Astrometric Measurement of Triple Stars WDS 00485+3924 MLB 4ABC

Natalia Smith[1], Justin Swan[1], Michael Pereira[2], Pat Boyce[3], and Grady Boyce[3]

1. San Diego Community Miramar College, San Diego, California
2. Casa Cielo Norte Observatory (Private), Santa Fe, New Mexico
3. Boyce Research Initiatives and Education Foundation (BRIEF), San Diego, California

Abstract: By utilizing the Las Cumbres Observatory Global Telescope Network (LCOGT) with CCD imaging, astrometric measurements of the triple star WDS 00485+3924 MLB 4ABC were made to determine if the components are physical. When compared to previous measurements taken over the past century, including those taken with the GAIA space telescope, no conclusive determination is made if stars A and B are physical, while star C is determined not to be physical with its visual components. This is given by the position angles and separation measured, respectively; 099.3±0.41 degrees and 6.73±0.023 arcseconds for AB, then 175.2±0.13 degrees and 13.34±0.056 arcseconds for the AC pair.

Introduction

As members of the BoyceAstro (boyce-astro.org) Fall 2023 DoubleSTARS™ seminar, we were challenged with determining if the components of a multi-star system are gravitationally interacting or are only a visual binary through astrometric measurements of position angle (θ) and separation distance (ρ).

We chose our target WDS 00485+3924 MLB 4ABC (herein after MLB 4ABC) based on filtered queries of Stella Doppie (Gianluca Sordiglioni, 2009-2023) and the Washington Double Star (WDS) catalog searching for stars with a minimum of three components with an undetermined physical relationship. To make exclusive use of LCOGT's worldwide network to minimize the number of observations and instruments utilized, our queries focused on stars brighter than 13.0 magnitude, an observed difference in magnitude (Δmag) between components less than 2.5, and stars whose components separated between 5" to 10". Measurements were to be made between October and November 2023, therefore only stars with right ascension (RA) of 00 to 06 hours were considered, and declination (DEC) was not a limiting factor due to LCOGT having telescopes capable of observing both celestial hemispheres.

MLB 4ABC has been measured 17 times in over a century, Table 1, and attracted us as a promising target as we hoped to advance the knowledge of this triple star system. MLB 4ABC was first measured and recorded by T.E. Espin, using a micrometer with a 0.6-meter reflector telescope in 1917 and then measured half a dozen times through to the mid-1930s. Nearly 50 years passed before it was measured again photographically with a 1.2-meter astrograph in 1986. Throughout the 2000s, it has been measured with greater frequency using a variety of more technically advanced systems: a 0.7-meter CCD imaging system, the Two Micron All-Sky Survey (2MASS), USNO Robotic Astrometric Telescope, and GAIA.

Equipment and Methods

Our measurements were made using 13 images captured by one of the LCOGT Meade 0.4-meter, three-element telescopes with SBIG STL-6303 charge-coupled device (CCD) camera using a Bessel B filter at Haleakala, Hawai'i, at an elevation of 10,013 ft ASL, Figure 1. At the time of observations, LCOGT was replacing these imaging systems across their network with Planewave DeltaRho 350 telescopes with QHY600 complementary metal-oxide semiconductor (CMOS) cameras (LCOGT, 2024); however, our images were collected with the precursor system.

Figure 1. LCOGT 0.4-meter telescope in Hawai'i, image taken using Las Cumbres Observatory

Historical MLB 4ABC measurements, Table 1, were used to aid our understanding of the system prior to conducting observations. We analyzed those and calculated a few useful parameters from GAIA Data Release 3 (DR3) (GAIA 2023j). Table 2 summarizes this data sourced from SIMBAD, VizieR, and Aladin Lite (browser version).

Observations were conducted over four nights within one week in November 2023, but images captured from only two nights were usable. The unusable images were blurry and unresolvable due to completely obscured stars due to high level clouds.

Table 1. Historical Measurements for WDS 00485+3924 MLB 4 ABC provided by the USNO.

