Optical or Binary? An Investigation of 21 WDS Systems

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Abstract

Twenty-one WDS systems were analyzed using the Gaia Early Data Release 3 to determine if they are real binary star systems or chance optical alignments. The systems were chosen based on the following parameters: apparent magnitudes were similar, the separations were 6" or less, they had a long WDS history of observation, and the components had similar proper motions. Based on the data available 5 systems were deemed to be potential real binary star systems, 3 systems were questionable as to their binary status, 4 were likely optical doubles and 9 were clearly optical doubles. The WDS catalog in its current form is discussed.

1. Introduction

With the publication of the Gaia Early Data Release 3 (EDR3) in December 2020 (the full data release is scheduled for 2022), an enormous high accuracy database of stellar parallaxes, distances, proper motions, magnitudes, radial velocities from a full 5 parameter astrometric solution became available. For double star investigators this created an opportunity to determine which systems in the Washington Double Star Catalog (WDS) were likely true binary star systems or chance optical alignments.

Using the earlier 2018 Gaia Data Release 2 (DR2), Harshaw's (2018) extensive analysis of the WDS found that less than 33% of its 139,000 systems were likely physically associated, 4.5% were either a "maybe" or "questionable", 8% were definitely optical doubles and 49% were classified as unknown due to the lack of good data.

The maximum separation for a binary star system is not easy to determine as there are several factors that influence the orbit. The Sixth Catalog of Orbits of Visual Binary Stars (Matson, R. et. al, 2021) has very few known binaries with separations exceeding 3,000AU. An analysis of wide systems >20,000AU from the Gaia DR2 (Jiménez-Esteban, et. al, 2019) studying binary formation models resulted in a catalog of 3,741 co-moving systems whose physical separation ranged from ~ 400AU – 500,000AU. Knapp (2019) points out that such co-moving systems with similar proper motions, radial and/or transverse velocities are not necessary requirements to define a double star as a physically bound system. The key factor is the distance between the components.

Nouh and Sharaf (2012) used a formula for known binaries to determine maximum separations based on spectral types of the primary components:

$$d(AU) = 2500\,(M_{pri})^{1.54} \qquad [1]$$

where d = distance in AUs and M_{pri} = mass of primary in solar mass units. They only chose known binaries from catalogs to avoid introducing optical doubles in the dataset. They found that main-sequence binaries have separations that decrease from the more massive early type stars to the less massive late type stars. Nouh and Sharaf (2012) used two other formulas for computing maximum separations in known binaries. They compared the three formulas (including equation [1]) in numerical tests with known binaries and their results showed maximum separations in the range of 400AU - 2,000AU.

A stable binary with a separation over 2,000AU is possible assuming there are no stellar encounters during the lifetime of the system. Realistically however, the Milky Way has over 100 billion stars in orbit within the galaxy. Over the lifetime of a binary/multiple star system, it is likely that numerous encounters can occur that will break up and/or perturb the system. For the analysis used in this paper, we will use 2,000AU as the separation limit for a double star to be considered a binary star. Beyond 2,000AU, we classify a double star as an optical double.

This investigation uses the Gaia EDR3 to analyze twenty-one double star systems from the WDS. The systems were chosen whose parameters gave the initial impression they were true binaries: small angular separation, similar apparent magnitudes and similar proper motions. Components were selected with separations of 6" or less that were relatively bright with apparent magnitudes of less than +10.5. With bright components, this assured a long WDS history of observation (146 – 239 years for this sample of doubles chosen). None of the systems chosen here are listed in the Sixth Catalog of Orbits of Visual Binary Stars (Matson, et. al, 2021).

2. Equipment and Methods

For each system the position angle (PA) and separation was measured using the video drift method (Nugent & Iverson 2018). The results are presented in Table 1. Then, Gaia distances from Earth were computed for each component. The errors in the parallaxes (and thus distances) ranged from 0.12% to 2.5%.

Table 1. Position angles and separations from the Video Drift method

WDS	Designation	PA°	PA-SEM°	Sep"	PA-SEM"	Date	Mag 1	Mag 2
12003-3644	HJ 4487	126.0	2.3	5.49	0.23	2021.36	9.18	9.75
12207+2255	STF 1634	147.5	1.8	5.26	0.16	2021.36	8.77	9.90
12325+2106	STF 1652	177.2	1.5	5.92	0.17	2021.36	10.12	10.40
12406+4017	HJ 2617AB	121.1	1.3	5.40	0.13	2021.36	8.41	9.61
12413-1301	STF 1669AB	313.4	1.7	5.21	0.16	2021.36	5.88	5.89
12563-0452	STF 1690	149.8	1.6	5.80	0.18	2021.36	7.18	8.95
13134-1850	SHJ 161	34.2	1.8	5.19	0.16	2021.36	6.78	7.19
13152-1855	BU 342	35.2	2.3	3.95	0.16	2021.36	8.68	9.04
13233-1456	STF 1738	277.8	0.8	3.63	0.08	2021.36	8.64	8.73
13423-3359	HJ 4608	10.2	1.0	4.01	0.10	2021.36	7.42	7.47
14048-0633	STF 1799	295.2	1.0	4.17	0.09	2021.36	8.17	9.04
14134+0524	STF 1813	194.6	1.9	4.56	0.30	2021.36	8.45	8.63
14226-0746	STF 1833AB	175.3	1.8	5.74	0.20	2021.36	7.51	7.52

