GAIA and CCD Observations Indicate that Herschel Double Star 10134-5054 HJ 4299 is not Gravitationally Bound

Karl Schmidt

The Branson School
Ross, CA

Abstract: The goal of this research was to contribute to the 191 year old dataset of the double star WDS 10134-5054 (HJ 4299) using measurements made by GAIA and the LCO 0.4m robotic telescopes because the true nature of these two stars is yet undetermined. The LCO measurements show continued change in separation and position angle, however, the Gaia parallax measurements strongly suggest that the stars are not gravitationally bound and are in fact separated by over 300 parsecs. GAIA temperature and magnitude measurements predict that these stars are roughly within 10 Myr of each other in age. And GAIA proper motion measurements better explain the relative motion of the two stars than a gravitational bond. This paper demonstrates some of the analysis possible in the field of double star astronomy using GAIA data to address uncertainty in the nature of historical double stars that continue to have ambiguous relative motion.

Introduction

The star named HJ 4299 (WDS 10134-5054) was first measured in 1834 by John Herschel and while it has had roughly 12 observations in the last 191 years there remained a note on Stelle Doppie that "the nature of this double is uncertain". This system includes an orange K4/5 star with a white A0 as the secondary (Houk 1978), with relative magnitudes of 7.4 and 8.6 respectively (GAIA DR2). Over the last 191 years, the separation has changed from 50.0" to 30.4" while the position angle has changed from 328° to 320° (WDS). As part of the Astronomy Research Seminar, the objective was to contribute CCD measurements of the separation and position angle and look at possible orbital calculations as no orbit calculation exits in the US Naval research ORB6 database. A secondary goal was to see what could be learned from the GAIA DR2 measurements.

When two stars appear very near each other in the field of view it is possible that they are gravitationally bound and in orbit around the center of mass. It is also possible that the two stars only appear very close together from our perspective, yet they are distant from each other and not gravitationally bound. In order to determine if two stars are gravitationally bound rather than an optical binary, the separation between the stars and their position angle can be successively measured. If an elliptical orbit fits the data well, then the likelihood of the stars being gravitationally bound is very high and information about the masses of the stars can be determined.

It is also possible to rule out that the stars are gravitationally bound by determining the distances to the stars by measuring the stellar parallax. Stellar parallax is a measure of how much the location of the star shifts relative to the much more distant background stars from two maximally separated viewpoints in Earth's orbit (6 months apart). Also, proper motion can be analyzed to predict the probability of the stars being gravitationally bound (Harshaw 2018).

Similar distances to the Earth is valuable supporting evidence in determining if the relative motion of stars is due to mutual gravitation. Gravitationally bound stars are usually within 1000 AU from each other (Harshaw 2018) and the occurrence rate of binaries decreases with the inverse of the separation out to around 3500 AU, this is known as Öpik's law (Lépine & Bongiorno 2007 as referenced in Longhitano and Binggeli 2009). The population of ultra wide binaries beyond 3500 AU separation decreases even more rapidly as the separation increases, and yet, there is evidence of binaries out to 100,000 AU (Lépine & Bongiorno 2007). Examples of these ultra wide binaries and triple star systems exist such as Kö 3 A-BC, where HD 221356 A likely orbits HD 221356 BC at a distance of roughly 11,900 AU (Caballero 2007), our nearest neighbor star Proxima Centauri is in a hyperbolic "orbit" of α-Centauri AB (a double itself) at a distance of 15,000 AU (Matvienko and Orlov 2014), and a there is a brown dwarf orbiting as a companion to TW Hya at 41,000 AU (Teixeira et al. 2008). Furthermore, there is evidence from computer simulations conducted by Reipurth and Mikkola that triple star systems can give rise to stable, ultra-wide binaries up to 80,000 AU (~0.5 pc) that are stable for 100 Myr (2012). Outside the range of 100,000 AU it is unlikely that a mutual gravitational force plays a key role in the motion of the stars.

Harshaw describes a methodology for prescribing a probability of a binary system being physical rather than optical based on 4 factors including a parallax factor and a proper motions comparison (2018). The parallax factor is a comparison of the distances from Earth, this factor ranges from 0.0 to 1.0 with greater values indicating similar distances, see equation 1. The proper motion factor compares the direction and magnitude of the motion of each star relative to Earth on a scale from 0.0 to 0.15 with identical proper motions resulting in a value of 0.15, see Equation 2. According to Harshaw, "two stars that are in orbit around one another should have identical, or very nearly identical, proper motions." The subject of this paper, HJ 4299, had not been analyzed by Harshaw 2018.

