Re-study of the stellar system WDS 18028-2705 = HLD 32 AB in the *Gaia* EDR3 era

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ABSTRACT

This paper reports a re-study of the system HLD 32 AB (= HD 164538), a pair of stars studied by the author in 2006 and composed of stars of 8.3 and 9.7 *V* magnitude separated by 5.2 arcsecs and located at 108 pc. *Gaia* EDR3 shows the stellar components with common parallaxes and proper motion. Our two independent dynamical studies using the *Gaia* astrometric solution and the WDS historical data conclude HLD 32 AB is gravitationally bound. The *Gaia* astrometric solution is not in agreement with the trend of the WDS historical data suggesting a possible detection of a submotion of an unresolved binary in A or B component.

Our astrophysical study using PARSEC isochrones determine the primary component could be evolved (F8/9 IV-V) and the secondary is a G1 V star. Tentative orbital solutions are presented using our dynamical result based on WDS data. Instantaneous positional vector (x, y, z) and velocity vector (Vx, Vy, Vz) are used.

1. INTRODUCTION

The *Gaia* satellite was launched by The European Space Agency (ESA) on December 19, 2013. It is an astrometric mission, which is a successor to the *Hipparcos* satellite (also launched by ESA). *GAIA* will produce a catalog of 1 billion stars (up to 20th magnitude) with an astrometric solution of 5 parameters (AR and DEC, proper motion, parallax and radial velocity). The accuracy of the astrometric data will be much greater than any existing catalog.

Gaia will publish its final results after the year 2024. Until then, intermediate data releases, with less accurate results, are being published. *Gaia* (GAIA Collaboration, 2018) EDR3 was published on 3 December 2020 reducing the astrometric errors of the earlier release (DR2) in a factor of two. The proper motion uncertainties are 0.02-0.03 mas yr^{-1} for G < 15, 0.07 mas yr^{-1} at G = 17, 0.5 mas yr^{-1} at G = 20, and 1.4 mas yr^{-1} at G = 21 mag. The parallax uncertainties are 0.02 - 0.03 mas for G < 15, 0.07 mas at G = 17, 0.5 mas at G = 20, and 1.3 mas at G = 21 mag.

Future missions as DR3 will be published in June 2022. The full data release for the five-year nominal mission, DR4, will include full astrometric, photometric and radial-velocity catalogues, variable-star and non-single-star solutions, source classifications plus multiple astrophysical parameters for stars, unresolved binaries, galaxies and quasars, an exo-planet list and epoch and transit data for all sources. Additional releases will take place depending on mission extensions. Most measurements in DR4 are expected to be 1.7 times more precise than DR2; proper motions will be 4.5 times more precise.

In this work, I report a re-study of the system WDS 18028-2705 = HLD 32 AB (= HD 164538) a pair of stars in the Sagittarius constellation with 8.3 and 9.7 *V* magnitudes separated by 5.2 arcsecs at a distance of 108.3 ± 0.5 pc (*Gaia* EDR3). This pair was studied by Rica (2006) and published in this magazine 16 years ago. In this study, based on the small relative motion of the secondary star with respect to the primary star, I conclude the probably physical nature and likelihood of the binary nature of the primary star.

In Section §2, I present the binary HLD 32 AB. In Section §3, I detail the astrophysical characterization performed using data from the astronomical literature and evolutionary isochrones. A dynamical study of B with respect to A is detailled in Section §4. In Section §5, I describe the orbital calculation method and present tentative orbital solutions.

Figure 1. Image of HLD 32 AB obtained by Antonio Agudo Azcona in 2019 using a 0.2 m telescope.

2. THE BINARY STAR HLD 32 IN THE LITERATURE

Binary star HLD 32 AB is composed of stars with 8.3 and 9.7 V magnitudes, separated by 5.2 arcsecs at a distance of 108.3 ± 1.0 pc[1] (*Gaia* EDR3). Figure 1 shows this stellar system imaged by Antonio Agudo Azcona from Badajoz (Spain) using a 0.2 m telescope. It was discovered in 1881 by Burnham (1882) when he was working in the Washburn Observatory using a 15.5" telescope (the 3rd largest of the USA in this epoch). The designation HLD of this double came from the astronomer E. S. Holden, the director of the Washburn Observatory at this time. Since then, HLD 32 AB has been measured on 19 occasions, the last one in 2019 (Azcona 2020).