WDS 00485+3924 MLB 4					
Epoch	θ (°)	ρ (")	Epoch	θ (°)	ρ (")
AB			AC		
1917.93	97.6	6.540	1917.93	164.1	18.200
1925.02	97.0	6.170	1928.95	165.9	18.522
1928.95	105.0	6.794	1929.90	164.6	17.816
1929.42	105.0	6.510	1991.84	171.5	14.854
1936.88	100.8	6.230	1998.92	172.2	14.470
1986.91	101.0	5.900	1998.92	-	-
1998.92	99.3	6.790	1998.92	-	-
2002.00	99.8	6.713	2002.00	172.7	14.382
2002.59	99.6	6.707	2002.59	172.9	14.347
2010.87	99.6	6.600	2010.00	-	-
2011.66	99.5	6.750	2010.00	-	-
2012.81	99.4	6.718	2010.87	173.8	13.720
2013.81	99.5	6.738	2011.66	173.9	13.930
2014.78	99.4	6.735	2012.81	174.0	13.864
2015.50	99.5	6.740	2013.81	174.0	13.808
2016.00	99.5	6.741	2014.79	174.2	13.747
2016.78	99.0	6.766	2016.78	173.9	13.724

Table 2. Summary of WDS 00485+3924 MLB 4ABC DR3 collected and calculated data used for pre-observational analysis

Attribute		Primary A	Secondary B	Tertiary C	Unrelated Star
Stellar Class		G (yellow)	G (yellow)	F (yellow white)	Unknown
Magnitude	(G)	10.077	11.729	11.674	18.016
	('R)	9.598	11.127	11.295	17.334
Proper Motion - Primary	RA microarcseond (mas) per yr	29.12	30.332	-3.715	-1.866
	DEC mas per yr	-47.523	-46.684	-3.958	-2.967
Proper Motion - Error	RA mas per yr	0.018	0.016	0.071	0.134
	DEC mas per yr	0.015	0.013	0.053	0.103
Harshaw Statistic (calculated)		N/A	6.424	1.801	Unknown
Radial Velocity	km per sec	-22.85	Unknown	Unknown	Unknown
Radial Velocity - Error	km per sec	0.44	Unknown	Unknown	Unknown
Parallax	mas	6.4292	6.4242	1.8007	0.5493
Parallax - Error	mas	0.0221	0.0195	0.0812	0.1409
Distance (calculated)	Parsec (Pc)	155.540	155.661	555.340	1820.500
	light-year (ly)	507.062	507.456	1810.407	5934.826
Delta Distance (calculated)	ly	N/A	0.395	1303.346	5427.765
T eff	K	5897.4	5232.2	6560.8	Unknown
Radius	solRad	1.23	0.82	1.64	Unknown
Luminosity	solLum	1.692	0.401	5.386	Unknown
J2000 WCS	RA deg	12.099	12.102	12.100	12.099
	DEC deg	39.407	39.406	39.403	39.41
	RA Error mas	0.017	0.015	0.06	0.109
	DEC Error mas	0.013	0.011	0.047	0.085
Other Name		BD+38 114	2MASS J00482444+3924228	TYC 2801-1783-1	Gaia DR3 368118485846011520

Results

A total of 13 images, Figure 2, were useful for measurement, Table 3. Each image was processed and calibrated through the Our Solar Sibling pipeline (OSS) developed by Fitzgerald (2018). We then analyzed and measured each image using AstroImageJ to calculate separation and position angle of each component.

The astrometric results, Table 4, highlight θ and ρ measured from A to B (AB) and A to C (AC), i.e. B and C's respective position relative to A. The separation and position angle are represented through mean, standard deviation, and standard error of the mean. The new measurements show the position angle to be 099.3±0.41 degrees separation to be 6.73±0.023 arcseconds for AB, and the position angle to be 175.2±0.13 degrees and separation to be 13.34±0.056 arcseconds for the AC pair.

Table 3. Summary of MLB 4ABC observations with LCOGT.

