Observation and Investigation of 5 Physical Doubles in the Washington Double Star Catalog

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Abstract

This paper examines five physical double stars selected from the Washington Double Star Catalog and observed using telescopes from the Skynet Robotic Telescope Network. To determine whether the systems are gravitationally bound, our approach involved utilizing Skynet's Afterglow tool to measure each system's position angle and separation, which was used with data from Gaia Data Release 3 (DR3) to calculate its relative proper motion (rPM), system escape velocity, and relative space velocity. To discern formations of orbits that indicate binary star systems, we requested data from the United States Naval Observatory to create orbital plots. Our findings show that all five systems lack the gravitational relationships necessary to be classified as binary systems due to their relative space velocities exceeding their system escape velocities and the absence of orbiting trends in their plots.

1. Introduction

Physical double stars are stars that could have formed from the same gas cloud, at the same distance, and have the same proper motion through the celestial sphere. The study of these stars, even if they may not be binary, is valuable because historical records and measurements can be analyzed to extrapolate a common origin point in the Milky Way Galaxy when the two stars are close together in space, allowing estimates of their ages to be made. If a double star system is part of a larger star cluster, the age of the system also reveals information about the cluster's age, which in turn deepens our understanding of the history of the Milky Way.

The stars we have chosen in our study have been carefully selected using several constraints. Each pair needed to have a secondary magnitude less than 18, a primary magnitude greater than 9, and a delta magnitude less than 5. They also needed to be visible, physical pairs that had similar parallax and proper motions in right ascension and declination or had orbits that were previously solved. During the months in which the stars were observed, stars with a right ascension between 4 and 13 hours and a separation between 5" and 20". These constraints allowed us to find double star systems where both primary and secondary stars can be captured in the same images.

2. Instruments Used

Instruments used in our observation projects include the telescopes PROMPT-MO-1 and Prompt5 from the Skynet Robotic Telescope Network. A 16-bit CCD with a flux of 0 - 65353 flux and a Hithru filter was used to take images among all the telescopes. 10 images were taken, each with 3x3 dithering and 10-arcsecond spacing. PROMPT-MO-1, located at Meckering Observatory in Australia, has a focal length of 4477.0mm, a field ratio of 11.0, and a field of view of 10.2 x 10.2 arcmin. Prompt5, located at Cerro Tololo Inter-American Observatory in Chile, has a focal length of 4576.0mm, a field ratio of 11.3, and a field of view of 10.0 x 10.0 arcmin.

3. Measurements

Skynet's image processing suite, Afterglow, was used to measure the positional angle and separation between stars. The images were aligned, stacked, and saturated for clarity, and then Afterglow's plotter tool was used to measure the position angle and separation, as shown in Figure 1. These measurements were then used with data obtained from Gaia Data Release 3 (DR3) to obtain the values shown in Table 2 in the following section (A. Vallenari, A. G. A. Brown, et al, 2022).