The mean proper motion of this pair is 51 mas yr^{-1} and no significant change in position has been observed.

The stellar components of this pair are very poorly studied. Cannon & Pickering (1918-1924) lists the brighter star as a G0 star while Houk (1982) classified it as a F7V spectral type, probably for the primary component. No bibliographic source was found where the individual spectral types and other atmospheric parameters were published. In the next section, they will be determined for the first time. *Gaia* EDR3 lists good astrometric solutions for both stars (RUWE of 0.94 and 1.15) and the 2MASS project observed both stellar components in JHK photometric bands.

A wide component with a magnitude of $V = 12.63$ (estimation based on Gaia photometry), called C, is listed in the WDS catalog at 41.9 arcsecs in direction 67 deg from the primary component. It was discovered in 1909 by the astronomer Fox (1915). Since then only two astrometric points are listed (using photographic plates of 1913 and digital images from the 2MASS project) and it is a background component with no physical relation with AB components.

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[1] Average of the distance for A and B components. The error is calculated as the half of the difference in the distance of A and B.

3. STUDYING THE ASTROPHYSICS OF THIS SYSTEM

This is a difficult system to study because of the angular separation, which is not close enough to observe the combined photometry and not wide enough to clearly separate both stellar components in the photometric images.

The *Gaia* EDR3 catalog (Gaia Collaboration et al. 2016, 2020) lists HLD 32 AB as a common proper motion (relative motion of about 11% of the total proper motion) and parallax within the error margins suggesting a physical nature for this pair.

For the primary, literature lists the Tycho-2, 2MASS and *Gaia* photometry, that is, in total 8 photometric bands (*B*, *V*, *J*, *H*, *K*, *G*, *BP*, *RP*). The secondary is not listed in the Tycho-2 catalog but we do have 2MASS and *Gaia* photometry.

Before estimating astrophysical properties, it is important to determine the interstellar reddening to correct the observed photometry. The low galactic latitude of this system (-2.3 deg) could suggest a significant reddening. Ruiz-Dern et al. (2018) determined a maximum value for E(B - V) of 0.0136 magnitude. In this article we use the web ***Stilism : STructuring by Inversion the Local Interstellar Medium***[2] to obtain a E(B - V) = 0.018 (Av = 0.07)[3]. This map produces tridimensional maps of the local InterStellar Matter (ISM) based on Lallement et al. (2014). The current map is based on the inversion of reddening estimates towards 71,000 target stars. For measurements of starlight absorption by dust (reddening effects) or gaseous species (absorption lines or bands), see Lallement et al. (2014) and Capitanio et al. (2017)

The effective temperature ($T_{\rm eff}$) inferred using the colors of the stellar components yields a temperature of 6000-6100 K for the primary star and about 6000 K for the secondary. The Mamajeck table were used. Table 1 lists the details with unreddening colors.

Table 1.
Effective temperature for HLD 32 AB

Primary		
Color	Value	$T_{\rm eff}$ [K]
(B – V)o	+0.54 ± 0.03	6100 ± 150
(Bp – Rp)o	+0.71 ± 0.01	6100 ± 50
(J – K)o	+0.32 ± 0.03	5950 ± 150
(V – K)o	+1.39 ± 0.04	5970 ± 50
Secondary		
Color	Value	$T_{\rm eff}$ [K]
(Bp – Rp)o	+0.77 ± 0.01	6000 ± 50
(J – K)o	+0.32 ± 0.12	5950 ± 700
(V – K)o	+1.91 ± 0.11	5300 ± 200

The $T_{\rm eff}$ - color calibration of Ramírez & Melendez (2005) yields $T_{\rm eff}$ of 6200K and 6000/6100 K for the primary and secondary components, in excellent agreement with our data.