Observations				
WDS 00485+3924			Discoverer Code MLB 4	
Date	Epoch	Observatory	Filter	# of Images
2023-11-23	2023.895	LCOGT Haleakala	Bessell B	9
2023-11-28	2023.908	LCOGT Haleakala	Bessell B	4

Figure 2. Image of WDS 00485+3924 MLB 4ABC taken with LCOGT Haleakala telescope.

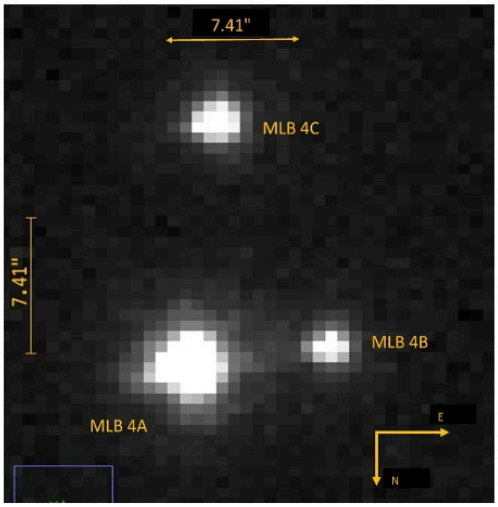


Table 4. Summary of astrometric measurements using AstroImageJ with a comparison to the last recorded WDS measurement.

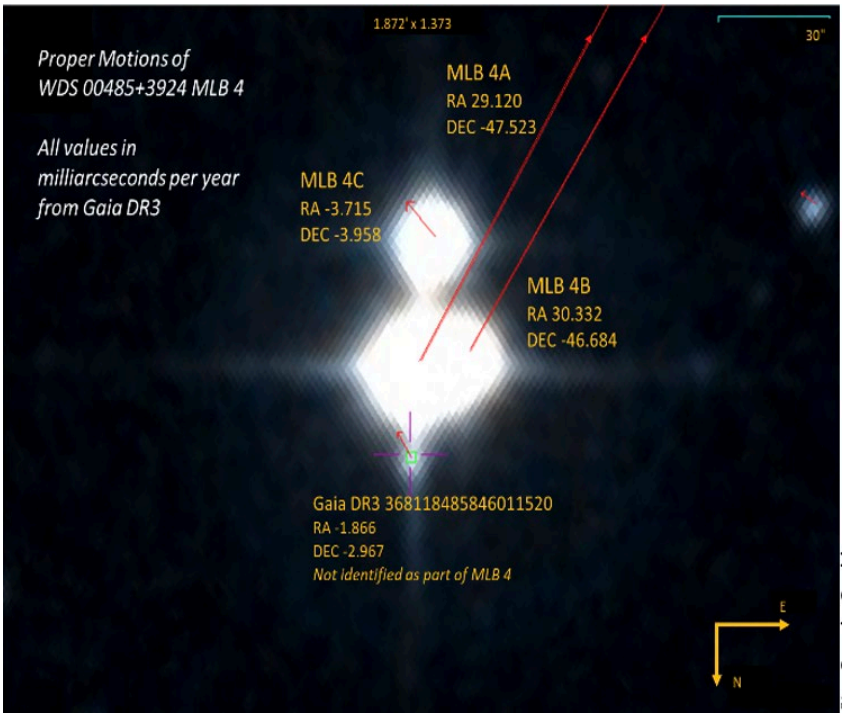
WDS 00485+3924 MLB 4				
Epoch	Measurement	Position Angle - θ (°)	Separation - ρ (")	Observed Delta Magnitude (Sloan r)
AB				
2023.901	Mean	099.3	6.73	1.88
	Standard Deviation	0.41	0.023	0.029
	Standard Error of the Mean	0.03	0.002	0.002
2016.779	Last Measurement	099.0	6.77	-
AC				
2023.901	Mean	175.2	13.34	1.48
	Standard Deviation	0.13	0.056	0.020
	Standard Error of the Mean	0.01	0.004	0.002
2016.779	Last Measurement	173.9	13.72	-

Discussion

We used a variety of software tools and calculations provided from the Boyce-Astro DoubleSTARS™ Seminar, and supporting GAIA data, to conduct a pre-observational analysis of the triple star system and to derive conclusions regarding MLB 4ABC.