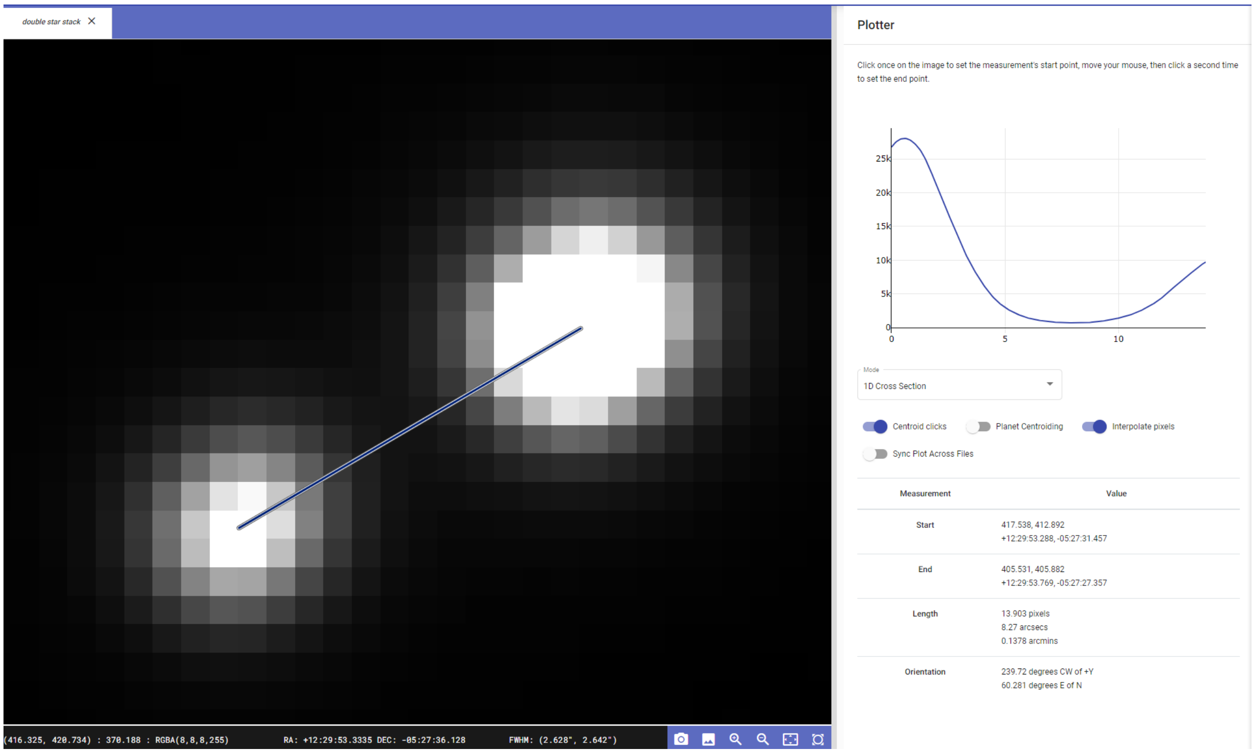

Figure 1: Position Angle and Separation measurements for B 2737.

4. Results

Table 1 contains the measurements made using Afterglow for each system selected in our study. The values for the columns titled, "Standard Error on Position Angle" and "Standard Error on Separation" were obtained by comparing the Afterglow measurements for each of the 10 images in our observations.

Table 2 contains the data obtained from Gaia DR3, in addition to the last column, titled "rPM," which represents the proper motion ratio of a double star system moving across the celestial sphere. It is calculated using the following equations. Equation 1 calculates the magnitude of the stars' relative motion by taking the magnitude of the difference vector between the primary and secondary proper motion vectors (Bonifacio, 2020).

$$pm_{Mag} = \sqrt{(pm_{RA1} - pm_{RA2})^2 + (pm_{Dec1} - pm_{Dec2})^2}$$

Equation 1: Proper motion of stars

Equation 2 calculates the rPM of a double star system by dividing the magnitude of the proper motion by the magnitude of the larger proper motion (Bonifacio, 2020). The rPM value is used to determine the classification of our systems based on their proper motions. There are three classifications: if the rPM range is less than 0.2, the system exhibits Common Proper Motion (CPM), which is the classification of the majority of our selections, and indicates that the stars are moving together through space; if the rPM range is between 0.2 and 0.6, the system exhibits Similar Proper Motion (SPM), which is the classification of the system BAL 1692, and indicates that the stars are moving in a similar way; and if the rPM range is greater than 0.6, the system exhibits Different Proper Motion (DPM), which indicates that the stars are not moving together through space (Harshaw, 2016).

$$rpm = \frac{pm_{Mag}}{\sqrt{{pm^2}_{RA1} + {pm^2}_{Dec1}}}$$

Equation 2: Relative proper motion of stars

Table 3 contains our estimates of the system escape velocity and relative space velocity for each system. These values are calculated using the equations presented in B. Bonifacio et al, 2020, and are what we compared to determine whether our double star systems could be binary systems.