To determine the fundamental astrophysical parameters for both stellar components, I used CMD 3.3 evolutionary isochrones[4] online tool based on PARSEC release v1.2S + COLIBRI S_35 (Bressan et al. 2012, Chen et al. 2014, 2015, Tang et al. 2014, Marigo et al. 2017, Pastorelli et al. 2019). The B - V color and V magnitude for A[5] and B were used and a 3.0 Gyr isochrone gives the best fit. As the secondary star is not listed in Tycho-2 catalog, I transformed the *Gaia* photometry to the standard system (B - V and V photometry) using the formulae (1) of Tokovinin & Briceño (2020) and using the Data Gaia Release Documentation (section 5.3.7)[6]. In addition to the B - V color, $T_{\rm eff}$ were also used

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[2] https://stilism.obspm.fr/

[3] In my old study of 2006 I estimated a reddening of E(B-V) = 0.07 significant higher than my modern result based in the Paresce maps published in 1984.

[4] The isochrones used were obtained using CMD 2.7 interface (http://stev.oapd.inaf.it/cgi-bin/cmd).

[5] The B_t and V_t photometric data of the Tycho-2 catalog (transformed to standard system) were used for the primary component.

[6] https://gea.esac.esa.int/archive/documentation/GDR2/Data_processing/chap_cu5pho/sec_cu5pho_calibr/ssec_cu5pho_PhotTransf.html

independently obtaining very similar results as is expected. Figure 2 and Figure 3 show the positions of both stellar components with solar metallicity evolutionary isochrones for different ages where it can be seen that the primary star is slightly evolved. Table 2 shows the fundamental parameters for the stellar systems obtained using the evolutionary isochrones. Spectral types of F8/9 IV-V and G1V were determined (in my old study of 2006 I determined spectral types of F6V and F7V).

Table 3 lists all the astrophysical data for A and B components obtained in the astronomical literature.