18277+1918	STF 2319AB	189.6	2.0	5.20	0.22	2021.67	8.41	8.23
18362+4117	STF 2351	159.9	1.8	4.90	0.13	2021.67	7.60	7.64
18459-1030	STF 2373	336.2	1.0	3.75	0.08	2021.67	7.39	8.43
19588+4721	STF 2611	207.5	1.7	5.08	0.11	2021.67	8.47	8.48
21124-1500	H 1 47	307.3	0.8	4.20	0.09	2021.67	8.25	8.31
22143-2104	H N 56AB	112.6	0.7	5.14	0.09	2021.67	5.63	6.72
22218+6642	STF 2903	100.4	0.6	4.05	0.03	2021.67	7.13	7.80
22497+4031	STF 2946	262.2	1.7	5.47	0.14	2021.67	8.12	8.25

*Table 1 notes
"SEM" = Standard error of the mean
Magnitudes are taken from the WDS Catalog. All position angle/separation measurements are for the Equator and Equinox of date.

Distances were then derived between the primary and secondary components for each system. From Figure 1 we know the primary and secondary distances from Earth (sides a and b of the triangle). Using the newly measured separation angle θ between the components, the law of cosines was used to solve for the distance between the primary and secondary (side c):

$$c = \sqrt{a^2 + b^2 - 2ab\cos\theta}$$

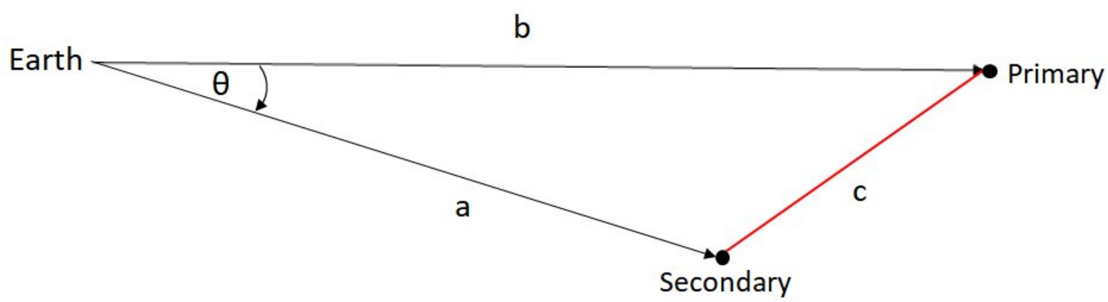


Figure 1. Law of cosines calculation for the distance between the components

With the Gaia distances and our measured separations, the primary-secondary distances from the system sample ranged from 5,289AU - 2.99 million AU (See Table 2). With certain assumptions, some of these primary-secondary distances were reduced to less than our 2,000 AU separation limit. With distances between both components known, the next step is computing the orbital period. This was done using Newton's version of Kepler's 3rd law:

$$\boldsymbol{P^2} = \left[\frac{4\pi^2}{G(M_{pri}+M_{sec})}\right] \boldsymbol{a^3} \quad [2]$$

In equation [2], P is the period, π the mathematical constant, G the gravitational constant, M_{pri}, M_{sec} are the masses of the primary, secondary and a is the distance between the components. To estimate the masses of the components, the spectral types and luminosity classes were used from the WDS confirmed by other sources (such as the *SIMBAD* database, 2021) plus the absolute magnitudes derived from the Gaia distances and apparent magnitudes. With this information, mass luminosity tables were used from Lang (1992) to get estimates for the individual stellar masses. (An example of an absolute magnitude calculation is given in the Appendix).

As an example, the components of the system WDS 12207+2255 STF 1634 have a 5,289 ± 163AU separation. Estimates for the total mass of this pair using the above method was 2.8$M_\odot$ so the period is 228,000 years. STF 1634's position angle change over 191 years was 2° and the separation change over the same time interval was 0.1". Gaia's parallax errors show that the component distances from Earth have overlap. A much shorter period and closer separation could be asserted by assuming the distances of each component was identical from Earth (see details below for STF 1634 in the discussions of the individual systems).

