 4400 ± 50 [c)]	
Log g	4.27 ± 0.02 [b)]	4.5 ± 0.25 [c)]	

Notes. a) From Tycho-2 transformed to standard system; b) Santos et al. (2013); c) This work; d) obtained transforming Pan Starrs photometry to standard system using the transformation of Kostov & Bonev (2017); e) Knutson et al. (2014); e) Gaia DR2; f) Stevens et al. (2017).

Table 1: Astrophysical data for the components of WASP 3 system WSP 3 (= WDS 18345+3540).

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Epoch	θ [°]	σ ["]	mg. A	mg. B	n	Author	Aperture	Source
1950.452	247.9	17.31			1	Dam2019m	1.2	POSSI-O
1950.450	246.0	17.90			1	RICA	1.2	POSSI-O
1989.512	245.9	18.20			1	RICA	1.2	POSSII-J
1991.532	245.4	17.92			1	RICA	1.2	POSSII-J
1998.3	245.9	18.36	9.603	11.755	1	TMA2003	1.3	2MASS
2001.68	245.8	18.31			1	Dam2019m	0.2	
2002.53	245.8	18.30	10.51	13.76	4	UC_2013a	0.2	UCAC4
2010.5	246.0	18.27			1	Dam2019m	0.4	WISE
2015.5	245.8	18.33			1	Fmr2019c	1.0	Gaia R2

Table 2: Astrometric data for WASP AB-C .

If the new component be a background and nomoving object, the relative motion with respect to AB would be of 22.57 ± 0.07 mas yr-1 therefore it can be rejected the background object hypothesis with a significance of 215 σ.

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References

Allard et al,. 2012, RSPTA 370. 2765A

Anthony-Twarog B. J., Twarog B. A. 1994, AJ, 107, 1577.

Arenou F. et al., 2018, A&A, 616, A17

Bayo A., Rodrigo C., Barrado y Navascués D., Solano E., Gutiérrez R., Morales-Calderón M., Allard, F., 2008, A&A 492,277B.

Chambers et al., 2016, arXiv: 1612.05560

Damm, F., private communication, email #219, 2019

Flewelling et al., 2016, arXiv: 1612.05243

Kesseli et al. 2017, ApJS, 230, 16K

Knutson H.A., Fulton B.J., Montet B.T. et al., 2014, ApJ, 785, 126K

Kostov, A. & Bonev, T,. 2017, Transformation of Pan-STARRS1 gri to Stetson BVRI magnitudes. Photometry of small bodies observations. Bulgarian Astronomical Journal, 28.

Lindegren L. et al., 2018, A&A, 616, A2

Ngo et al., 2015, ApJ, 800, 138N

Pecaut & Mamajek, 2013, ApJS, 208, 9.

Rica, F. M., IAU Double Star Information Circular num. 198 (June 2019) of Commission G1.

Santos N. C., Sousa S. G., Mortier A. et al., 2013, A&A, 556A, 150S

Schlafly & Finkbeiner, 2011, ApJ, 737, 103

Skrutskie et al., 2006, AJ, 131, 1163S

Stevens D.J., Stassun K.G., Gaudi B.S., 2017, AJ, 154, 259S

Torres G., Fischer D.A., Sozzetti A. et al., 2012, ApJ, 757,161T

Wright et al., 2010, AJ 140, 1868W