Table 1: Summary of Measurements.

System	Date	Number of Images	Position Angle (°)	Standard Error on Position Angle	Separation (")	Standard Error on Separation
B 2737 (WDS 12298-0427)	Feb 6, 2024	10	61	0.119	8.2	0.004
HJ 4545 (WDS 12459-7511)	Feb 6, 2024	10	193	0.053	9.2	0.009
BAL 1692 (WDS 06233+0245)	Feb 4, 2024	10	276	0.037	8.9	0.012
GRV 729 (WDS 07103+2540)	Feb 4, 2024	10	74	0.071	9.6	0.009
B 2657 (WDS 08272-2845)	Feb 7, 2024	10	90	0.121	6.8	0.018

Table 2: Skeleton Table for Gaia Data.

System	Parallax of Primary (mas)	Parallax of Secondary (mas)	Proper Motion of Primary (mas/yr)	Proper Motion of Secondary (mas/yr)	rPM
B 2737 (WDS 12298-0427)	46.986647 ± **0.04307**	47.08963 ± **0.06245**	-570.1723 **(R.A)** - 304.26559 **(DEC)**	-560.82031**(R.A)** - 293.6948**(DEC)**	0.022 **(CPM)**
HJ 4545 (WDS 12459-7511)	4.273027 ± **0.01272**	4.28004 ± **0.01268**	-28.224 **(R.A)** 2.43691 **(DEC)**	-28.54036**(R.A)** 2.29978**(DEC)**	0.012 **(CPM)**
BAL 1692 (WDS 06233+0245)	5.7027 ± **0.0257**	5.603 ± **0.254**	-3.426 **(R.A)** -4.162 **(DEC)**	-2.203**(R.A)** - 4.091**(DEC)**	0.227 **(SPM)**
GRV 729 (WDS 07103+2540)	2.96048 ± **0.01491**	2.92625± **0.01232**	-10.05923**(R.A)** - 35.566**(DEC)**	-10.2826**(R.A)** - 35.5405**(DEC)**	0.006 **(CPM)**
B 2657 (WDS 08272-2845)	2.45544 ± **0.03855**	2.37059± **0.01986**	0.97789**(R.A)** 5.24517**(DEC)**	0.80577**(R.A)** 5.3873**(DEC)**	0.041 **(CPM)**

Table 3: Estimates of System Escape Velocity and Relative Space Velocity.

System	System Escape Velocity (m/s)	Relative 3D Space Velocity (m/s)
B 2737 (WDS 12298-0427)	397	1428
HJ 4545 (WDS 12459-7511)	370	383
BAL 1692 (WDS 06233+0245)	87	1019
GRV 729 (WDS 07103+2540)	81	360
B 2657 (WDS 08272-2845)	50	429

5. Plots

For each system our group studied, we requested historical data from the United States Naval Observatory. Using the position angles and separations measured over the past, we created plots to determine if they had any trends or orbits. If a curve resembling an orbit was found, it would suggest the possibility of a double star system being a binary pair. Our plots, as shown in Figure 2, are labeled according to their WDS numbers and discoverer codes.