Ten of the systems had parallax errors (resulting in distance overlap) which when taken into consideration could put both components at the identical distance from Earth. The system WDS 12406+4017 HJ 2617AB had component distances of primary 64.8 ± 0.22 parsecs and secondary 65.0 ± 0.3 parsecs (1 parsec (pc) = 206,265AU). With these distances, their separation came to 30,409 ± 715AU. WDS lists the spectral type as G0. The known distance and apparent magnitude implies absolute magnitudes of M_{abs} = +4.2, +5.6 which more or less agrees with the spectral type and suggests a pair of two luminosity class V stars. We will thus assume the masses are 1$M_\odot$ each. Using equation [2] this equates to an orbital period of 3.75 million years.

The errors in the HJ 2617AB parallaxes have enough overlap which could put both components at the same distance from Earth thus minimizing their separation. Assuming this is the case, the component separation based on the angular separation is now 350AU. The new period is now 4,630 years. The position angle (PA) change for HJ 2617AB from 1831 to 2021 was 10°. If it is further assumed this system has an orbit that is face on or nearly face on (inclination approaching 90° to our line of sight), the 10° PA change in 190 years could be extrapolated to a full orbit (360°) resulting in a ≈ 6,840 year period.

3. Analysis

Proper Motions and Radial Velocities

The proper motions for the systems analyzed here are nearly identical in direction and magnitude. The radial velocities of all the systems which Gaia data was available are also similar. This is expected for pairs of stars located in the same place in the galaxy as they are in orbit around the galactic center and are moving through space together. As mentioned earlier identical or nearly identical proper motions and radial velocities do not necessarily imply a true binary system (see discussion on 12413-1301 STF 1669AB below). Consider open star clusters. Individual stars in the clusters (not binaries) have similar proper motions as the cluster moves through space yet their internal separations are usually very high, on the order of 1 parsec and higher.

Discussion of Individual Systems

Table 2 summarizes the Gaia distances, errors and the primary-secondary distances from the published parallaxes and the newly measured separations. For these WDS systems, if there was overlap in the distances from the parallax errors, the separations were calculated presuming both stars were equidistant from Earth. This assumption would minimize their physical separations. Not every system with an assumed minimum separation less than 2,000AU was asserted to be a binary. Other factors played a role in the determination of a binary, especially the distance errors. Otherwise a system's status was classified as questionable or an optical double.

Table 2. Gaia distances from Earth and Primary-Secondary distances

Washington Double	Earth-Primary		Earth-Secondary		Primary-to-Secondary		Primary-to-Secondary			Primary-Secondary	
Star Catalog #	Distance-parsecs		Distance-parsecs		Distance-parsecs		Distance-AU's			Distance Minimized*	
12003-3644 HJ 4487	372.90	± 3.5pc	373.90	± 3.0 pc	1.03	± 0.04pc	213,227	± 8,850 AU		2,048	AU
12207+2255 STF 1634	148.51	± 0.5pc	148.53	± 0.46 pc	0.026	± 0.0008pc	5,289	± 163 AU		780	AU
12325+2106-STF 1652	297.20	± 7.3pc	297.30	± 7.6 pc	0.103	± 0.003pc	29,289	± 614 AU		1,760	AU
12406+4017HJ 2617AB	64.80	± 0.22pc	65.00	± 0.27 pc	0.147	± 0.003pc	30,409	± 715 AU		350	AU
12413-1301 STF1669AB	71.90	± 0.8pc	81.40	± 0.4 pc	9.5	± 0.3pc	1,967,483	± 61,896 AU			
12563-0452-STF 1690	148.60	± 0.85pc	134.10	± 0.8pc	14.5	± 0.5pc	2,996,013	± 94,578 AU			
13134-1850 SHJ 161	208.10	±1.8pc	203.80	±1.7pc	4.3	± 0.13pc	885,015	± 27,268 AU			
13152-1855 BU 342	178.15	± 0.99pc	178.44	± 0.85pc	0.29	± 0.012pc	60,288	± 2,501 AU		704	AU
13233-1456 STF 1738	80.25	±0.16pc	80.30	± 0.15pc	0.05	± 0.005pc	9,742	± 207 AU		292	AU
13423-3359 HJ 4608	73.33	± 0.12pc	73.28	± 0.20pc	0.05	± 0.001pc	10,475	± 262 AU		370	AU
14048-0633 STF1799	136.98	± 0.54pc	136.16	± 0.37pc	0.826	± 0.018pc	170,462	± 3,758 AU		570	AU
14134+0524 STF 1813	181.48	± 1.0pc	183.64	± 0.94pc	2.16	± 0.14pc	444,982	± 28,904 AU			
14226-0746-STF 1833AB	41.12	± 0.05pc	41.01	± 0.04pc	0.107	± 0.003pc	22,065	± 754 AU			
18277+1918 STF 2319AB	139.22	± 0.40pc	137.79	± 0.44pc	1.42	± 0.06pc	293,500	± 12,417 AU			
18362+4117 STF 2351	223.33	± 2.27pc	227.97	± 1.74pc	4.6	± 0.12pc	956,553	± 23,378 AU			
18459-1030 STF 2373	347.98	± 2.52pc	347.21	± 2.50pc	0.76	± 0.016pc	158,190	± 3,375 AU		1302	AU
19588+4721 STF 2611	377.82	± 2.22pc	386.93	± 3.51pc	9.1	± 0.20pc	1,878,254	± 42,150 AU			
21124-1500 H1 47	46.33	± 0.053pc	46.48	± 0.053pc	0.15	± 0.003pc	31,127	± 659 AU			
22143-2104 HN 56AB	74.01	± 0.16pc	73.31	± 0.60pc	0.69	± 0.011pc	143,401	± 2,427 AU		377	AU
22218+6642 STF 2903	233.87	± 0.76pc	231.54	± 1.15pc	2.33	± 0.015pc	480,276	± 3,083 AU			
22497+4031 STF 2946	82.08	± 0.14pc	84.68	± 0.71pc	2.59	± 0.06pc	535,722	± 13,417 AU			