The CCD Images were to be taken with the Las Cumbres Observatory (LCO) robotic telescope network and measured in AstroimageJ, more on these methods below. Along with these measurements, measurements of the stars position angle, seperation, parallax (distance), and proper motion presented in the GAIA DR2 were analyzed, however tracking these down proved unexpectedly difficult.

Accessing GAIA DR2

GAIA is an ESA spacecraft attempting to map nearby stars in the Milky Way galaxy (ESA 2018). GAIA is orbiting around the Sun with the Earth at L2, a gravitational inflection point in the Earth-Sun system that allows the spacecraft to orbit the Sun with the Earth on a 1 year timescale and only minor course corrections every 23 days (NASA/WMAP Science Team 2019). This orbital position allows GAIA to view the entire celestial sphere and make repeated measurements through the year including measurements of parallax (stellar distance) and proper motion (direction of motion across the celestial sphere). Prior to GAIA's measurements it is unclear if there had been parallax measurements made for these stars and no distances were given on Stelle Doppie as of October 2019. Queries to GAIA DR2 through VizieR using any of the star names and designations on Stelle Doppie did not yield any measurements of these two stars. As you can see in figure 1 there are many other fainter stars in the field, however, the bright stars were mysteriously not in the results list.

Better luck was had with Aladin Software. Aladin is a software package that can access online databases including plate solved images of the sky that can be used to make measurements. After searching the name of the star produced no results, the J2000 coordinates were searched and the target stars were located, with the DSS2 image, shown in figure 3, superposed. Clicking on these two stars showed different star names, HD 88812 (blue) and HD 88813 (red). Clicking on these star name links opens the star information page in the Simbad database, where there are the many identifiers for these stars as well as links to VizieR database queries in various data sets, such as GAIA DR2 (See Appendix for GAIA DR2 designations).

The Simbad star information pages list these stars with several names: including 10134-5054A and 10134 -5054B, while only HD 88812 (blue star) is labelled as HJ 4299 B, a double star. (The designation HD stands for Henry Draper Catalog, a catalog of over 272,000 objects made between 1918 and 1924.) In Positions and Proper Motions - South, Bastian et al. marked both HD 88812 (blue) and HD 88813 (red) as double stars (1993). However, later in 1996, Lasker et al. gave HD 88812 (blue) a "False" marker for multiple objects in the HST guide star catalog, while HD 88813 (red) does not have an entry in this database, adding to the mystery.

Methods

Observations were made with the Las Cumbres Observatory (LCO) robotic telescopes. For these observations I used the 0.4m telescopes with a SBIG 6303 CCD camera. The telescopes are Schmidt-Cassegrain, modified Meade telescopes and are mounted on equatorial mounts and the SBIG cameras have a field of view of 29.2 x 19.5 arcminutes, with the plate scale being 0.571 arcseconds per pixel (LCO 2019).

Twenty images were captured at Siding Spring Observatory in New South Wales, Australia (Lat: 31 16′ 23.88"S, Long: 149° 4′ 15.6"E, Elev: 1,116 m) (LCO 2019) on October 23, 2019, between UTM 17:47:11 and 18:06:54 with exposure times of 1.28 seconds. The LCO network reduced and plate solved the images. In AstroimageJ, the separation and position angle (from North to East) were measured from centroid to centroid