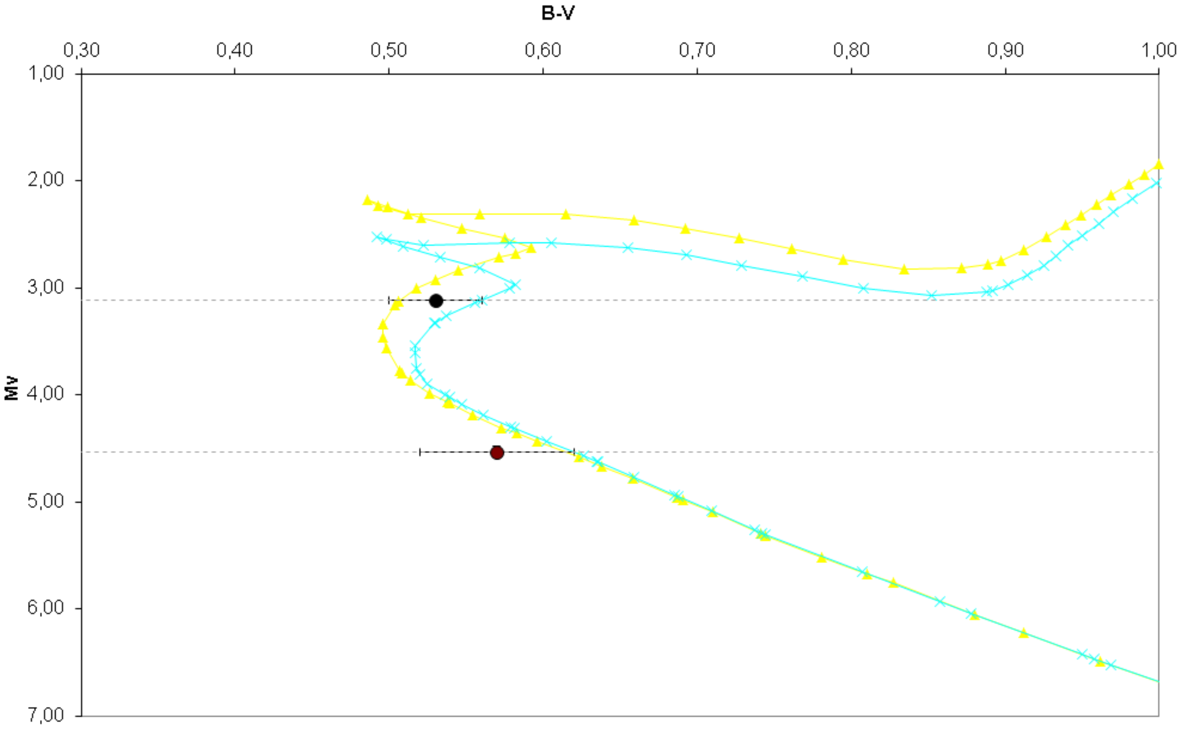

Figure 2. PARSEC isochrones of 2.8 Gyr (yellow) and 3.2 Gyr (blue) with the stellar components (solid points) of HLD 32 A,B. *B* - *V* colors were used.

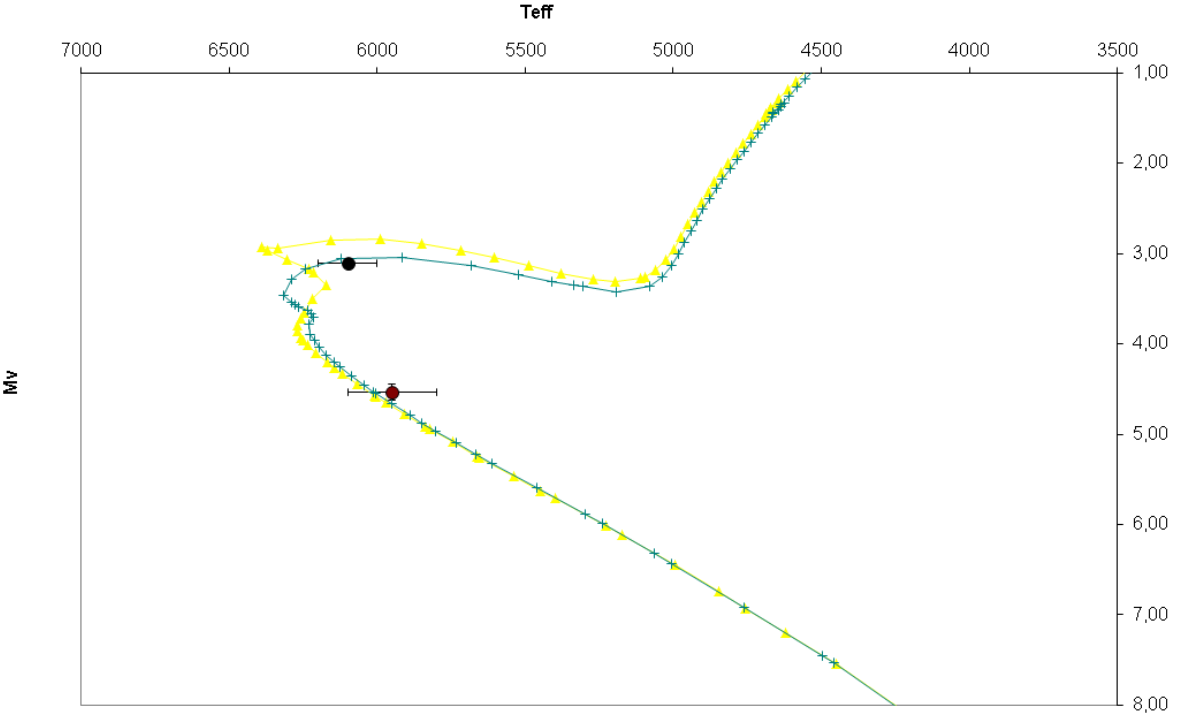

Figure 3. PARSEC isochrones of 3.6 Gyr (yellow) and 4.0 Gyr (green) with the stellar components (solid points) of HLD 32 A,B. T_{eff} were used.