*Values in last column given only if primary and secondary distances have overlap. See text for description of method used.

With regard to the accuracy of the Gaia parallaxes, the Gaia EDR3 website https://gea.esac.esa.int/archive/documentation/GEDR3/index.html states for the five-parameter astrometric solution, parallaxes for stars brighter than m = +15 have errors on the order of 0.02-0.03 mas. For proper motions of stars brighter than m = +15, the five-parameter astrometric solution errors are 0.02-0.03 mas/yr. The error margins for the six-parameter astrometric solutions are nearly identical for the five-parameter solutions. The Gaia EDR3 represents a major advance with respect to the Gaia DR2 in terms of astrometric and photometric precision and accuracy as well as homogeneity across color, magnitude, and celestial position.

However this doesn't mean that 100% of the stars in the Gaia catalog have this precision with the parallaxes. The Gaia DR2 had some spatial resolution issues with stars that had separations of 1.5" and less. DR2 regarded some close stars as duplicate stars thus giving incorrect parallaxes. The handling of this issue in EDR3 has been improved and close pairs with separations between 0.18" and 0.4" which were erroneously considered duplicate stars in Gaia DR2 now appear as two stars in Gaia EDR3. For details on the Gaia errors, the reader is referred to the above webpage.

12003-3644 HJ 4487: Parallaxes and measured angular separation show the stars to be separated by 1.03pc = 213,227AU with an orbital period of 42 million years. The errors in parallaxes allow overlap in the distances which could put the stars equidistant from Earth. Thus their physical separation could be as low as 2,048AU. Spectral types A2V, A2IV indicate the component masses ≈ 2.5$M_\odot$, 3.0$M_\odot$. This new separation means an orbital period of 39,514 years. The parallax uncertainty equates to a >3.0pc error in distance, this is too wide a range to assume they could be equidistant from Earth. This system is not likely a binary.

12207+2255 STF 1634: Gaia parallaxes and the newly measured separation indicate the primary-secondary distance of 5,289AU. Spectral types and absolute magnitudes indicate masses of 1.2$M_\odot$ and 1.6$M_\odot$ primary and secondary. Orbital period is thus ≈ 229,800 years. The parallax errors could put the components equidistant from Earth with a separation of 780AU indicating an orbital period of 13,000 years. The position angle change in 191 years is 2° and separation change 0.2". Is this system a binary? A larger orbital arc needs to be measured to confirm any physical separation. This one could be a binary.

12325+2106 STF 1652: Gaia distances are very similar for components A (297.17pc) and B (297.27pc). A 3rd star (m = +15.2) 15" southwest of the system (see Figure 2) is an unrelated star not part of the system. Its distance is over 8pc further away from the components. Taking into account the Gaia distance errors, there is substantial overlap in the distances, if equidistant from Earth, the component separation would be 1,760AU. However, the large distance errors (±7.3 pc) of the components from Earth suggest this is likely not a real binary.

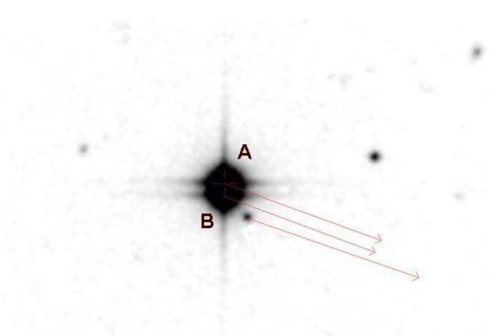


Figure 2. POSS-II image of WDS 12325+2106 STF with proper motion vectors plotted from the Aladin Sky Atlas. The components A and B each have 7.4 pc distance errors from Earth. A 3rd much fainter star to the lower right with similar proper motion is 8 pc further away from AB and is unrelated to the system.

12406+4017 HJ 2617AB: As discussed above the period could be as low as 4,630 years with a 350AU separation with the components equidistant from Earth. The proper motions differ by just 2.5° in direction and the radial velocities are nearly identical. This data plus the low parallax errors indicates this system might be a binary.