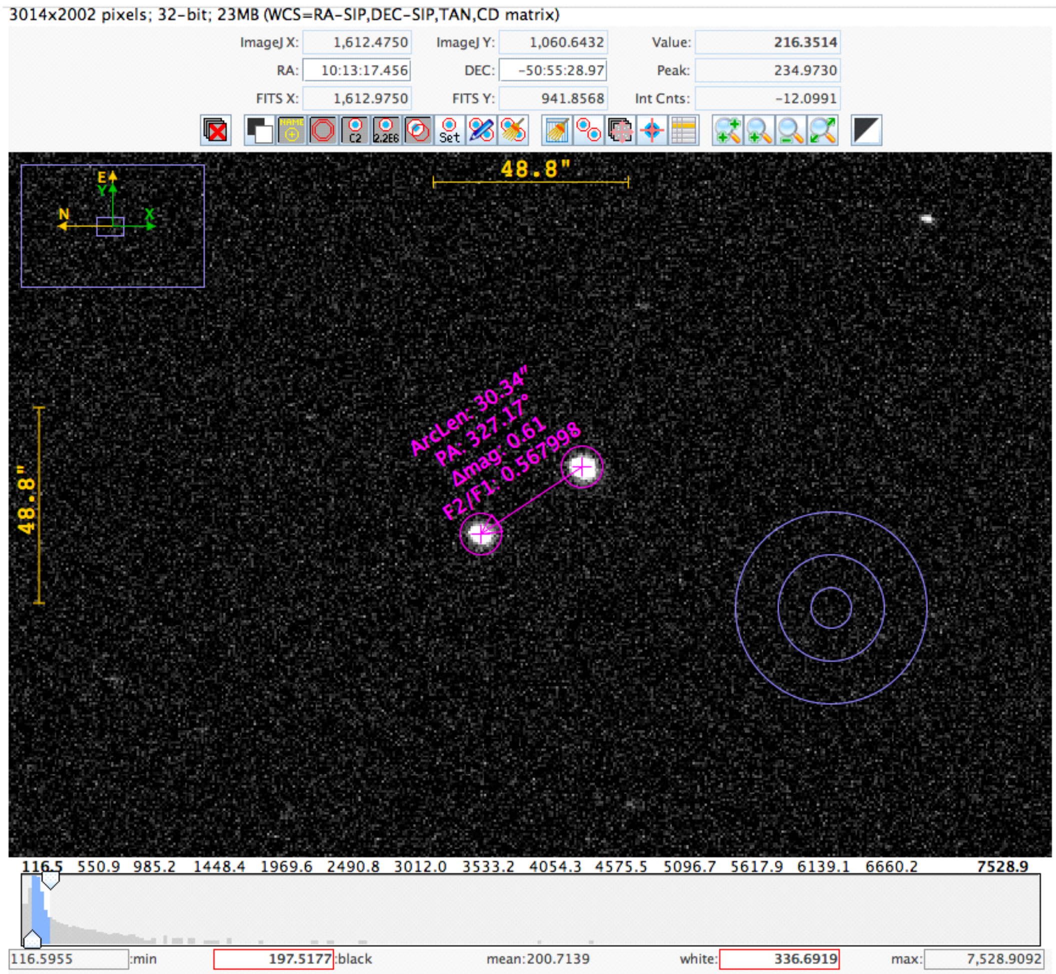

Figure 1. AstroimageJ analysis example.

of each star as shown in Figure 1. These measurements were repeated on each of the 20 images and then averaged. The standard deviation and standard error of the mean (SEM) were calculated for each average.

GAIA DR2 observations of the two stars' right ascensions and declinations made around 2015.5 were used to calculate the separation and position angle. The separation was calculated using a spherical geometry equation presented by Michael Richmond (2005). And the position angle was calculated using the position angle equation presented in Buchheim 2008.

The parallax factor and proper motion factor were calculated using the equations presented in Harshaw 2018 by using the Excel spreadsheet linked in that paper.

$$P_{px} = 1 - \left| \frac{P_d - C_d}{\frac{1}{2}\left(P_d + C_d\right)} \right| \qquad [1]$$

$$P_{pm} = \left| 1 - \frac{\sqrt{\left(P_{pmra} - C_{pmra}\right)^2 + \left(P_{pmdec} - C_{pmdec}\right)^2}}{\sqrt{P_{pmra}^2 + P_{pmdec}^2} + \sqrt{C_{pmra}^2 + C_{pmdec}^2}} \right| * 0.15 \qquad [2]$$

Findings

The position angle and separation measurements from LCO in 2019.8 and GAIA in 2015.5 (see Table 1) follow the historical trend of decreasing separation of the stars, while they also exemplify that there is scatter among the data and the decreasing trend is not consistent, see Figure 2A.

The disparity between the parallax measurements strongly suggests that these two stars make a visual pair and not a gravitationally bound system. The parallax angles shown in Table 2 are very small, however, and, according to Harshaw, GAIA parallax measurements below about 5 mas are unreliable or at least have much greater error bars than are presented in the GAIA DR2 (personal communication, November 2019). The ESA

GAIA and CCD Observations Indicate that Herschel Double Star 10134-5054 HJ 4299 ...