Table 2. Astrophysical data for the binary HLD 32 AB

	comp. A	comp. B
*V*o	8.29	9.70
(*B* - *V*)o	0.54	0.62
Mv	3.11	4.53
Mass [M_{sun}]	1.30	1.06
T_{eff} [ºK]	6200	6025
log *g*	3.98	4.40
log L/L_{sun}	0.69	0.13
SpT	F8/9 IV-V	G1V
Distance [pc]	108 pc	
Age [Gyr]	3 - 4 Gyr	

Table 3. Astrophysical data for the components of HLD 32 AB (HD 164538) system

	A	C	Reference
V	+8.36 ± 0.02 [a)]	…	
B -*V*	+0.56 ± 0.02 [a)]	…	
G	+8.260 ± 0.003	+8.639 ± 0.003	*Gaia* EDR3
G_B -G_R	+0.730 ± 0.005	+0.790 ± 0.005	*Gaia* EDR3
J	+8.73 ± 0.02	+8.12 ± 0.08	2MASS
H	+6.97 ± 0.05	+7.77 ± 0.11	2MASS
K	+6.91 ± 0.02	+7.79 ± 0.09	2MASS

$\mu(\alpha)$ [mas yr $^{-1}$]	-48.97 ± 0.05	-51.63 ± 0.04	*Gaia* EDR3
$\mu(\delta)$ [mas yr $^{-1}$]	+7.18 ± 0.04	+11.51 ± 0.03	*Gaia* EDR3
Spectral type	F7V$^{b)}$		
Parallax [mas]	9.23 ± 0.05	9.14 ± 0.04	*Gaia* EDR3
Distance [pc]	107.3 ± 0.5	109.4 ± 0.4	*Gaia* EDR3
Radial Velocity [km s^{-1}]	…	-24.08 ± 0.63	*Gaia* EDR3

Notes. a) From Tycho-2 transformed to standard system; b) Houk (1982)

4 DYNAMICAL STUDY

From the astrometric data of *Gaia* EDR3 a relative motion of 5.08 ± 0.08 mas yr^{-1} (2.61 ± 0.03 km s^{-1}) for the secondary star with respect to the primary component of HLD 32 AB was determined. This relative motion is about 11 percent of the total proper motion suggesting a common proper motion. An escape velocity (assuming face-on and circular orbit) of 2.85 km s^{-1} was calculated and as the relative motion is lower, I conclude a possible gravitational relation between A and B.

The quality of astrometric parameters of *Gaia* (`ASTROMETRIC_EXCESS_NOISE` and RUWE) show no astrometric problem in the astrometric fit for A and B, RUWE of 0.94 and 1.15 (lower than the limit of 1.4 proposed by Lindegren).

In addition to the astrometric data listed in *Gaia* EDR3 catalog, the historical astrometric points of the WDS catalog (18 points in 138 years), see Table 4, were used to characterize the dynamic of the system.

Table 4. Astrometric points for HLD 32 AB

Epoch	θ [°]	σ ["]	mg. A	mg. B	n	Author	Aperture
1881.44	101.50	4.54	8	8.8	3	Bu_1882b	0.4
1888.52	99.10	4.83	8.4	9	3	Com1890	0.4
1898.3	98.80	5.22	.	.	1	See1927A	0.6
1906.51	99.40	4.79	8.4	9.5	3	Doo1915b	0.5
1909.97	99.60	5.12	.	.	5	Fox1915	1.0
1913.5	97.40	4.51	.	.	1	WFC1998	0.3
1925.41	101.20	4.99	.	.	1	Ol_1928	0.7
1929.66	99.50	4.81	.	.	4	Fen1932	0.5
1930.64	100.10	5.07	.	0.8	3	Ol_1939	0.5
1937.56	99.70	4.95	.	.	1	Vat1939	0.4
1940.26	100.60	5.11	8.3	9.3	5	B__1948	0.7
1962.6	100.80	5.08	10	10.4	2	Knp1963	0.7
1979.293	100.68	5.24	.	.	6	vAd1985	0.6
1998.21	100.60	5.13	7.227	8.123	1	TMA2003	1.3
2001.549	100.00	5.20	.	.	6	FMR2001	0.3
2001.635	99.60	5.20	.	.	1	Bvd2003	0.1
2015.5	100.58	5.26	8.248	9.631	1	ElB2018	1.0
2019.5566	100.50	5.20	.	.	1	Azc2020a	0.2

The dynamical analysis based on the WDS historical measures are listed in the Table 5.