12413-1301 STF 1669AB: The components have identical apparent magnitudes of m = +5.75 with a component separation of 5.2". The proper motion components differ in direction by only 3.5°, see Figure 3. The PA change over 198 years is 14° possibly from component orbital motion that might be face on to our line of sight. Without knowing the distances, on first glance this system appears to be a real binary system. However, the Gaia distances close the book on this one: the primary and secondary are 9.5pc apart.

The belief that this system was a binary came from the identical Gaia apparent magnitudes of the components (Gaia photographic g mean magnitude), their identical spectral types of F5V and the small 3.5° difference in the direction of the proper motions. The primary's proper motion is 10% larger (faster) in magnitude than the secondary. With this proper motion difference, over the 198 years of observations, the primary moved 2.7" further west than the secondary resulting in the observed 14° PA change from 299° to 313°. Without knowing the precise distances, this gave the illusion of real orbital motion. See Figure 4.

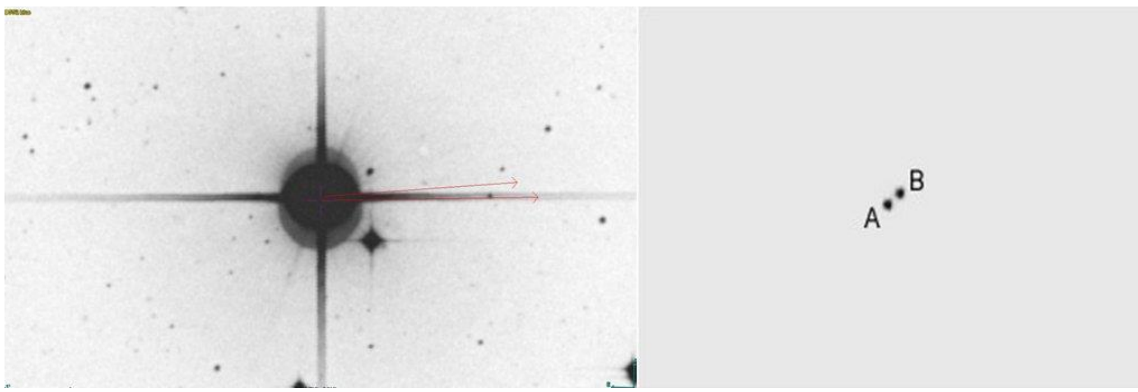


Figure 3. Left: POSS-II image of WDS 12413-1301 STF 1669AB, components merged. Right: Single video frame resolving components A and B. The proper motion (lower red arrow) shows component A (primary) moving 10% faster than B (secondary). This explains the PA change of 299° to 313° over 198 years. See Figure 4.

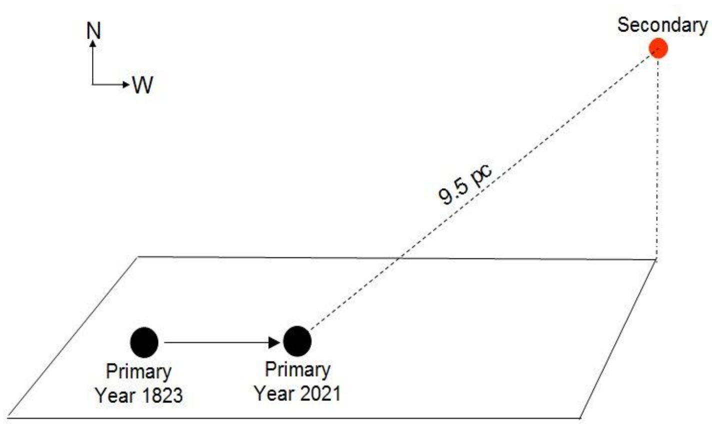


Figure 4. TF 1669AB. Effect of Gaia proper motions on position angle and separation over 198 years. Primary is 9.5 pc closer to Earth than secondary. Over this time period, the primary moved 2.7" further west than the secondary. Without knowing the component distances this likely gave the false impression of real orbital motion.

12563-0452 STF 1690: This system has 2 components with identical proper motions, separation 5.8" with spectral types A0V. The first impression is that the two stars may have formed together and comprise a real binary system. This would be a reasonable assumption except the Gaia distances show the components are 14.5pc apart. This is not a binary system.

13134-1850 SHJ 161: The position angle change over 239 years is just over 1°, separation change over the same time interval = 1.2". The parallaxes show the components 4.3pc apart with no overlap in distance from the parallax errors. Considering the parallax errors, the closest these stars can be is 0.88pc. This one is not a binary.