	Separation (arcsec)	Standard Dev. Sep. (as)	SEM (as)	PosAng (deg)	Standard Dev. PA (deg)	SEM (deg)
LCO (2019.8)	**30.47**	0.11	0.024	**327.48**	0.19	0.043
GAIA DR2 (2015.5)	30.45			327.53		

Table 1. Contemporary Separation and Position Angle Measurements

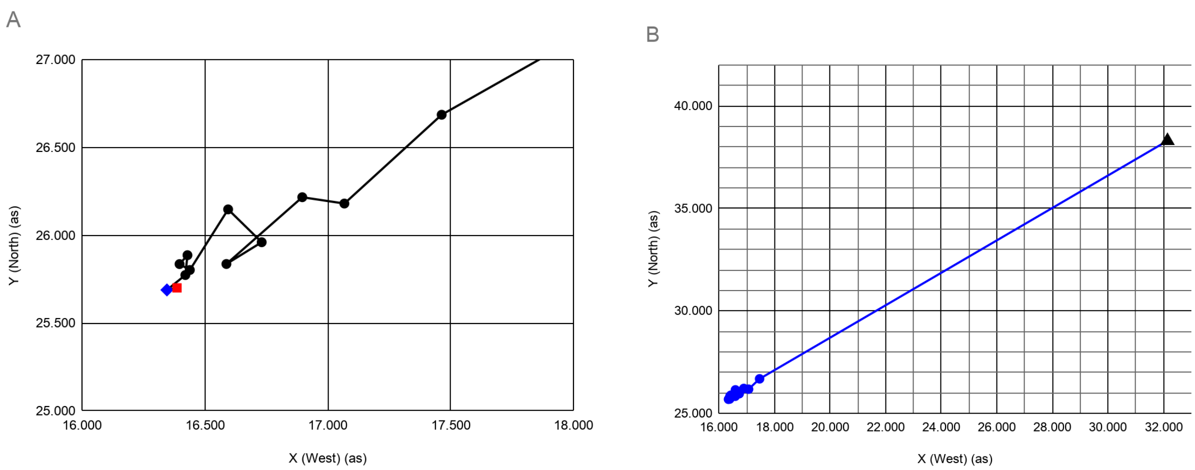

***Figure 2**: Historical measurements of companion star (Blue 88812) relative to the primary (Red 88813). (A) There is a drift in the position over the century, with some scatter. The red square represents the measurements made with the LCO images and the blue diamond represents the position measured by GAIA. (B) The Herschel measurement shown as the black triangle, made 65 years earlier than the next measurement, is twice as distant as the other measurements. It is hard to say if this is a significant movement or uncertainty in Hershel's measurement.*

reports the measurement error is at least below 0.1 mas (2018). The difference between the parallax measurements of more than a factor of 2 means these stars are not the same distance from Earth. The distance between these two stars is 8.4 x 107 AU, a distance well beyond the commonly found values for physical binaries of within 1000 AU (Harshaw 2018), and beyond the widest known binaries that may extend out to 105 AU (Lépine & Bongiorno 2007).

The disparity between the parallax measurements strongly suggests that these two stars make a visual pair and not a gravitationally bound system. The parallax angles shown in Table 2 are very small, however, and, according to Harshaw, GAIA parallax measurements below about 5 mas are unreliable or at least have much greater error bars than are presented in the GAIA DR2 (personal communication, November 2019). The ESA reports the measurement error is at least below 0.1 mas (2018). The difference between the parallax measurements of more than a factor of 2 means these stars are not the same distance from Earth. The distance between these two stars is 8.4 x 107 AU, a distance well beyond the commonly found values for physical binaries of within 1000 AU (Harshaw 2018), and beyond the widest known binaries that may extend out to 105 AU (Lépine & Bongiorno 2007).