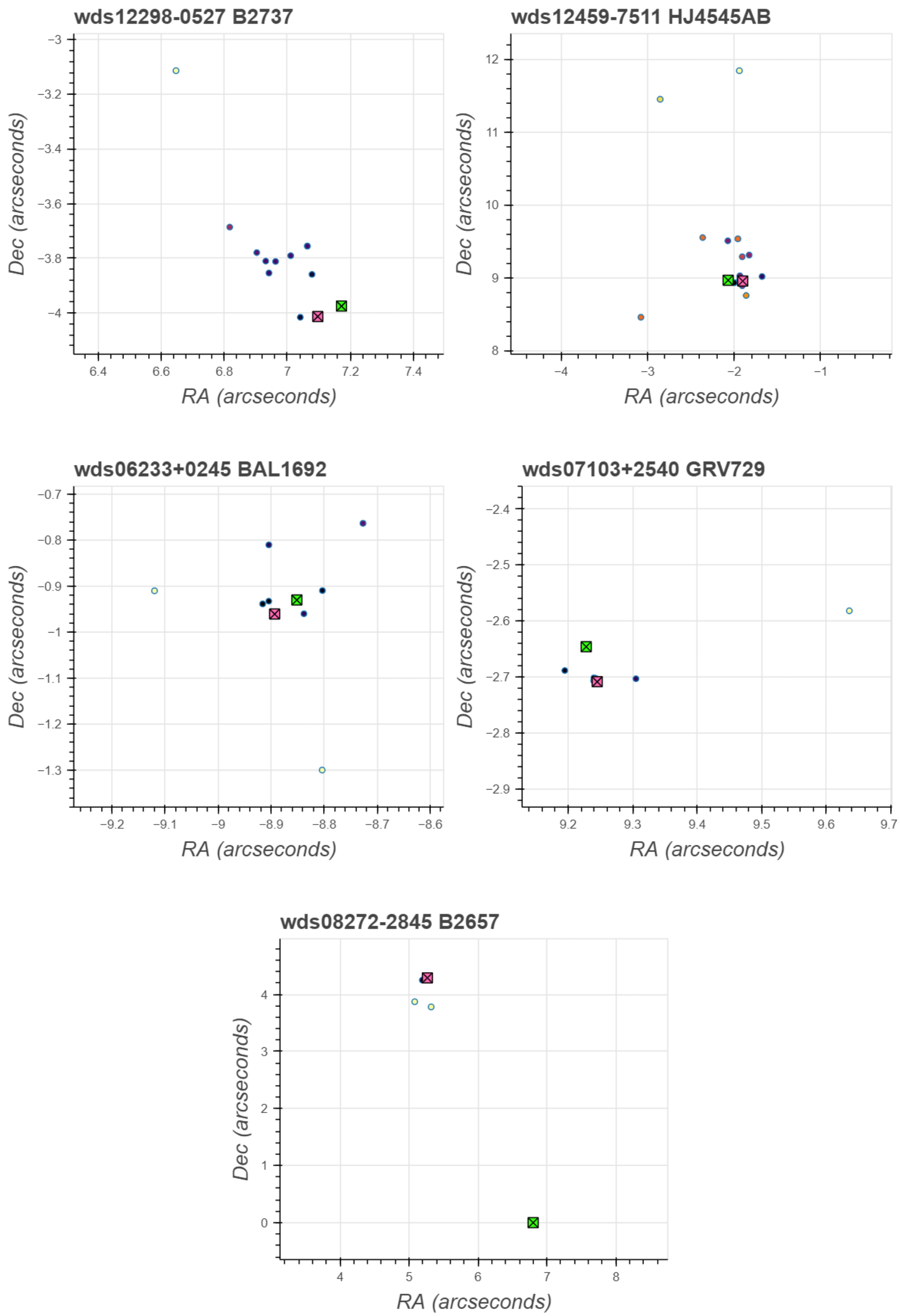

Figure 2: Historical data plots, where darker points are more recent, green boxes marked with an X are our measurements, and hot pink boxes marked with an X are measurements from Gaia.

6. Conclusion

The values in Table 3 show that in each system, because the system escape velocity is exceeded by the relative 3D space velocity, the double star system is not gravitationally bound and is therefore not binary. The data plots in Figure 2 support these assessments, as all plots except for system B 2737, have scattered data points and thus do not show any signs of orbit. However, these deductions are not definitive; each system requires further observations and analyses from astronomers in the future.

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This work makes use of observations taken by the 0.4m PROMPT MO-1 and Prompt5 telescopes of the Skynet Robotic Telescope Network located in Meckering, Australia and Cerro Tololo Inter-American Observatory, Chile.

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