13152-1855 BU 342: Gaia parallaxes show distances of 178.15 ± 0.99pc and 178.44 ± 0.85pc indicating a separation of 60,288AU. The parallax errors have overlap in distance. If the components were equidistant from Earth, their separation could be as low as 704 AU. The apparent magnitudes primary: +8.49, secondary: +8.84 (and thus absolute magnitudes) are nearly the same. The spectral types of F2V indicate masses of 1.5$M_{\odot}$ each, thus the orbital period could be 10,780 years. The PA and angular separation in 146 years remained nearly unchanged at the values 35° and 4.0" indicating little or no measured relative motion of the components. This lack of motion in the PA and separation could be explained by a highly elliptical orbit with a very low inclination ($i \approx 0°$, see Figure 5) nearly edge on to our line of sight. If this is the case, both stars would be at the furthest point from each other on the semi-major axis of the orbit moving at the slowest orbital velocity.

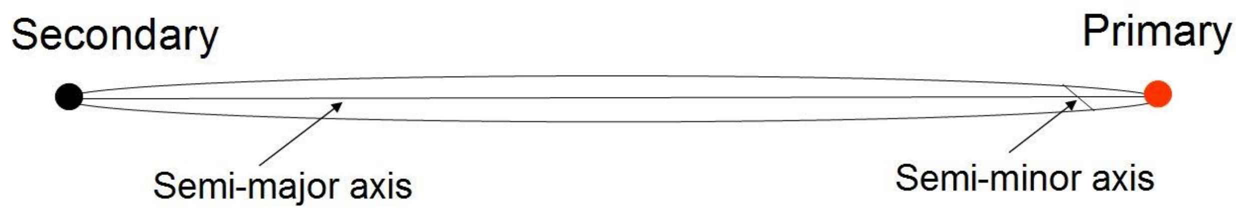


Figure 5. BU 342. The motion of the secondary star would be at it slowest orbital velocity at the position shown on the semi-major axis assuming a highly elliptical orbit.

This theory of a highly elliptical orbit is flawed. As indicated by their spectral types, luminosity class and absolute magnitudes, the components have nearly the same mass. Therefore the center of mass of the system would be approximately half-way between the components and not close to the primary as shown in Figure 5. Hence the orbital velocity of both components would be similar throughout a complete orbit. There are several assumptions here making this system's binary status questionable.

13233-1456 STF 1738: The Gaia distances indicate the component separation of 0.047 ± 0.005pc or 9,742 ± 1031AU. The parallax errors allow overlap in the distances from Earth. Equidistant from Earth, their separation could be 292AU. The spectral types of F7V signify masses of 1.2$M_{\odot}$ each thus the orbital period could be as low as 3,200 years. This system could be a binary.

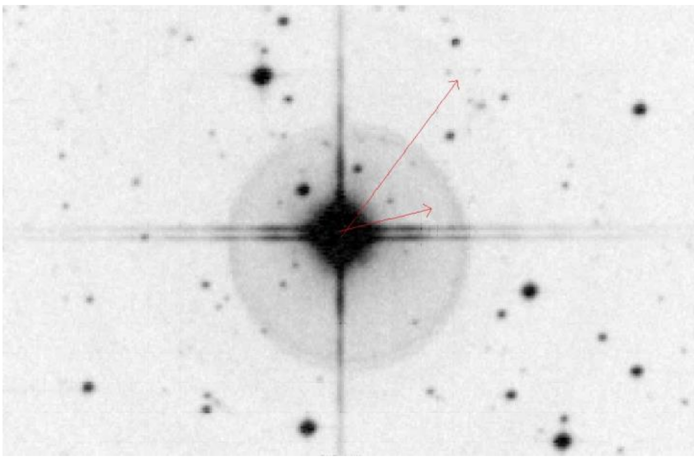
13423-3359 HJ 4608: The Gaia parallaxes indicate a separation of 0.05pc or 10,475AU. The parallax errors have overlap in the distances, so if the components were at identical distance from Earth, their separation could be 370AU indicating an orbital period of 4,041 years. Here we are using published spectral types of F5 and F2 plus their absolute magnitudes osf +3.0 to estimate the component's masses of 1.5$M_{\odot}$ and 1.6$M_{\odot}$.

The proper motions of the components differ in direction by 59°, (see Figure 6). The proper motions in right ascension are: primary = -.017"/yr and secondary = -0.0021"/yr, thus the primary is moving 8X faster westward than the secondary. This explains the 20° PA change over the last 187 years. If this system is a binary, this large PA change could also be partly from orbital motion. The 1834 separation can be calculated using the current measured separation in 2021 and running the Gaia proper motions backwards to the year this double star was first measured. In this computation, Earth's axial precession and nutation is not taken into account as it only affects the PA. The calculated separation in 1834 from the Gaia proper motions is 4.14". The observer who made the 1834 observation reported the separation as 4.0". Considering the telescopes and optics available in 1834, plus the skill of the observer (all observations back then were visual), this 4.0" separation measurement was quite good.