The proper motion of these two stars explains why the separation is decreasing; both stars move roughly northwest, while the speed of HD 88813 (red), further to the southeast, is greater, see Figure 3. Combining the proper motions and the parallax measurements, Harshaw's analysis predicts these stars are not a physi-

	Proper motion right ascension (mas/yr)	Proper motion declination (mas/yr)	Parallax (mas)	Distance (pc)
HD 88813 (red)	-17.201 +/- 0.067	12.647 +/- 0.077	**1.3994 +/- 0.04**	714.6
HD 88812 (blue)	-13.646 +/- 0.070	7.272 +/- 0.071	**3.2733 +/- 0.04**	305.5

Table 2: Proper motion and Parallax data from GAIA DR2

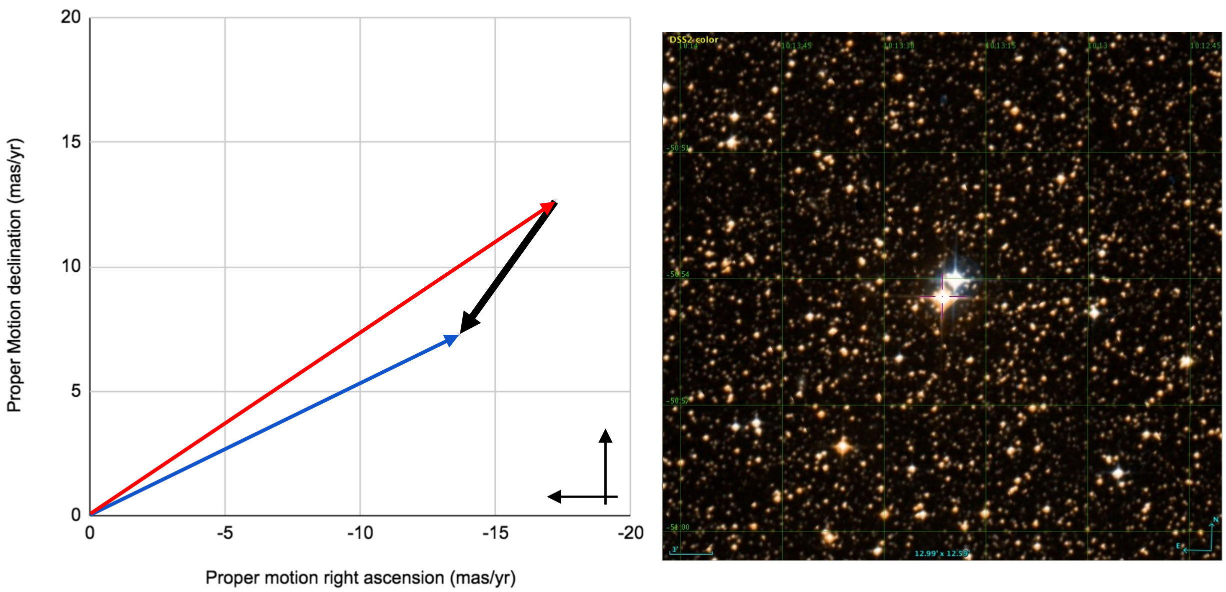

Figure 3: Directions of proper motions. (L) The proper motion of each star is shown with the relative motion vector (shown in black) as the difference between the two motion vectors shows the direction of the motion of HD 88812 (blue) relative to HD 88813 (red).The relative motion vector agrees with the historical trend of the relative positions. This relative motion does not rule out an orbital motion, however this relative motion has continued throughout the last century and therefore suggest only a very long orbital trend and a large distance between the stars. (R) Image of the two stars, in the same orientation, the relative motion is such that the separation has decreased.

cal binary, see Table 3, primarily due to the very low distance probability.

Using the GAIA DR2 parallax measured distances (Table 2), the absolute magnitude can be approximated (Table 3) using the distance magnitude relationship shown in Equation 3.

The stars' temperatures and absolute magnitudes were

$$\text{Absolute mag} = \text{apparent mag} - 5\log\left(\frac{d}{10}\right) \qquad [3]$$

plotted on an HR Diagram, shown in Figure 4, allowing an approximation of the size and age of the stars to be made.

Distance Probability [1]	Proper Motion Probability (scaled by 0.15) [2]	Binary Probability	Physical?
0.1436	0.0977	0.2413	No

From Harshaw 2018 spreadsheet

Table 3: Binary Probability Factors

Star	Apparent Mag (G band (optical)	Distance (pc)	Absolute magnitude [3]	Effective Temperature (K)	Spectral class	Notes:
HD 88813	7.3785	714.6	**-1.89**	3984.03	K4/5 E	Red giant
HD 88812	8.5978	305.5	**1.17**	8806	A0V C	Just leaving main sequence to the giant branch

Data are from GAIA DR2, spectral class is from Houk 1978.