The initial assessment employed the Harshaw Statistic (Harshaw, 2014) which utilizes the proper motion to quantitatively assess the likelihood that binary system components are physically bound. The likelihood that a pair is physical increases as the value approaches zero (0) while a value approaching unity (1) suggests no such relationship. The proper motion values were superimposed on a DSS image using Aladin's capability to integrate GAIA measured proper motions onto a single image, Figure 3. Note that in comparison to Figure 2, Figure 3 shows an additional star approximately 18-magnitude (GAIA DR3 368118485846011520) adjacent to the A star. This star was ruled out as a companion of this system through an assessment of its measured parallax of 0.5493 suggesting a distance approximately 5,934 light-years (ly) away which is much further than MLB 4ABC components. Therefore, this star is not considered in this analysis. This process indicated a Harshaw Statistic of 0.013 due to their similar proper motions suggesting they are physical.

Figure 3. DSS image from Aladin Lite of WDS 00485+3924 MLB 4ABC from with measured proper motion superimposed; DR3 368118485846011520 is an unrelated star to the system.



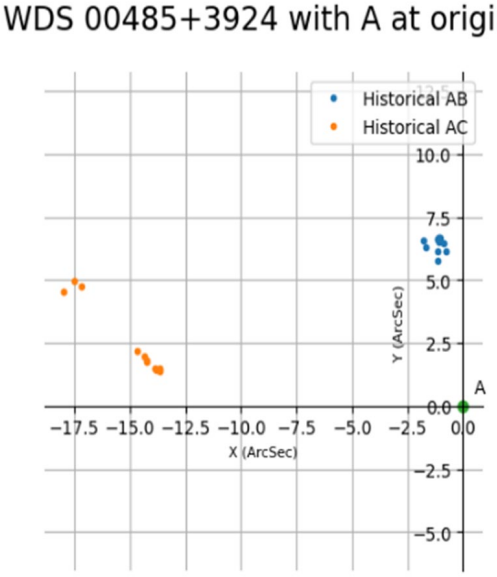
As the parallax measurements are not exact, we calculated the probability distribution of the standard error to the mean (SEM) of parallax measurements between the primary and a secondary star to determine the probability that the system components are within one light-year (1-ly) of one another. This can also be mathematically represented as SEM(Primary-Secondary) = √ [(SEM Primary)2 + (SEM Secondary)2]. The likelihood that these stellar objects are gravitationally connected goes down the further they are from one another, as demonstrated in Table 5.

Table 5. Summary of probability distribution calculation to assess if WDS 00485+3924 MLB 4 components are within 1-ly of one another.

Attribute	A	B	C	AB	AC
Mean of Probability Distribution Function (ly)	507.062	507.456	1810.407	-0.395	-1303.346
-1 SEM (ly)	505.325	505.921	1732.292	-	-
+1 SEM (ly)	508.811	509.001	1895.900	-	-
SEM(Pri-Sec) (ly)	-	-	-	2.326	81.823
Probability within 1-lyr	-	-	-	32.8%	0.0%

To provide a historical and current perspective of this system, we used DoubleSTARS™ Seminar graduate Mary Kovic's Python-coded astrometry plotting tool (Plot_Tool_0_0_2.ipynb) to enable an overview plot of the historical WDS observations in relation to our own herein, Figure 4.