If this system is a binary and if the orbit is nearly face on to our line of sight, the 20° PA change extrapolated to 360° indicates ≈ 3,260 year orbit. The radial velocities are similar at -2.9 km/sec and -2.5 km/sec for the components indicating little or no motion of the components toward or away from us placing most of the star's motion perpendicular to our line of sight. Given these assumptions this system could very likely be a binary.

Figure 6. POSS-II image of HJ 4608. Proper motion vectors plotted from the Aladin Sky Atlas.

14048-0633 STF 1799: The Gaia component distances of 136.98 ± 0.54pc and 136.16 ± 0.37pc indicate a separation of 170,462AU. With the distance overlap from parallax errors and assuming equidistant from Earth the components could be separated by as little as 570AU. The estimated mass of the system is $3.0M_\odot$ and the estimated period is now 7,855 years. The proper motions are nearly identical in magnitude and differing by just 1° in direction. The PA has changed by 2° and 0.4″ in separation in 191 years. The small changes in PA and separation plus the identical distance from Earth assumption doesn't necessarily indicate orbital motion in a real binary system. These small PA and separation changes could be the result of the projected orientation of an orbit. It is questionable whether this system is a binary.



14134+0524 STF 1813: The Gaia distances are primary: 181.48 ± 1.0pc, secondary: 183.64 ± 0.94pc. Applying the parallax errors to compute the range of their separations we get a maximum separation of 4.2pc and the closest they could be is 0.22pc, or 45,606AU. This system is not a binary.

14226-0746 STF 1833AB: The spectral types of both components are listed from the WDS as G0V indicating $1M_\odot$. The component apparent magnitudes and proper motions are nearly identical (m = +7.51, +7.52, proper motion directions to within 2°) and the radial velocities are very close at -33.1 km/sec and -32.4 km/sec. An initial look at this system would give the impression that the stars may have formed together and comprise a real binary.

The Gaia data shows the separation as 22,065 ± 754AU which equates to a 2.3 million year orbital period. Applying the parallax errors to compute the range of distances between each star, we get a maximum separation of 40,018AU and minimum separation of 4,110AU. This minimum separation equates to an orbital period of 186,300 years. The Gaia parallaxes indicate no overlap in distance from Earth, but come very close with the 4,110AU separation. If we allow for the error in the measured separation (arc-seconds), this could bring the components closer together.

These two stars are very close to each other, but not quite close enough to be a binary using the 2,000AU separation standard. With the available parallaxes, measured separation and associated errors, this system would be questionable as to being a real binary.

18277+1918 STF 2319AB: Gaia distances and the current measured separation indicate the components are 1.4pc apart. The proper motions are identical in magnitude and differ by only 0.7° in direction. The Gaia distance errors are ±0.4pc and ±0.43pc for the primary and secondary respectively. Placing the components at the closest separation the parallax errors allow still has them 0.58pc apart. This system is not a binary.

18362+4117 STF 2351: Here we have both components with nearly identical apparent magnitudes (+7.60, +7.64) and spectral types (A1V, A0V). Visually, it appears to be a binary. The Gaia parallaxes and measured separation show them 4.6pc apart. The Gaia distances do not overlap when the parallax errors are considered, the closest separation they could be taking into account the errors is 0.62pc. This system is not a binary.

18459-1030 STF 2373: Gaia parallaxes produce 347.98 ± 2.5pc and 347.21 ± 2.5pc placing the components 0.77pc apart. There is substantial overlap in the distances. Assuming they are equidistant from Earth with the measured separation indicates the components could be as close to each other as 1,302AU with a period of revolution that is ≈ 11,700 years. This assumes the component masses are $8M_{\odot}$ based on their spectral types and absolute magnitudes. With distances of 347pc for the components, the large 2.5pc errors make it highly unlikely that they are at the point of being equidistant from Earth. This system is very likely not a binary.

19588+4721 STF 2611: The Gaia parallaxes place the components 9.1pc apart. Applying the parallax errors to bring them to their closest separation, they are still 3.4pc apart. This one is definitely not a binary.

21124-1500 H1 47: The spectral types indicate two Sun-like stars (G3IV, G3V) and they look identical in brightness (apparent magnitudes +8.25, +8.31). The proper motions differ by just 2° in direction. The Gaia distances of 46.33 ± 0.053pc and 46.48 ± 0.053pc are very close but the component stars are still 0.15pc or 31,127AU apart with the current measured angular separation. Despite the highly accurate parallaxes and small errors, the distances do not quite overlap. Applying the parallax errors to place the components as close as the numbers allow, their physical separation is still 0.044pc or 9,110AU. This system is close, but not likely a binary.