Table 5. Dynamic parameters for HLD 32 AB

Data	Value
Mean Epoch	1950.498
θ (deg)	100.09 ± 0.13
ρ (arcsec)	5.090 ± 0.042
x (AU).[E-W]	542.9 ± 2.5

y (AU).[N-S]	-96.6	±	0.4
dθ/dt (mas yr^{-1})	+2.66	±	0.66
dρ/dt (deg yr^{-1})	+0.0076	±	0.0021
dx/dt (mas yr^{-1}).[E-W]	+2.57	±	0.64
dy/dt (mas yr^{-1}).[N-S]	-1.24	±	0.17
V_x (km s^{-1}).[E-W]	+1.32	±	0.33
V_y (km s^{-1}).[N-S]	-0.64	±	0.09
V_{tot} (km s^{-1})	1.46	±	0.29
V_{esc_max} (km s^{-1})	2.78		

In my old study of 2006, I estimated a relative motion of +3 mas yr^{-1} in AR and -2 mas yr^{-1} in DEC in good agreement with my modern values (+2.6 ± 0.6 mas yr^{-1} in R.A. and -1.2 ± 0.2 mas yr^{-1} in declination).

Figure 4 and Figure 5 show the relative motion vs time in polar (θ / ρ) and rectangular (x / y) coordinates. The black line is based on the WDS historical measures and the red line is based on *Gaia* EDR3 astrometric solution. The relative motion obtained using the WDS historical measures is not in agreement with the relative motion based on *Gaia* EDR3 (dx/dt = -2.66 ± 0.06 mas yr^{-1} and dy/dt = +4.33 ± 0.05 mas yr^{-1}).

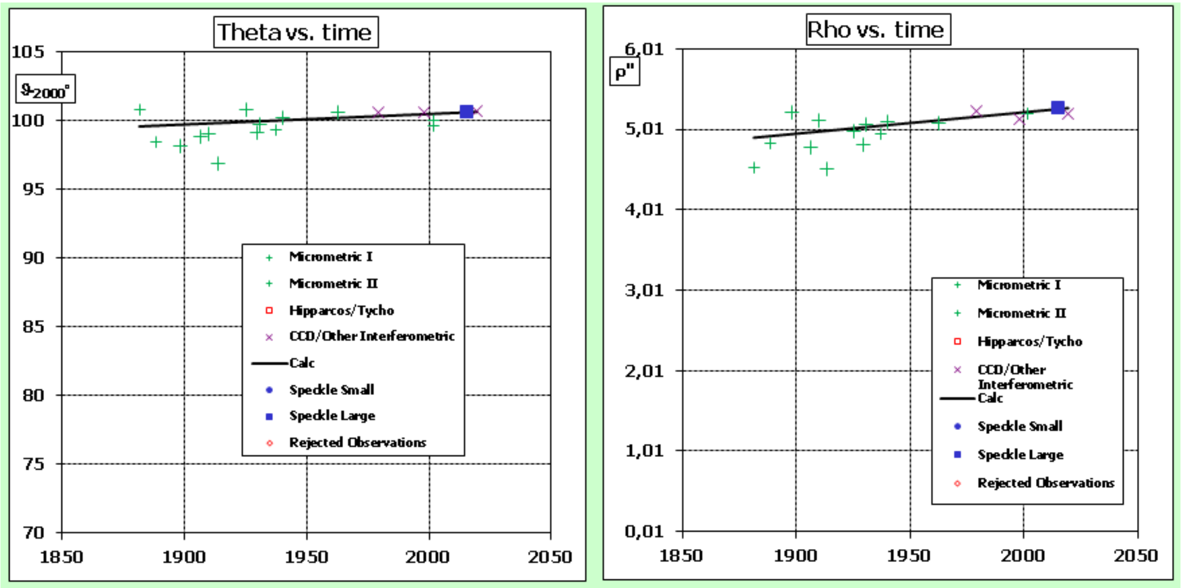

Figure 4. Relative motion of B with respect to A in polar coordinate (θ and ρ). The line is the astrometric fit using the WDS historical measures (points of different symbols).