Table 3: Magnitude and Temperature data

GAIA and CCD Observations Indicate that Herschel Double Star 10134-5054 HJ 4299 ...

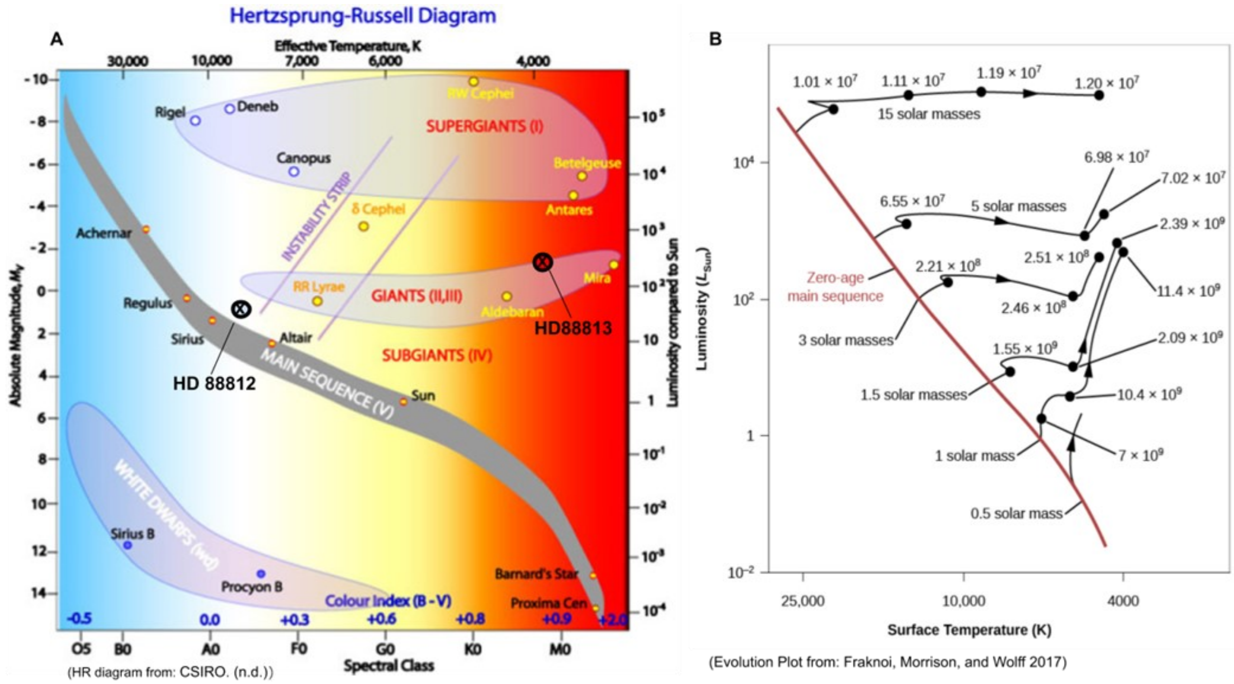

Figure 4: Spectral analysis. (A) HD 88813 is a red giant late in its lifespan. HD 88812 is a white star starting to branch from the main sequence to become a red giant. These spectral classes and luminosities suggest the stars have similar masses. (B) Evolutionary tracks of stars based on mass.

Based on the spectral classes shown in Figure 4, it can be determined that the stars have similar masses, roughly 4 solar masses, based on the luminosities (Fraknoi, Morrison, and Wolff 2017). Figure 4B shows that stars of this mass take between 2.2 x 108 yrs and 7 x 107 yrs to branch from the main sequence across the red giant branch (Fraknoi, Morrison, and Wolff 2017). If HD88812 has the lower mass of the two, it is possible that it is within 7 x 107 years of the age of the red giant HD 88813. It is therefore possible that these stars did from around the same time, from the same molecular cloud, and were once gravitationally bound, even if they have since drifted apart. However, with the system mass constrained to between 7 and 10 solar masses from the HR diagram evolutionary tracks, a rough analysis of this system using Kepler's Third Law, an approximate system mass of 8 times the solar mass, and a semimajor axis of the difference in distances from Earth (409 parsecs) approximates an orbital period of ~1011 years (Genet, et al. 2015). This orbital period is entirely unrealistic for two reasons: first these stars' lifetimes are much shorter at ~109 years, and second, binaries distant from each other can be pulled apart as they pass through the spiral arms of the Milky Way in their orbit around the galactic center (Harshaw, personal communication, November 2019), every ~108 years.