22143-2104 HN 56AB: Gaia distances are 74.01 ± 0.16pc and 73.3 ± 0.6pc for the primary and secondary. With the measured separation, the pair is 0.7pc apart. The parallax errors result in a small overlap in the distances from Earth that spans 13,758AU. The proper motion vectors point at 25.5° position angle for the primary and 24.2° for the secondary – nearly identical direction of movement. The PA change of the pair is 9° over 198 years. The spectral types from WDS are K0III and F2V suggesting masses of $1.1M_{\odot}$ and $1.5M_{\odot}$ for the primary and secondary. Applying the parallax errors to minimize the distance between the pair (equidistant from Earth) and the component masses in equation [2], the derived period is 4,539 years with a separation of 377AU. The data indicates this pair could be a real binary.

22218+6642 STF 2903: Gaia parallaxes indicate distances of 233.87 ± 0.77pc and 231.54 ± 1.15pc for primary and secondary components. There is no overlap in distance. Adjusting the parallax errors to minimize the distance between the components still leaves a 0.41pc (84,415AU) separation. This pair is not a binary.

22497+4031 STF 2946: Gaia distances are 82.09 ± 0.14pc and 84.7 ± 0.71pc for the components. Applying the errors in the parallaxes to minimize their distance apart, the closest they could be is 1.75pc. This system is not a binary.

4. Discussion and Conclusions

In the 1700's and all the way into the 2000's, as double stars were measured and cataloged, observers did not have the highly accurate distances of these systems as we do now with Gaia. Most double stars were assumed to be physically connected (in the sense of a real binary) and continued to be measured. Over time, many more doubles were added to the database (which is now the modern WDS) and as of the time of this writing the WDS website lists over 154,000 double and multiple star systems. And the WDS keeps growing. The creators and keepers of the WDS over many decades have done a fabulous job in maintaining and updating the catalog and its many supplemental catalogs.

To determine if a visual double star is a real binary, accurate distances between the components are needed. Historically, it was assumed by double star observers that over enough time, the position angle and separation would change enough indicating a real binary system in which eventually an orbit could be calculated. The *General Catalog of Trigonometric Parallaxes Fourth Edition* published in 1995 (van Altena 1995, third addition published 1963) contains parallaxes of just 8,112 stars. These are all from ground based observatories. The quoted errors in the parallaxes ranged from 1 mas to values in excess of 40 mas. With so few distances to double stars from this catalog (and the large relative errors for many of the entries), no definitive conclusion could be reached in computing the distances and actual separations of many suspected binaries. The Hipparcos mission in the late 1990's added to the database of accurate distances.

So unless a true visual binary system was measured over a large enough portion of its orbit arc to compute a definitive period and thus distance, astronomers didn't have much data for the vast majority of double stars in the WDS. The *Sixth Catalog of Orbits of Visual Binary Stars* (Matson, et. al, 2021) has 3,383 systems as of late 2021 with orbits computed and graded.

We know that the majority of WDS entries are likely unrelated stars and chance optical alignments. This was known long before the Hipparcos and Gaia missions. So why do these double/multiple star systems continue to be measured? Other than as an exercise, it serves no purpose to continue the practice of measuring unrelated stars. An image of just about any field will show numerous stars that "appear" to be double/binary. Just because two or more stars appear close and have similar magnitudes as this paper and others show, this doesn't mean they are physically connected as a binary. Most of the time they aren't. With the introduction of Gaia EDR3 data, it's time to take a fresh look at the current WDS catalog. Perhaps the basic WDS could be divided into two (or more) catalogs – 1) real and suspected binaries where measurements are needed to derive orbits and 2) the rest kept for historical purposes.

Visual double stars that are true binaries need to be measured to determine their orbits and hence obtain their distance from Earth. With their distances known, we get the component's absolute magnitudes and hence their actual luminosity. Using Newton's version of Kepler's third law (equation [2]) we can get the masses of the components. We now have Gaia distances to nearly all WDS objects. Do we still need orbits? Yes we do! We need the orbits to determine the stellar masses, actual luminosity, temperature and in many cases the radius of the components. This crucial data is important for constructing the H-R diagram, which is the most fundamental diagram in astronomy. H-R diagrams are valuable because they reveal many important stellar properties such as age and evolutionary state.

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Appendix

Absolute Magnitude Calculation

Apparent magnitude m, absolute magnitude M and distance r from Earth (in parsecs) are related by the following formula known as the distance modulus. The absolute magnitude of a star is equivalent to its apparent magnitude at a distance of 10 pc.

$m – M = 5 \log r - 5$

For a star that is 10 pc away, its absolute magnitude M will equal its apparent magnitude m:

$m – M = 5 \log 10 – 5,$

$= m – M = 5 (1) – 5,$

$= m – M = 0,$

thus $m = M$

Example: For STF 1669AB, both the Primary and Secondary apparent magnitudes are $m = +5.9$.

Primary's distance = 71.9 pc,
Secondary's distance = 81.5 pc (from Gaia parallaxes)

The absolute magnitude of the primary is : $M = – (5 \log 71.9 – 5) – 5.9 = +1.61$
The absolute magnitude of the secondary is : $M = – (5 \log 81.5 – 5) – 5.9 = +1.34$

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