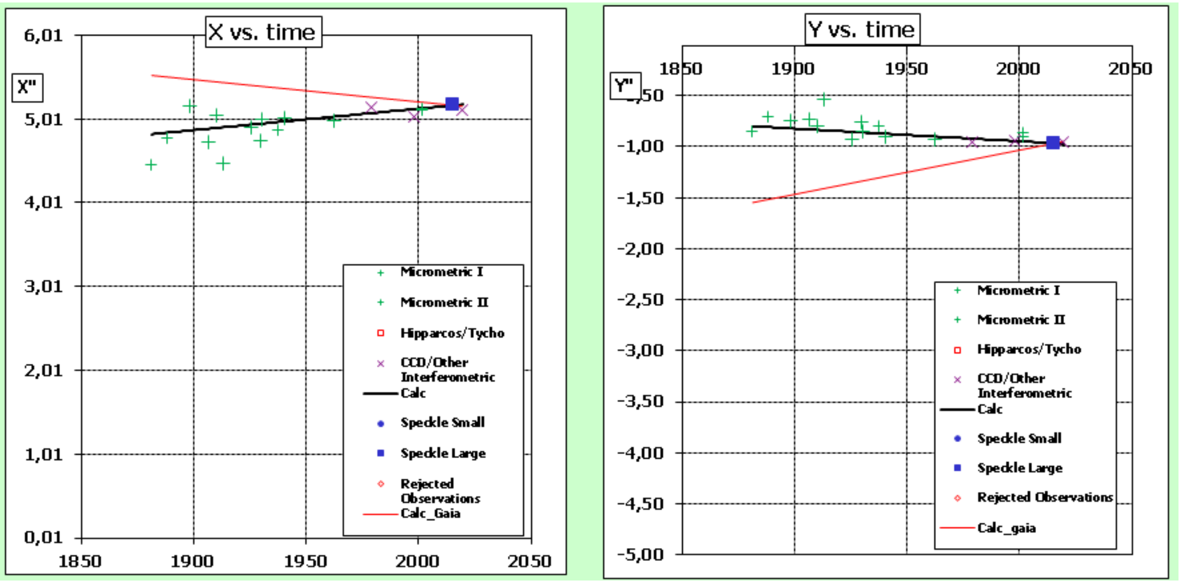

Figure 5. Relative motion of B with respect to A in rectangular coordinates, that is, R.A (X direction) and declination (Y direction). The black line is the astrometric fit using the WDS historical measures (points of different symbols). The red line is the *Gaia* EDR3 astrometric solution passing by the Gaia position in 2016.0.

As the WDS historical data covers about 138 years (*Gaia* data only cover a few years) the measures probably shows the motion of the center of mass of B with respect to A ($\Delta\mu,_{\mathrm{WDS}}$) and *Gaia* probably shows an additional orbital motion of an unresolved duplicity for A or B ($\Delta\mu,_{\mathrm{GAIA}}$), that is, the motion of A or B photocenter with respect to the AB center of mass, name it as Δμ(fc,cm), and can be calculated as

$$\Delta\mu(\mathrm{fc,cm}) = \pm\,(\,\Delta\mu,_{\mathrm{WDS}} - \Delta\mu,_{\mathrm{GAIA}}\,) \qquad (1)$$

In this work I calculated a Δμ(fc,cm) of ±5.2 mas yr^{-1} for R.A. axe and ±5.6 mas yr^{-1} for declination axis.

Other possible evidence hints to the possible unresolved nature is the V - K color of the secondary component yielding a cooler temperature (about 5300 K) than its colors J - K and B_p - R_p (about 6000 K). Could component B be an unresolved binary?

5 ORBITAL STUDY

Since HLD 32 AB is a gravitationally bound pair, it is possible to apply Newtonian mechanics to obtain orbital parameters using the method published in Hauser & Marcy (1999). This method uses the instantaneous positional vector (x, y, z) and velocity vector (Vx, Vy, Vz) in addition to the stellar masses and the parallax. Only the projection of positional and velocity vectors are known. That is, the line-of-sight z and V_z are unknown but their extremal or maximum values are known. This method obtains orbital solutions which always gives a dynamical total mass equal to the sum of the masses entered as inputs.