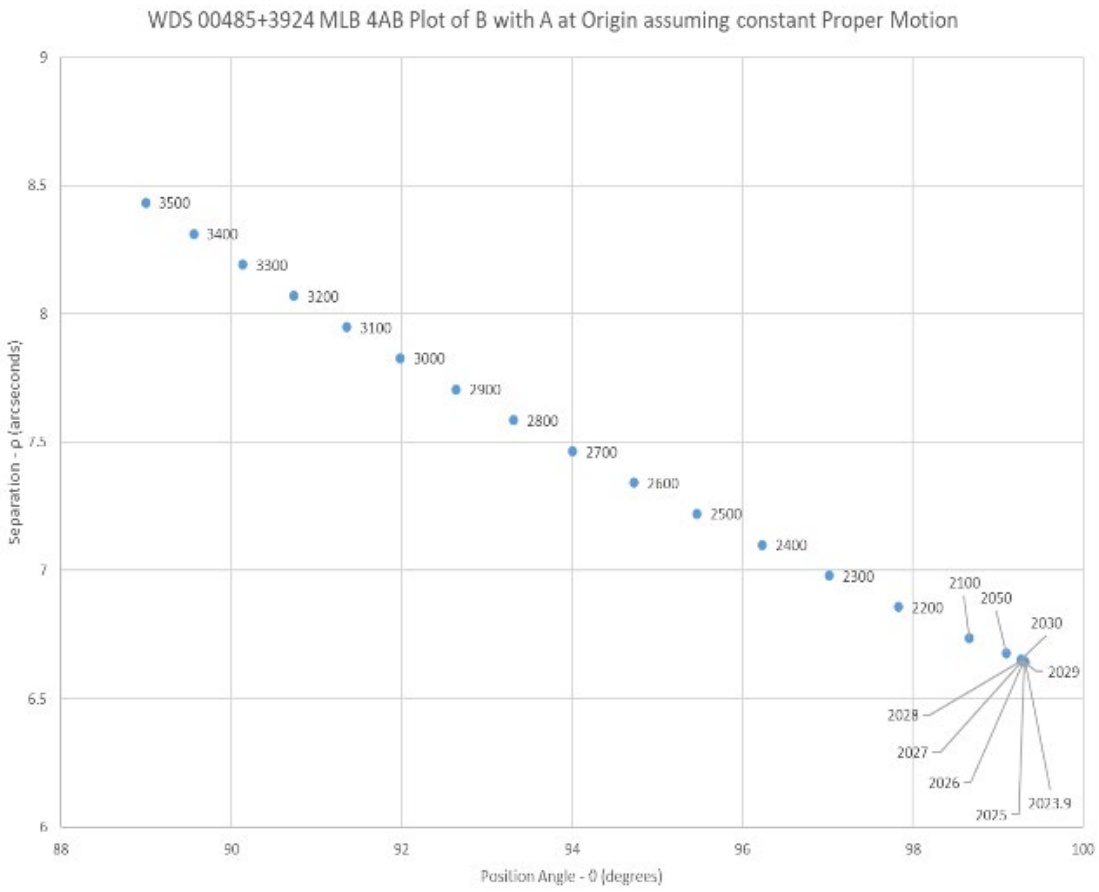
Figure 4. Historical plot with current measurements of MLB 4ABC.



Combining the analysis of data from GAIA we conducted before making observations with the astrometric measurements we made of images taken with LCOGT, we cannot conclusively determine if or if not MLB 4AB are physical. As Figure 4 and the distance between either star demonstrates, Tables 1 and 4, there is no significant change in pair AB's position from our observations as compared to those in 2016 nor in other measurements over the years. Previous measurements of the system or orbital motion over the past century cannot conclusively support the hypothesis that MLB4 AB are physical, either. We visually determined from Figure 4 that measurements made over the last 20 years are likely within the error bars of one another. The GAIA parallax measurements indicate they are within 1-lyr of one another, and their Harshaw Statistic of 0.013 due to their similar proper motions suggests they are physical. However, their SEM of 33% probability of being within 1-lyr of one another provides less certainty that they are bound. As such, they may not be related at all, they could be physical binaries, or they could be a common proper motion (CPM) pair.