Discussion

GAIA parallax data strongly suggests that HD 88812 (white) is closer to the Sun than it is to HD 88813 (red). Though the relative proper motions agree with the historical trend and do not rule out an orbital motion, and the parallax measurements suggest similar ages to the stars, it is extremely unlikely that these stars are gravitationally bound based on their distance to each other. I hope this paper offers some context to understanding more deeply Harshaw's parallax and proper motion factors and that this paper exemplifies the impact of the GAIA data to the field of double star astronomy.

Acknowledgements

The following resources were used

- Washington Double Star Catalog
- Aladin Sky Atlas v10.0
- Simbad: VizieR

Thanks to Dr. Brian Mason for supplying the historical data for this system.

Thanks to Rachel Freed for guidance and feedback and the Fall 2019 cohort of the Astronomy Research Seminar for comradery and inspiration.

Thanks to Dr. Richard Harshaw for review and

feedback.

References

Buchheim, R., 2008, "CCD Double-Star Measurements at Altimira Observatory in 2007", *Journal of Double Star Observations*, **4**, 27-31.

Caballero, J. A., 2007, "Southern very low mass stars and brown dwarfs in wide binary and multiple systems", *The Astrophysical Journal*, **667**,.520.

CSIRO. (n.d.) The Hertzsprung-Russell Diagram., Retrieved on December 10, 2019 from: https://www.atnf.csiro.au/outreach/education/senior/astrophysics/stellarevolution_hrintro.html.

European Space Agency (ESA). (April 27, 2018). GAIA Data Release 2 (GAIA DR2). Retrieved from https://www.cosmos.esa.int/web/gaia/dr2.

Fraknoi, A., Morrison, D., and Wolff, S. C., 2017, "Evolution from the main sequence", Astronomy. OpenStax. Rice University. Pg. 772

Genet, R. et al., 2015, "Speckle Interferometry of Short -Period Binary Stars", *Journal of Double Star Observations*, **11** (1S), 323.

Harshaw, R., 2018, "Gaia DR2 and the Washington Double Star Catalog: A Tale of Two Databases", *Journal of Double Star Observations*. **14** (4), 734-740. http://www.jdso.org/volume14/number4/Harshaw_734_740.pdf.

Houk, N., 1978, "Catalogue of two dimensional spectral types for the HD stars, Vol. 2." Michigan Spectral Survey. Ann Arbor, Dep. Astron., Univ. Michigan.

Las Cumbres Observatory, 2019, "0.4-meter", Retrieved from: https://lco.global/observatory/telescopes/0-4m/.

Lépine, S. and Bongiorno, B., 2007, "New distant companions to known nearby stars. II. Faint companions of Hipparcos stars and the frequency of wide binary systems", *The Astronomical Journal*, **133**, 889 - 905.

Matvienko, A.S. & Orlov, 2014, "Dynamic status of the wide multiple system α Centauri + Proxima V.V.", *Astrophysical Bulletin*, **69**, 205. https://doi.org/10.1134/S1990341314020084

NASA/WMAP Science Team. (March 18, 2019). What is a Lagrange Point? Retrieved from: https://solarsystem.nasa.gov/resources/754/what-is-a-lagrange-point/

Reipurth, B. and Mikkola, S., 2012, "Formation of the widest binary stars from dynamical unfolding of triple systems", *Nature*, **492**, 221-4. doi:10.1038/nature11662

Richmond, M. (March 10, 2005). Precession, Proper Motion, and Angular Separation. Retrieved from: http://spiff.rit.edu/classes/phys301/lectures/precession/precession.html#sep

Teixeira, R., Ducourant, C., Chauvin, G., Krone-Martins, A., Song, I. and Zuckerman, B., 2008, "SSSPM J1102-3431 brown dwarf characterization from accurate proper motion and trigonometric parallax", *A&A*, **489**, 825-827, DOI: 10.1051/0004-6361:200810133

Washington Double Star Catalog (WDS) (n.d.). Naval Oceanography Portal (Retrieved in October 2019).https://www.usno.navy.mil/USNO/astrometry/optical-IR-prod/wds/WDS

Appendix

HD 88812 (blue): Gaia DR2 5358556096510172288
HD 88813 (orange): Gaia DR2 5358556096510171520