In this work I have used the dynamic parameters obtained based on the WDS historical measures. Among the possible orbits for $V_z = 0$ km s^{-1}, the smallest orbital period is of 5160 years (with an eccentricity of 0.97 and an inclination of 0 deg).

The Figure 6 shows two tentative orbital solutions for assuming $V_z = 0$ km s^{-1} , one for e = 0.70 and the other for e = 0.80.

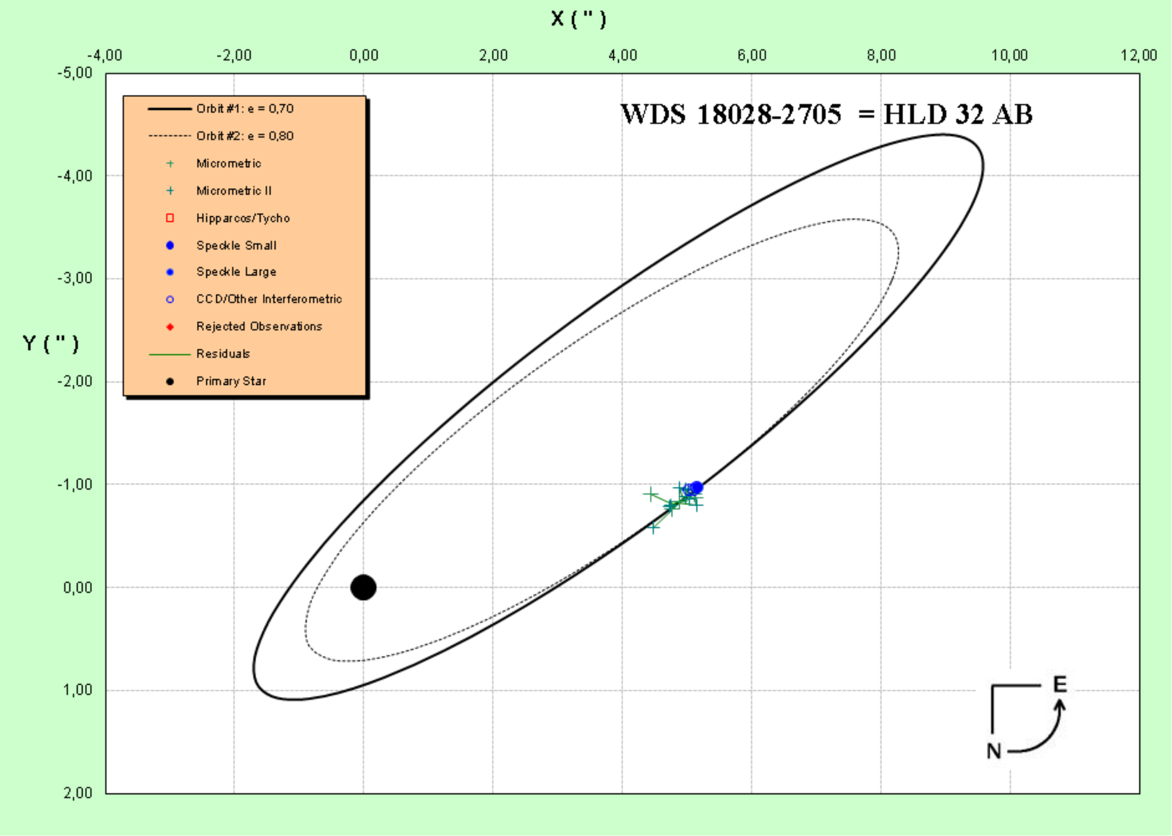

Figure 6. Tentative orbital solution of HLD 32 AB for $V_z = 0$ km s^{-1}. The dotted line is for e = 0.80 and the continuous black line is for e = 0.70.

The tentative orbital parameters are listed in the Table 6 only to allow the ephemeris calculation.

Table 6. Orbital parameters for HLD 32 AB

	e = 0.80	**e = 0.70**
P ^{yr}	8239.52	11319.75
To ^{yr}	451.21	-98.87
e	0.80	0.70
a "	5.04	6,23
i °	70.2	75.2
ω °	167.0	348.6
Ω_{2000} °	115.8	-64.2

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