In a further analysis of the AB pair proper motion, we attempted to answer whether it might be possible in the future to note a greater separation of AB as these appear to not be physical. Using their relative proper motion and ignoring the relatively small measured proper motion error of each, their relative positions were calculated and plotted from now to centuries into the future, Figure 5. If our forecast matches with reality, then one could conclude at that later date that MLB 4AB are not physically bound. To accomplish this, we utilized AstroImageJ (AIJ) 5.2.1.04 (Collins et al, licensed under GPL 3.0) to measure the θ and ρ from our captured LCOGT images for an additional analysis of AB. Excel and trigonometry were used to convert between θ, ρ, RA, and DEC to forecast future location of MLB 4AB components to one another based on proper motion. Because GAIA RA proper motion data is corrected for DEC (as the lines of RA are not parallel and converge at the poles), the equation $\mu_{\alpha*} = \mu_\alpha coscos\delta$ where the terms are respectively corrected RA, RA, and DEC, and were used to convert between coordinate systems, Figure 5.

Figure 5. Forecast of position for WDS 00485+3924 MLB 4AB assuming constant proper motion over the next 1,476 years



MLB 4C is not a physical component of the system—it is about 1,300-ly beyond the primary and secondary as measured by GAIA. The SEM of 0% validates this result. In addition, its Harshaw Statistic of 0.892, due to its proper motion being close to orthogonal to that of its two visual companions, suggests a physical relationship is unlikely. Our measurements support this, as they appear to show statistically significant change in pair AC's position from when last observed to now.

Although recent measurements could potentially be more accurate than those previous, we did not have full access to the error measurements for all of the past WDS measurements and can only attempt to answer how accurate our measurements are by comparing to GAIA. Converting GAIA's mean J2000 WCS RA and DEC measurements shown in Table 2 into position angle and separation for pair AB results in θAB = 099.6° and ρAB = 6.72". Our mean measurements shown in Table 4 closely match with this calculation, implying we measured accurately using AIJ. Conversely, the calculated θAC = 172.5° and ρAC = 14.47" for pair AC is considerably further off in comparison. Accounting for both GAIA and our measurement errors, attempts were made to statistically compare how alike our values are to GAIA's measurements. Unfortunately, a sensical mathematical approach eluded us, though in iterative calculations (not presented in this paper) of θ and ρ with the extremes of GAIA's microarcseconds (mas) RA and DEC errors applied indicated there was little impact to our calculated results, implying we were less accurate using AIJ to measure MLB 4AC than we were for MLB 4AB.

Conclusion

It is likely MLB 4AB may be traveling together through space, as their similar proper motions and close proximity to one another (within 1-lyr) as measured by GAIA suggest are a Common Proper

Motion (CPM) pair. Although it's unclear if they are gravitationally bound to one another, it's possible they may have been born in the same stellar nursery, resulting in shared trajectories.

Conversely, from GAIA's measurements and our own, we conclude MLB 4C is not physically bound to its visual components. We realized only after completing our observations that during our target selection process, we should have assessed that we would draw no conclusion on pair AB's physicality. Closer examination of Table 1 and Figures 4 and 5 prior to adding our measurements would have shown we should not have expected much change in their relative positions from now and seven years ago. If we would have concluded this, we likely would have continued our search for another target.

Though A and B are identified in SIMBAD as being high proper motion stars, their proper motions have not yielded significant change in their relative positions since when they were first measured in 1917.

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This research has made use of the WDS Catalog maintained at the USNO. We thank Dr. Rachel Matson for providing a historical record of observations for WDS 00485+3924 MLB 4 and the other nine triple star systems we considered for this project.

This work makes use of observations from the LCOGT using the 0.4-meter, three-element telescopes with SBIG STL-6303 CCD camera using a Bessel B filter at Haleakala, Hawai'i. We thank LCOGT for providing us access to their sites and equipment.

This work has also made use of data from the European Space Agency (ESA) mission GAIA (https://www.cosmos.esa.int/GAIA), processed by the GAIA Data Processing and Analysis Consortium (DPAC, https://www.cosmos.esa.int/web/GAIA/dpac/consortium). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the GAIA Multilateral Agreement.

This research has made use of the SIMBAD database, CDS, Strasbourg Astronomical Observatory, France *2000, A&AS, 143, 9*, "The SIMBAD astronomical database", Wenger et al.

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